UNKNOWN EARTH:

A HANDBOOK OF GEOLOGICAL ENIGMAS

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PREFACE

My interest in geology anomalies was ignited almost 30 years ago when I picked up a copy of George McCready Price's EVOLUTIONARY GEOLOGY AND THE NEW CATASTROPHISM from a table of second-hand books. Price was a Fundamentalist and totally ignored by uniformitarian science, but he had a way with words and a long list of facts that seemed to contradict conventional geology. Were some strata really inverted? Did past catastrophes really slaughter terrestrial life wholesale? In short, I asked myself questions I never would have thought to ask otherwise. Many of Price's anomalies turned out to have rather prosaic explanations; but now over fifty years after he wrote EVOLUTIONARY GEOLOGY, science has definitely moved away from uniformity toward catastrophism. Most important from my standpoint, I was put on the trail of the scientific anomaly. I discovered that there were many more puzzling things in geology than Price had dreamed of.

The primary objective of this Handbook is to provide libraries and individuals with a wide selection of reliable descriptions of unusual geological phenomena. To meet this goal, I have analyzed hundreds of volumes of geological journals as well as the complete files of Nature and Science. The result of this research is an incomparable collection of information on the frontiers of geology. From this assemblage, I have selected the most interesting and controversial for this book.

My criteria for selecting "anomalous" data were: (1) the information contradicted current geological theories, or (2) the article raised personal questions not answered adequately to my knowledge. Usually both criteria were satisfied simultaneously. Much of the information printed herein will prove controversial, particularly that selected from the more popular publications. It will soon become obvious to the reader that secondary objectives are the posing of challenges to establishment science and the stimulation of useful controversy.

I make no claim to completeness because new and relevant material is being discovered constantly as my search of the literature continues. Indeed, the near-infinite mine of government reports, university theses, and foreign journals has scarcely been touched. Even so, I have collected much more intriguing geological information than I can conveniently publish here. However, the complete master file is being published in looseleaf "sourcebooks." The Sourcebook Project welcomes inquiries concerning these cumulative Sourcebooks.

The looseleaf Sourcebooks were, in fact, the first publications of the Sourcebook Project. Although thousands of these notebooks have been sold to libraries, feedback from librarians indicated that casebound books would be more acceptable. Such suggestions were a major factor in the decision to publish selections from our collection in a series of casebound Handbooks.

My hope is that this Handbook will become a useful reference work on the frontiers of geology. To this end, I have utilized reports taken primarily from scientific journals. The screening provided by editors and referees of these publications helps to minimize hoaxes and errors. In expectation that establishment geology is too conservative and too confined by dogmas, I have introduced a handful of articles from fringe periodicals and books that are doubtless considered offbeat and "wild" by most professional geologists.

Most of the 120 illustrations consist of line drawings by John C. Holden and are based on sketches and photos in the original articles. Since many of the articles are decades old, it was impossible to ferret out all original photos. Actually, in the older literature, line drawings predominate in any case.

Since the bulk of this Handbook consists of direct quotations from original sources, I hasten to acknowledge the many writers of papers, letters-to-the-editor, and sundry publications who have contributed these descriptions of phenomena. When lengthy quotations are taken from publications still protected by copyright, permissions have been obtained.

William R. Corliss

Box 107
Glen Arm, MD 21057
February 15, 1980.

Chapter 1

STRATIGRAPHIC ANOMALIES

INTRODUCTION

The most casual traveller cannot help but note that the earth's upper crust is often layered. Viewed simplistically, these strata are likened to pages in our planet's history book. To some degree, this picture is true. Some pages, however, are missing; others are mutilated; whole chapters are lacking in some parts of the world; and occasionally a few pages seem out-of-order. The book analogy is good, but perhaps this weighty tome might better have been shelved with "mysteries" rather than "histories."

The top stratum is a logical place to begin. Unhappily, complexity reigns here. The vagaries of the vast layer of debris supposedly left behind after the continental ice sheets retreated have long puzzled geologists. Clearly allied to the glacial "drift" are the loess and patterned ground. These surficial deposits are mostly recent---within the time of man---but our ancestors recorded little on their bones and cave walls about such calaclysmic events. This is unfortunate because the deposits themselves seem to provide more questions than answers.

Deeper down and considerably older are the strata containing coal, oil, natural gas, and evaporites. Not only are these substances economically important, but they tell us much about life and the terrestrial conditions prevailing during their formation. Still at issue here are the way in which coal beds were formed from plant debris and the true origin of petroleum. While petroleum is widely proclaimed to have an organic origin, some facts point to abiogenic and possibly extraterrestrial origins!

The earth's rocky pages tell of many crises in the planet's history. Some catastrophes evidently erased some pages altogether. Other pages are wrinkled and afflicted with puzzling imperfections. Geology books of paper, cloth, and glue tend to gloss over these enigmas. Here, anomalies are highlighted.

CYLINDERS, BOULDERS, AND INCLUSIONS IN STRATA

The prevailing concept of the formation of sedimentary strata envisages a steady, uniform rain of sand, silt, lime, and other fine materials down through a watery medium. Conglomerates and cross-bedded strata of course require more random and more energetic processes, but such minor deviations from the uniformitarian credo are acceptable. The geological literature, however, does record many departures from this appealing and rational scenario.

A major type of sedimentary anomaly involves the inclusion of very large boulders in matrices of otherwise fine-grained materials. Frequently, these exotic boulders seem to have travelled hundreds of miles and are so large that they challenge the believability of the usual explanation; namely, ice-rafting.

More startling are the geometrically neat cylindrical pillars that penetrate some sandstones and limestones. Are these structures simply holes in the strata later filled with sediments, or are they log-like concretions? Interestingly enough, sandstone and limestone "dikes" and other linear structures are also known, challenging the notion that such rocks always have sedimentary origins.

Flint and chert have always taxed geological theorists. Flint nodules frequently reside in chalk beds, sometimes in extensive horizontal layers. In the chalk beds near Norfolk, however, rather grotesque flint structures of large size are arranged in unlikely patterns. Are these immense nodules fossils of some rare sea organism or aberrant concretions?

• Cylinders and Pipes in Strata

CYLINDRICAL STRUCTURES IN SANDSTONE

Simpson, George Gaylord; *Geological Society of America, Bulletin,* 46:2011-2014, 1935.

A recent publication by Hawley and Hart has again directed attention to peculiar, tree-like, cylindrical structures long known to occur in Paleozoic sandstones near Kingston, Ontario. In view of this renewed interest, it seems worthwhile to place on record a description of similar, and in some respects even more remarkable, structures which occur in central Patagonia and on which there seem to be no published data.

These Patagonian structures occur over an area about half a mile in greatest diameter in Canadon Hondo, an irregular basin which drains northward into the Rio Chico del Chubut at Paso Niemann. This is the type locality of the early Tertiary Rio Chico formation, and the cylindrical structures are in that formation, in the same part of Canadon Hondo as that from which the largest collection of Rio Chico mammals was made, and in a bed the top of which is about twenty feet below the principal horizon from which mammals were derived.

These observations were made by the Scarritt Expedition of the American Museum of National History, in March, 1931. The structures had previously been seen by Ing. A. Piatnitzky, who also guided us to the locality, and whose original discovery and helpful cooperation I gratefully acknowledge. He does not, however, mention the cylindrical structures in an account of the geology of Canadon Hondo which he has recently published.

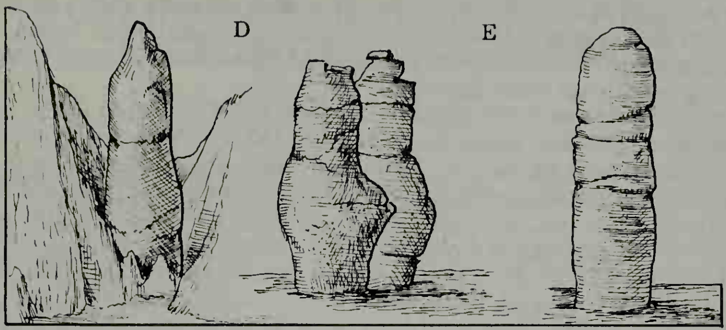
The horizon of these structures, which may be called the pillar bed, occurs in a thick series of clays, most of which are bentonitic, and of sandstones which vary from fairly coarse arkose to soft, fine impure quartz sands, with some included volcanic ash, but nowhere is this series predominantly of ash or tuff. The pillar bed, or zone, is about twenty feet in thickness. The pillars are distributed over the whole exposed part of this zone, an area of perhaps one to two hundred acres in all. Although irregular in density, there are, on the average, five or six pillars per hundred square feet.

Almost all the pillars are from one to two feet in diameter, and complete pillars are from three to ten feet in height. Although adjacent pillars are usually at the same level and of the same height, in the area as a whole, and even in some of its more limited parts, the pillars do not appear invariably to begin and end at the same levels, and none was observed with a height equal to the whole thickness of the pillar zone, about twenty feet.

The pillars are always exactly normal to the true bedding of the enclosing sandstone. This is tilted in places, and the pillars are there correspondingly inclined. In horizontal section, most of the pillars are circular, and almost all are isolated, although a few twin pillars were observed. Where unweathered, the apices are generally more or less conical. Below the apices some show horizontal fluting, probably not wholly due to weathering, or they may more vaguely tend to bulge near the middle, but most are almost evenly cylindrical except as modified by weathering. The weathered bases are often somewhat undercut; where unweathered, they generally expand, like the base of a tree trunk, but were not observed to pass out into root-like projections.

Where the bases are clearly displayed without excessive erosion, they were observed to pass into a fairly continuous, hard layer of sandstone. In some, but apparently not in all, cases the apex reaches and similarly blends with a hard capping layer. This capping generally occurs above the pillar bed, even when the pillars themselves do not reach it or are locally rare or absent.

The matrix of the pillars, or the pillar bed itself, is a fine, soft sandstone which erodes easily into badlands forms. It is very homogeneous but has vague horizontal bedding. Some pillars are of material macroscopically indistinguishable from the matrix but more firmly cemented, but they are sometimes composed of a sand slightly coarser than the matrix, more like the variable, harder capping and basal beds, and in some cases include small pebbles and even bone fragments, neither of which were observed in the rest of the pillar bed. The rock in the pillars is not truly bedded, even to the vague extent of their matrix, but may be slightly zoned horizontally by a barely perceptible segregation of coarser and



Sandstone pillars from Patagonia. (D) partially exposed pillar; (E) twin pillars; and (F) typical well-exposed pillar.

finer material which does not correspond to any similar structure of the immediately contiguous matrix rock.

The surface of many of the weathered pillars is pale orange in color, apparently from oxidation of the cementing substances. This characterizes most of the harder strata of the formation as a whole, but is not seen on the soft pillar matrix. Except for this surface discoloration, probably due to weathering after exposure, there is no apparent radial, or concentric structure, in the pillars.

A number of the pillars show very steeply inclined fissures, the surface of which may be slightly slickensided, as may also the outer surfaces of the conical apices. These surfaces are often discolored. These fractures, displacement along which has been less than a centimeter in all those examined, may be due to compacting of the bed after the pillars were well consolidated, no similar feature being observed in the less-consolidated, surrounding, soft sandstone.

In one or two places in the pillar area there are irregular, low, wall-like projections, which have weathered out much as have the pillars and which have the appearance of very irregular sandstone dikes.

It is evident that the pillars are not due primarily to erosion but are actual structures in the rock, which are sculptured out by erosion because they are more firmly consolidated than the bed as a whole. The absence of the general bedding planes, the presence of a vague sorting not seen in the surrounding matrix, and a grain size in the pillar different from that of the matrix strongly suggest that some, at least, of the pillars are not merely cemented or concretionary parts of the bed but have a different origin. Since this is fairly clear in some cases, it is probably true of all, because it is logical to suppose that all the pillars were formed in the same way. It seems most probable that the pillars represent either the fillings of cavities in an older bed or were in some way caused by injections into the latter, from above or below. In either case, the problem is why they have taken this peculiar and, on the whole, remarkably uniform shape.

Various explanations have been offered for the cylindrical structures near Kingston. Kavanagh suggested that they are concretions about vegetable cores. This cannot be true of the Patagonian pillars, as no such core is, in fact, present, the structure is not radial or concentric, the country rock structures do not persist into the pillars, and the size of the sand grains is not always uniform in pillars and contiguous matrix. The latter considerations, likewise, prevent considering the pillars as simple concretions, as has also been advanced for the Kingston cylinders. Baker's suggestion of formation by whirlpools is also impossible, as it can hardly be supposed that thousands of whirlpools existed at the same time, spaced only a few feet apart, of nearly uniform diameter, and each of long duration in one exact spot.

After reviewing these previous theories, Hawley and Hart concluded that the Kingston cylinders were due to springs rising through the unconsolidated sands, with subsequent concretionary cementation of the cylinders of disturbed and somewhat altered sediment thus formed. This explanation is conceivable for the Patagonian structures as well, and surely it is tempting to suppose that they have the same origin as those of Kingston. Whatever may, however, be true of the latter, the Patagonian pillars have well-marked distinctions, some of which seem to make such an origin only a bare possibility and hardly a probability for them. The presence of such an enormous number of springs, so closely spaced, and distributed not along a line, as are the Kingston cylinders, but widely scattered over a large area, argues against such an origin, as do also the sharp, smooth boundaries of the pillars (which do not include any country rock in their cemented zones), their almost uniform size, their generally very even dimensions, their perfectly straight axes, their tendency to become smaller at the top, and perhaps some other characteristics.

An alternative hypothesis is that the Patagonian pillars do actually represent standing trees, which they so much resemble. On this hypothesis, it may be supposed that a forest was buried in sand to a depth of several feet, that the wood decayed, leaving holes in the sediment, and that these were filled with sand by subsequent floods. There are plain difficulties in the way of this supposition, also, and the evidence is inadequate to advance it as a definite theory. This extraordinary phenomenon is, indeed, one for which I can think of no entirely adequate explanation.

PILLARS, POLYSTRATE FORMATIONS, AND POTHOLES

Cox, Douglas E.; *Creation Research Society Quarterly,* 14:149-155, 1977.

Abstract. Three kinds of column-like formation are discussed. There are columns of unconsolidated material, often differing from their surroundings, embedded in sand or drift. There are pillars of consolidated material, often sandstone, embedded in rock. And there are free-standing solid pillars.

It is proposed that all of these kinds of pillars, and also potholes, are to be ascribed to one cause: disintegration following upon the release of pressure as the material was raised out of the water at the end of the Noachian Flood. It is hard to believe that sedimentary processes could have caused these formations; hence the cross stratification, often found with them, can not be an effect of sedimentation.

Top of a pillar poking through side of a gravel pit. (Douglas E. Cox)

Some reasons are suggested why the study of these formations may be especially worth while to a Creationist.

Introduction. Strange polystrate pillars occur in sandstone and in drift in many places. The writer has examined many pillars in gravel and sand in the region of Waterloo County and other places in Southern Ontario. Pillars in the Potsdam sandstone, near Kingston, Ontario, were investigated by the writer and H. L. Armstrong.

These pillars, also called "pipes" or "pots", transect the pattern of cross stratification. They are anomalous and difficult to explain in terms of sedimentary deposition.

Polystrate fossils such as trees, vertically embedded in sediments, have been cited as evidence that rock strata accumulated rapidly.[1] This explanation cannot account for unconsolidated pillars; but they, too, may have been formed rapidly.

Causes for vertical pillars in cross stratified sandstone and drift are difficult to find in nature today, but past causes may have been different from those existing now.

One such cause is a possible disintegration process, due to rapid release of former high pressure. Uplift of the continents from the depths of the flood waters would be accompanied by a decrease of pressure on rocks.

In a previous article, it was suggested that the pattern of cross stratification may be an effect of a shattering or disintegration process.[2] Some features of cross stratified formations support this interpretation.

The presence of polystrate pillars in cross stratified sandstone and drift is evidence that cross stratification is not a sedimentary phenomenon, but may result from a pressure-related disintegration process. Such a process can account for many similarities between the pillars in sandstone and those in the drift. Also, from this point of view, a relationship between pillars and the contents of potholes would be expected.

Drift Pillars. Over a period of several years, the writer observed a group of pillars in cross stratified drift gravel exposed in the sides of a gravel pit at Blair, a few miles south of Kitchener, Ontario. The gravel pit is operated by Forwell Ltd., of Kitchener. In the course of excavations over the past few years, removal of the coarse gravel has revealed many pillars.

They were distinguished from the enclosing gravel in various ways. Many were stained dark brown or black, and appeared as finger-like extensions of the soil profile into the gravel below. Some of these contained a light coloured interior, thus exhibiting a concentric structure.

The pillars were cylindrical in shape, with tapering or rounded bottoms. All were in the uppermost part of the drift, beginning within or just below the soil. The pillars extended downwards to varying depths.

At this site, pillars one to two ft in diameter, and up to 10 ft in vertical extent were common. Don Metzloff, foreman at the site, also observed the pillars in the course of excavations. He reported that the pillars were mostly clustered together in one section of the pit. The largest pillars reached 20 ft vertically and were 3 to 4 ft in diameter. These were described by Metzloff as consisting of "dirty coloured, fine sand, just like ground."

Some of the pillars consisted of sand and clay which transected coarse gravel, and others were composed of gravel, although different in appearance from that of the enclosing drift. More clay was present in some pillars, which made them more compact and resistant to weathering than the enclosing gravel.

Concentric structures were present in many pillars. In one pillar exposed in cross section, there was distinct colour banding, and an outer lining of pebbles formed the perimeter of the pillar. Another pillar was lined by sand and clay, which formed a smooth cylindrical margin about the pillar.

The pattern of cross stratification in the gravel near some pillars was bent downwards.

Several features of the pillars resemble features of other structures described in the geologic literature. A recent report by Conant et al. describes "pots" in gravels in Maryland and Virginia, which were somewhat different in shape to the pillars in the Blair gravel pit, but otherwise seemed quite similar.[3]

The pots were more spherical or bulbous in shape than the pillars in the Blair gravel pit. The pots also exhibited concentric structure, and the stratification of the surrounding gravel was bent downwards around some of the pots.

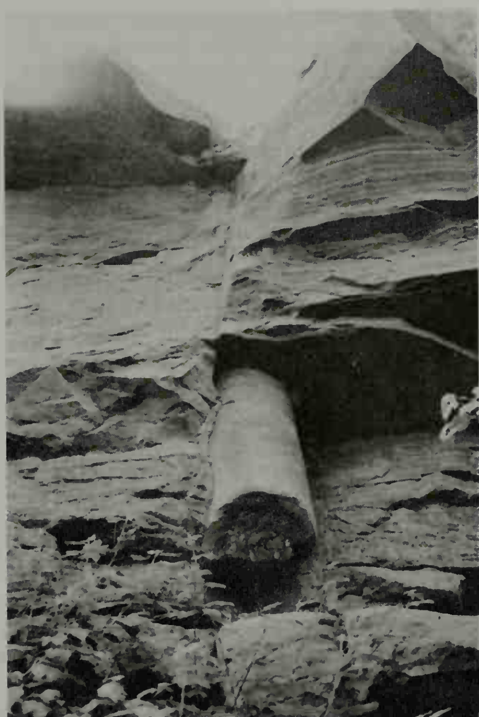
The pots were about 7 ft in depth and about the same width, though some were much larger. All were at the top of the gravel. One pot was wrapped in a layer of white clay 1/2 in. thick. Describing the contents of the pots, the authors say:

The filling of the pots is chiefly a clayey silt containing a few percent to perhaps 40 percent of admixed sand and gravel. The silt is generally medium gray and mostly structureless, but in some pots it is faintly or distinctly stratified parallel with the margins. In some pots, flat pebbles also tend to be aligned parallel with the margins. The uppermost 1 ft. of the filling is commonly more gravelly.[4]

"Till clumps" similar in shape to the pots in Maryland and Virginia were reported by Mather et al. from Cape Cod, Massachusetts.[5]

The mechanism favoured by Conant et al. for the formation of the pots involved seasonal frost action during a Glacial Period; but such a mechanism would seem unworkable in the case of the pillars at the Blair gravel pit, which are much narrower and deeper than the Maryland pots. Yet there are similarities which suggest a common origin for all these peculiar structures.

A Pillar with Cross Stratified Contents. Some pillars in the drift seem clearly to indicate that the pattern of cross stratification cannot be of sedimentary origin. The drift in Southern Ontario is explained in terms



Columnar structure in sandstone near Kingston, Ontario, Canada. (Douglas E. Cox) of the Glacial Theory either as till, thought to be a direct deposit of the ice-sheets, or out-wash, which is considered to be glacial debris which has been transported in streams flowing from the melting ice-sheets, and deposited in rapid currents. Till is unstratified while outwash exhibits the pattern of cross stratification.

A pillar was found in sand near Campbellville, Ontario, with internally cross stratified contents. The pillar was enclosed by fine, cross stratified sand, and consisted of coarse sand and pebbles, with nearly horizontal strata. No pebbles were present in the enclosing sand. Only a part of this pillar was intact, about 5 feet below the original level of the gravel pit. The diameter of the pillar was about 1 ft.

The perimeter of this pillar was well defined, and consisted of a thin film of clay enclosing the structure. It is hard to imagine how such a structure could have formed in an invironment of rapidly flowing currents, as assumed in the glacial explanation for cross stratified drift.

In particular, the cross stratification of the contents of the pillar could hardly have been caused by currents within the structure. Since the pillar was unconsolidated, and was enclosed by unconsolidated sand, it would likely have been washed away by currents of outwash streams. Another, non-sedimentary explanation is indeed called for.

Some geologists have proposed rather special circumstances to explain pillars in drift. A pillar of sand, with concentric layers, was found in coarse and medium Quaternary sand at St. Jerome, north of Montreal, Quebec, by Dionne.[6]

Height of the pillar was 152.5 cm, and diameter was 34 cm at the top and 24 cm at the base. The sand comprising the pillar was fine at the center, and the pillar transected cross stratified beds.

It was proposed that a whirlpool eroded a deep cylindrical hole in the unconsolidated sand, and refilled the hole immediately afterwards, forming a pillar.

While some such mechanisms may seem plausible for individual structures, this could hardly apply to a large group of pillars in drift; and as more observations of these peculiar structures are reported the improbability of isolated polygenetic causes for the pillars is increased.

Can Freezing Explain Pillars? Explanations for pillars in drift that involve frost effects fail to account for many similarities between the drift pillars and those in sandstone, to be described later.

As previously noted, the deep narrow shape of many pillars does not seem to support a theory of frost action. Further evidence against this theory was found in a very striking example of a pillar, in which many of the boulders seemed to have been subjected to intense heat.

This pillar was located in a gravel pit about 5 miles east of Drayton, Ontario. It was bulbous, about 10 ft in diameter and about the same depth. The pillar was enclosed in beds of fine cross stratified sand.

The perimeter of the pillar was line with large boulders up to 8 inches in diameter. These were cemented together by white calcite, like a mortar.

The boulders in the outer wall encircling the pillar seemed to have been baked or heated. Many were coated with a thick glaze of glass, and many were cracked.

The peculiar structure was also examined by Dr. Mat Hill of the University of Waterloo anthropology department, since it was thought the pillar may have been man-made.

The sand adjacent to the pillar, and the soil above seemed undisturbed, however; and human manufacture seemed unlikely.

A pillar consisting of boulders could hardly have been derived from the enclosing sand by any Uniformitarian mechanism such as frost action. The presence of such a pillar in sand is also anomalous if the sand is explained in terms of glaciofluvial deposition.

Formation of the Pillars. The idea of a non-Uniformitarian process of rock disintegration, causing the pattern of cross stratification, would lead to a simple explanation for the pillars.

Many Creationists believe the major part of the sedimentary rocks which contain fossils, that occur in the earth's crust, was formed during the Noachian Deluge. Uplift of the continents at the end of the flood would be accompanied by a release of pressure. This would provide the environment for a process of rock disintegration.

Disintegration would likely be limited to consolidated rocks, and it is believed that sediments formed in the Deluge consolidated as they were elevated from the depths. Lithification occurred as diffused cementing agents crystalized at the lower pressures.

As pressure on the topmost rocks decreased, due to lower depths of water and erosion of overlying sediments, water diffused within rocks could not remain diffused at the lower pressure, and tended to be expelled from the rock. Near the surface of the rock, expansion of the occluded water caused shattering of successive thin layers.

Concretions developed in rocks due to changes in the diffusion equilibria, becoming pebbles and boulders as the shattering process changed the rock about them into sand and clay. It is proposed that the pattern of cross stratification was formed by this mechanism of disintegration.[7]

In many places the disintegration began in a small area of the rock surface, and penetrated vertically downwards, resulting in a cavity filled with the disintegration product. In effect, a pothole was formed.

Where the surrounding rock was also subsequently disintegrated, this pothole (with its contents) became a pillar within the cross stratified sand and gravel. This mechanism for the formation of the pillars in the drift implies a relationship exists between the pillars and the contents of potholes, before excavation.

Concentric structure in many pillars may be explained by lateral enlargement of the pillars during the pothole stage. Disintegration of the rock walls would account for linings of pebbles, orientation of the pebbles parallel to the margins, and lining of the margins by clay which has been reported in some pillars.

Discolouration of the contents of the pillars, which also produces a concentric effect, probably occurred during the pothole stage. Diffusion of volatiles, calcite, iron oxide, and other minerals from the rock enclosing the pillar towards the low-pressure surface would cause concentric banding. Precipitation of these minerals at the margin of the pillars occurred due to changes in diffusion equilibria during the lowering of pressure.

Down warping or bending of the pattern of cross stratification of the gravel around some pillars indicates the pillars were present when the pattern of cross stratification was formed. This bending may indicate more rapid disintegration of the rock near some pillars.

Pillars Compared with Potholes. Potholes are believed, in the Uniformitarian view, to have been formed by erosion such as the action of streams;

but it is difficult to explain all the features of potholes in this way. Several problems with the Uniformitarian explanations for potholes were outlined in another article.[8]

Potholes which are exposed by streams, or other agents such as wave action along the shores of lakes or coasts, may have been present in rocks prior to the initiation of present conditions.

Before exposure, potholes are usually filled with drift, consisting of sand, clay, and gravel. In some rocks potholes may contain sandstone.

The mechanism outlined for the formation of drift pillars also explains potholes, and a resemblance between the pillars and the contents of potholes would support the proposed theory.

The pillars in drift resemble potholes in shape, many are bulbous like potholes, and the range of sizes is similar. Like potholes, the pillars are rounded at the base, and penetrate to varying depths.

In distribution patterns the pillars resemble potholes, which may occur individually or in clusters. Observations by the writer on a remarkable cluster of pillars illustrates the similarity of the pillars to groups or clusters of potholes.

A group of pillars was exposed in a field adjacent to Pinebush and Balmoral Roads, Cambridge, Ontario, in the summer of 1976. The topsoil had been removed from the field prior to a construction project. Wind erosion of the sand revealed the tops of a large cluster of pillars, numbering about 100.

The pillars were reddish brown, and were enclosed by yellow-gray sand. The largest pillar was about 3 ft in diameter, and excavation of one of the pillars showed a vertical dimension of 4 ft. Some of the pillars in the cluster were connected, which is also a common feature of potholes. The pillars resembled "hoodoos", which are sometimes eroded from soft sandstone.

Dikes of white clay connected some pillars, possibly formed by deposition of calcite in cracks in the original rock before disintegration. The sand in some pillars was speckled, possibly due to disintegration of concretions.

The characteristics of the contents of potholes are rarely given much attention in the geologic literature. Some large potholes in Norway were excavated in 1874, and described by Brogger and Reusch.[9]

The largest kettle excavated was near Bakhelagel, and the work occupied 3 men for 50 days. Careful records were kept of the position of the boulders found in the kettle. The depth was found to be 33-1/2 ft, or 44 ft if measured from the highest side.

The larger rocks in the kettle formed layers at various levels, and the authors wrote, "The contents of this kettle, therefore, plainly showed a sort of stratification."[10]

Deep within the pothole two large boulders were found, which appeared to have a smaller hole begun in them. The small hole was in the centre of the kettle.

In the theory of disintegration causing potholes, the smaller hole may represent part of an initial pothole, which widened and deepened by further disintegration of the enclosing rock.

Indications of a concentric structure in the contents of a pothole were found by the writer in a large filled pothole at Rockwood, Ontario. Here the larger rocks seemed to be concentrated around the walls. This may also indicate widening of the pothole by disintegration.

Further studies of pothole contents are needed to confirm the presence of a concentric arrangement of the contents, and other points of resemblance between the pillars in drift and the contents of potholes.

The Park of Pillars. From the point of view of Uniformitarianism, a relationship is not readily perceived between the drift and cross stratified sandstone. But the theory of disintegration would require such a relationship.

Pillars or pipes are present in many sandstones, which show similarities to pillars in the drift. A well known example of pillars occurs in an outcrop of Potsdam sandstone on the property of Bill Hughes, R.R. 6 Kingston, Ontario and the front cover of this Quarterly.

Several vertical pillars are visible, the largest measuring 14 ft in diameter. Some exposed in the sides of a cliff, evidently the site of an old quarry, extend 20 ft vertically.

Concentric bands occur within many of the pillars, and also in the rock enclosing them. This feature led some to conclude the pillars were "fossil trees," and sections of the pillars were exhibited as such in shop windows in Kingston in 1888.[11]

Hughes now operates a quarry near the site of the pillars, and he told me a pothole was recently found during the excavations. It was filled with sand and small pebbles.

One of the explanations which has been offered for the pillars is that they are potholes filled with alluvial sediments.[12] It seems clear that they are not fossil trees, but, being polystrate, they may show as well as polystrate trees that the rock around them was formed quickly.

The pillars are described in an article by Hawley and Hart,[13] and a thorough description is not attempted here. These authors proposed that the pillars were formed by springs rising through the strata while it was still unconsolidated, and referred to the pillars as "quicksands enclosed by concretions."

Similar pillars have been reported from other exposures of the Potsdam formation. Some occur across the Rideau Canal opposite the Hughes farm, others are present at Morton, Ontario, and at Redwood, New York.

The rock in which the pillars occur is a reddish sandstone with cross stratification. The rock may have been formed by alteration of the granite bedrock, in a process similar to disintegration. One indication of this is a gradual transition of the rock from granite to sandstone, within a few hundred yards from the site of the pillars.

The formation of the sandstone may have occurred in either of two ways. Disintegration of the granite may have formed cross stratified sand, which was recemented by silica and iron oxide, or the alteration may not have been a complete disintegration but more a recrystallization of granite, resulting in a pattern of cross stratification.

The pillars may have been formed in a manner similar to that described for the formation of pillars in drift. Vertical pillars were formed by disintegration in localized areas, and subsequently the surrounding rock was also altered. Concentric structures were formed in the pillars due to decreased pressure upon disintegration, and deposition of hematite at successive surfaces of the rock during disintegration.

Structures similar to those in the Potsdam sandstone near Kingston have been reported from cross bedded siltstone and conglomerate in the Bush Creek region of Eagle County, Colorado.[14]

These were up to 4 ft in length and 8 inches across. Some of the pillars interlocked, and some completely enclosed smaller ones. Concentric bands surrounded the pillars.

Another report described pillar-like structures up to 200 feet in height.[15] These occur in the Laguna area, New Mexico, and are referred to by Schlee as "sandstone pipes." The pipes range from a few inches up to 150 feet in diameter. The pipes are grouped in clusters, and many have a concentric internal structure. Cross bedding was present within the pipes and in the enclosing sandstone.

Other similar structures have been reported in the St. Peter Sandstone of Arkansas, and in northern Arizona and Colorado.[16]

Dietrich described cylindrical pillars in the Potsdam sandstone at Redwood, New York, and noted that similar structures also occur at East Anglesey, England: near Brussels, Illinois: along the coast of Syria and Palestine: at Barnstaple Bay, Devonshire, England: and at Canadon Hondo, Chubut, Argentina.[17]

In some regions the disintegration of the rock enclosing pillars may have been more complete than the disintegration which formed the pillar itself. In such cases a free-standing pillar may be formed by erosion of the loose sand.

Free-Standing Pillars. Free-standing pillars of sandstone were described by Simpson at Canadon Hondo, Central Patagonia, and associated with the Potsdam pillars near Kingston.[18] These pillars were exposed by erosion of the soft sandstone beds in which they were embedded. Most of the pillars were from 1 to 2 ft in diameter, and from 3 to 10 feet in height.

Many of the features of the pillars mentioned by Simpson have their counterpart in typical potholes. Some twin pillars were observed, some contained horizontal flutings on the sides, some tended to bulge in the middle. The bases of some weathered pillars were undercut.

The pillars seem to be the antithesis of potholes, which may be explained in terms of the disintegration theory of cross stratification. The pillars originally formed by rock disintegration in small areas, and subsequently the enclosing rock also disintegrated more completely. The material in the pillars was indistinguishable from the matrix except for a slightly coarser sand and firmer cementation.

The pillars described by Simpson seem to be sandstone counterparts of pillars in drift observed by the writer.

Islands, composed of sandstone, such as those in the Wisconsin River at Wisconsin Dells, may really be large pillars. One of these island pillars is known as the "Inkstand." Many potholes occur in crevices along the Wisconsin River.

The pillars are cross stratified, and these may have been formed by more complete disintegration of the rock enclosing pillars. Sand enclosing the pillars would have been washed away by the Wisconsin River, leaving the pillars as islands.

Predictions Based on the New Theory. Four kinds of phenomena can be related by the theory of rock disintegration forming the pattern of cross stratification. These are potholes, pillars in drift, sandstone pipes, and free-standing pillars. All of these show similarities, which suggest a similar cause.

One of the ways in which theories can be tested is by means of predictions. The following two predictions can be made on the basis of the theory outlined in this article:

1. The contents of potholes should reveal concentric features, or internal cross stratifaction, or other features similar to those of pillars in sandstone and in drift.

2. Pillars similar to those which occur in drift may also be expected in cave fill. Potholes are common in caves, and the fill has been explained in terms of the disintegration similar to that proposed for the drift.[19]

Both these predictions can be easily tested, and future observations may either support or refute the present theory. Another prediction, based on the Uniformitarian premise, is possible, to test its validity: potholes ought to occur in rock strata at all levels, as fossils of bygone times. Are there any such examples of fossil potholes?

Why Pillars Are of Interest to a Creationist. There are at least two reasons why these pillars, or related formations, are of interest to a Creationist. First of all, while many of them are clearly not fossils, in the sense of having once been living, yet, being polystrate, they provide as good evidence as that from the polystrate fossils for rapid formation of the strata.

The other point is this. Uniformitarian methods have not been very successful in explaining these structures. Even those who suggest explanations do not seem to be very well convinced. The explanation proposed in this article may be verified on the basis of its predictions. Thus the superiority of the Creationist approach could be demonstrated.

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CYLINDRICAL STRUCTURES IN PERMIAN (?) SILTSTONE.....

Gabelman, John W.; *Geological Society of America, Bulletin,* 64:1545, 1953.

Abstract. In East Brush Creek, Colorado, a calcareous siltstone bed 16 feet thick contains numerous cylindrical structures. The bed is 122 feet below the arbitrary base of the Triassic "Bright Red" siltstones, 760 feet thick. A 230-foot maroon sequence directly beneath the "Bright Red" is characterized by coarse-grained quartzites, arkosic conglomerates, and limestone intraformational conglomerates interbedded with limestones and calcareous siltstones. Irregular bedding, local cross-bedding, channeling, and rapid facies changes are also present. This sequence probably represents continental flood-plain conditions as opposed to the littoral or shallow environment indicated for the 8000 or more feet of underlying Pennsylvanian Maroon formation. The cylindrical structures are all perpendicular to the bedding. Their composition is identical with that of the rest of the bed. Cylinder contacts are sharp and somewhat irregular, although a general circular plan and uniform diameter are maintained throughout the length of the cylinder. Diameters range from less than 1 inch to 2 feet. The structures cross the crude bedding indiscriminately, and all seem to extend to the base of the bed. They are erratically distributed but are confined within several hundred feet along the outcrop. The cylinders are interpreted as fossil springs or quicksand pipes in a small area of semi-compacted surface mud. The bedding within pipes was destroyed by particle flotation in meteoric water rising under local hydrostatic pressure from a channel or aquifer at the base of the bed.

CONICAL AND CYLINDRICAL STRUCTURES IN THE POTSDAM SANDSTONE.....

Dietrich, R. V.; *Geological Society of America Bulletin,* 63:1244, 1952.

Abstract. Two cylindrical structures, one inverted conical structure, and seven structures having circular horizontal sections and vertical sections of unknown shapes occur in the upper Cambrian Potsdam sandstone 2 miles north of Redwood, New York. Their axes are approximately perpendicular to bedding planes of the Potsdam. The structures, composed

of sandstone similar to that constituting the adjacent flat-lying strata, are delineated by buff and red laminations subparallel to their borders and by the abrupt termination of stratification of adjacent beds at their borders. The nearly circular sections range from 2 inches to 15 feet in diameter; at least two of the structures have axes greater than 9 feet long.

Similar structures in the Potsdam sandstone of this region have been interpreted previously to represent concretions, sediments deposited by whirlpools in potholes, and typical flat-lying Potsdam sandstone in which the original pigmentation was modified by guyser action or by the rising of springs through the unconsolidated Potsdam sand, the affected areas subsequently undergoing concretionary cementation.

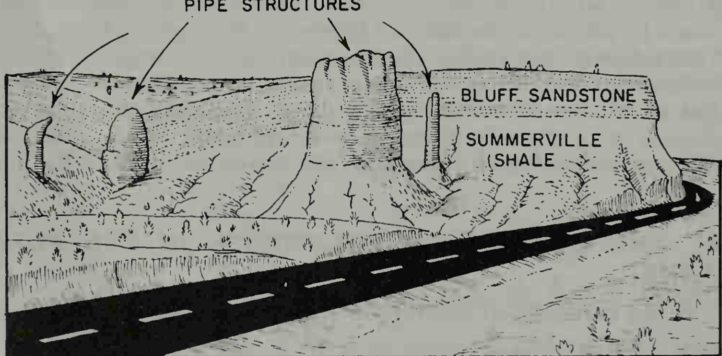
Field relationships suggest that the structures at the Redwood locality were formed by movement of unconsolidated and/or partly consolidated sand into cavities developed in underlying sand by falling of that sand into cavities in the underlying Precambrian Grenville marble. Strikingly similar structures have been observed to form in sand---some with interstices filled with a liquid, giving larger units a higher degree of integrity---placed in a box and allowed to run through a hole in the bottom of the box.

SANDSTONE PIPES OF THE LAGUNA AREA, NEW MEXICO

Schlee, John S.; *Geological Society of America, Bulletin,* 70:1669, 1959.

Many hundreds of cylindrical sandstone columns---termed sandstone pipes---are exposed in the Laguna area. They cut nearly horizontal strata of the Summerville, Bluff, and Morrison formations of Jurassic age.

The pipes range from a few feet to a few hundreds of feet high, and a few inches to 150 feet wide. Comparative petrographic studies of the material in the pipes and of the enclosing strata show that each pipe is composed largely of reworked massive subarkosic sandstone derived from the



Strata near Mesita, New Mexico, pierced by sandstone pipes. (Adapted from Geological Society of America, Bulletin, *76:1347-1360, 1965.)*

uppermost units cut by the pipe. In places a breccialike texture is present, with sandstone or mudstone fragments embedded in a matrix of similar lithology. The wall rocks sag inwardly around the pipes, and the pipes are bounded by one or more ring faults with downward displacement on the inner side. The bottoms of the pipes, rarely exposed, are in sharp contact with little deformed underlying beds. The pipes commonly flare outward at their tops, near the middle of a sandstone unit, and are buried by successively less deformed beds.

Most pipes are in belts along gentle structural depressions of Jurassic age; some are associated with local thinning or absence of an underlying gypsum unit.

The pipes originated during sedimentation of the uppermost unit that contain them and involve sediments that were then poorly consolidated. They probably formed in part by gravitational foundering of sand into mud and locally by collapse resulting from the removal of underlying gypsum. Contemporaneous structural depressions apparently localized both processes.

COLUMNAR STRUCTURE IN LIMESTONE

Roy, Sharat K.; *Science*, 70:140-141, 1929.

The occurrence of columnar structure in limestone is rare. As a result, its origin and characteristics have not been adequately recorded in geologic literature.

The late Dr. Salisbury mentions columnar structure in subaqueous clay in the vicinity of Menomonie, Dunn County, Wisconsin. He found distinct concentric lines on the cross-section surfaces of the columns and ascribed their origin to concretionary action. Other columnar structures in Devonian water-lime have been reported from the vicinity of Stroudsburg, northeastern Pennsylvania, but no detailed account of the nature of their origin is available. They are known to be very similar to columnar structure in basalt and have ball-and-socket joints.

In limestone only one example of this structure has ever been recorded. This occurs in the lower two thirds of a bed in Silurian limestone at the base of Mt. Wissick on the shore of Temiscouata Lake, opposite Cabano, Quebec. Dr. E. M. Kindle in an excellent article, "Columnar Structure in Limestone," describes the stratigraphy of the locality and shows that the limestone was formed under littoral conditions. He assigns its development into columns to mud-cracks which extended to a depth of from ten to twenty-four inches and which were filled up by sediments having a somewhat more argillaceous composition than the limy beds cut by the mud-cracks.

In the summer of 1927, the writer, while a member of the Rawson-MacMillan Expedition for Field Museum, had the opportunity to observe at Silliman's Fossil Mount, Frobisher Bay, Baffin Land, another example of limestone breaking into irregular columns. Silliman's Fossil Mount is in 63° 43' north latitude and 69° .02' west longitude. It stands at the head of the bay, about 300 feet from high tide and two and one half miles south of Jordan River. It is a hill of horizontally bedded limestone which lies unconformably on the hills of Meta Incognita. It is about three fourths of a mile long and 320 feet high (by aneroid) and runs in a general northwest and southeast direction. The entire mount, so far as its stratigraphy is known, is of Middle Ordovician age. It is significant to note that the mount is the only sedimentary deposit in place that has been found in the entire region of the bay, which is nearly 150 miles long and about fifty miles wide at its entrance from the Davis Strait. The existence of such an isolated hill of Ordovician age is at once interesting and problematic. It has been suggested by previous explorers that the mount is an accumulation of glacial drift. The fact, however, that the limestone is horizontally bedded is evidence enough that it must have been a deposit in place. The chronology of the geologic history of Frobisher Bay will be discussed in a later paper. For the present, it suffices to say that Silliman's Fossil Mount is either a remnant of erosion of the deposits laid down by the Ordovician and later seas on the irregularly eroded Archean surface or it is the result of erosion of sediments from graben developed during post Ordovician-Devonian faulting.

The columns observed by the writer are few in number and occur only in the uppermost beds at the southeast end of the mount. They vary in width and in the number of faces. The columns stand approximately perpendicular to the bedding plane, although some lie at an inclination of several degrees. Disintegration of the columns appears to be very rapid. In fact, talus has reached within fifteen feet of the summit. The limestone composing the column is of buff color, slightly brownish when freshly fractured. It is fine-grained and compact, and when dissolved in acid leaves a small amount (10 per cent.) of argillaceous residue. Although fossiliferous, it seldom yields small fossils. Large cephalopods and gastropods are its principal fauna.

These columns can not be ascribed to concretionary action. There is no evidence of concentric lines on their cross-section surfaces. Neither can they be ascribed to mud-cracks, since no filling material adheres to their adjacent faces. Again, as a rule, the fissures between columns resulting from mud-cracks diminish downward and terminate abruptly upward. In cross-section, mud-cracks are wedge-shaped (unless the walls of the cracks are parallel) and columns originating from them are likely to correspond with the walls and be wedge-shaped.

In the view of the writer the irregular columns in the limestone at Silliman's Mount are the result of a joint system developed from tensional forces acting during the uplift of the area. Joints producing cubical blocks in stratified rocks have two directions, vertical and at right angles. In this case there is an additional diagonal direction which does not lie in the line of intersecting points of the vertical and right-angled joint planes. In such a joint system there will be a series of columns having from three to six faces. Ordinarily the three-sided columns (being thinner and more angular) will disintegrate first separating the other columns and somewhat increasing the columnar effect of the strata.

• Erratic Boulders in Strata

ORIGIN OF THE GIANT CONGLOMERATES OF GREEN MOUNTAIN AND CROOK'S MOUNTAIN.....

Knight, S. H.; *Geological Society of America, Proceedings, 1936,* p. 84.

Abstract. Green Mountain and Crook's Mountain of central Wyoming are composed of beds of comglomerate of early Tertiary age, aggregating more than a thousand feet in thickness. At some horizons, granite boulders from five to ten feet in diameter are piled one on top of the other. The spaces between the boulders are filled with arkosic debris. At other horizons, large numbers of sporadic boulders measuring as much as 40 feet in length are embedded in arkosic grits and gravels. The boulders increase in size from the bottom toward the top of the succession. The basal beds contain fragments of older sedimentary rocks. The upper beds are composed entirely of pre-Cambrian granite or related rocks. The succession rests on folded and eroded Mesozoic rocks.

The conglomerates are exposed in the northward-facing escarpments of the mountains, which extend in an east and west direction for a distance of 25 miles. Paralleling these escarpments and lying 2 or 3 miles north of their bases is a major thrust-fault zone. Here the granite of the Sweetwater arch is thrust southward over the Paleozoic formations. It is believed that the conglomerate succession was deposited in front of the rising thrust block during the time of movement. Increased gradients permitted the transportation of successively larger boulders. Boulders weighing more than one thousand tons are numerous in the upper portion of the succession.

CATASTROPHIC STRATIGRAPHY

Ager, Derek; *The Nature of the Stratigraphic Record,* Macmillan, London, 1973, pp. 37-38.

Certainly there are many smashed-up-looking deposits around the world carrying huge exotic blocks far from their place of origin. One of the most remarkable I have heard of is in the island of Timor, where there is a deposit, known as Bobonaro Scaly Clay, that extends for some 600 miles of outcrop, 60 miles wide and 1-1/2 miles thick. In fact, if its alleged occurrence on other islands is correct, it extends for at least a thousand miles. Plate 4.3 shows a rounded exotic pebble in this deposit, with some men at the bottom to provide a scale. Quite apart from the problem as to how this massive chunk of basic igneous rock became rounded, it is difficult to use a term other than 'catastrophic' for the arrival of such a pebble. It is interesting to note, in passing, that rather similar chaotic deposits and slump topography have now been found at the foot of many present-day continental slopes. (37-38)

On the east side of Scotland, in Sutherland, there are what are---to me---the most exciting deposits in the British Jurassic. The Kimmeridgian stage of the Upper Jurassic is here developed to an exceptional thickness in a narrow strip along more than 10 miles of coast. Interbedded in the usual deepish water black shale are numerous boulder beds, that have been variously interpreted as ordinary sedimentary conglomerates, as tectonic breccias, as deposits from melting ice and as rock falls from towering cliffs. Sir Edward Bailey's lucid explanation of these deposits was that the boulders (up to more than 100 feet long) fell from a submarine fault scarp, probably triggered by earthquakes which also produced the clastic dykes that are a feature of the sections. Each seismic shock produced a tsunami, which swept shallow water sediments and fauna (including reef corals) down the fault scarp to settle among the boulders. Bailey's interpretation of the 'natural seismograph', as he called it, is certainly applicable in many other places around the world.

The gigantic Tertiary boulder beds of Ecuador are perhaps the best-known example. Boulders up to 3 km long are said to have fallen down a scarp along an outcrop more than 300 km long. The Tertiary 'Wildflysch' of Switzerland may be another example. I have used this kind of explanation myself for repeated boulder beds within a thick Cretaceous limestone sequence near Lagueruela in Teruel Province, in eastern Spain. (38-39)

THE ORIGIN AND AGE OF THE BOULDER-BEARING JOHNS VALLEY SHALE.....

Moore, Raymond C.; *American Journal of Science,* 227:453, 1934.

The Johns Valley shale is a dark clayey shale, locally some 1,000 to 1,500 feet in thickness, that occurs in the upper part of the geologic section of the northern and western Ouachita Mountains in west central Arkansas and southeastern Oklahoma. Its most distinctive character is the occurrence of numerous large and small boulders distributed irregularly through the shale. Since the boulders are identifiable as having been derived from fossiliferous Early, Middle and Late Paleozoic formations that are foreign to the Ouachita stratigraphic section and since some of the boulders have a maximum diameter measured in hundreds of feet, the origin of the Johns Valley beds is an exceptionally interesting problem. The age of the boulder-bearing shale is likewise a subject that has given rise to much discussion, for some evidence seems to indicate definitely a Lake Mississippian age while other evidence quite as definitely supports the conclusion that the deposit is of Early Pennsylvanian age. Study of the Johns Valley shale has importance, therefore, not only because it is an unusual type of sedimentary deposit but because determination of the origin and age of the formation is believed to have bearing on the location of the Mississippian-Pennsylvanian boundary.

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Erratic Boulders.---The erratic rock fragments in the Johns Valley shale range in size from small pebbles to masses 369 feet or more in greatest diameter. Most common are boulders of various sorts of limestone, but there are also masses of chert, sandstone and, according to Harlton's view and mine, of shale. Some of the limestone and chert boulders are peculiarly scratched, grooved or gouged.

Many of the boulders contain fossils, and it is possible by means of these and by observation of distinctive lithologic features to identify the geologic formations that supplied the boulder material. Ulrich has demonstrated that the source beds of the boulders range in age from Cambro-Ordovician to so-called Early Pennsylvanian. Especially common are boulders of Arbuckle and Simpson limestone. These and many other of the boulders correspond so closely to well-known formations of the Arbuckle Mountains area that Ulrich concludes that this region was undoubtedly their source. It is certainly significant that the formations represented by the boulders are entirely foreign to the Ouachita geosynclinal area, in which the formations corresponding in age to that of the boulders are entirely different. That the boulders were not actually derived from the existing Arbuckle Mountains area is, however, indicated by absence of Johns Valley type of boulder-bearing shale in any part of the Arbuckle Mountains region, and by the occurrence among the boulders of fossiliferous Devonian chert closely resembling the Camden chert of Tennessee, but absent in the Arbuckle Mountains district. As noted by Ulrich, however, a small outcrop of cherty beds containing this fauna occurs at one locality at the northwest margin of the Ouachita Mountains, just north of the Ti Valley fault. Many of the boulders observed near Boles, Arkansas, resemble units known in the Ozarks more closely than any formations in the Arbuckle Mountains. Among these Ozark-type boulders, Miser has discovered a fossiliferous fragment of Boone (Middle Mississippian) limestone containing fossils. The Boone is entirely unknown in the Arbuckles, but extends an unknown distance southward from the Ozarks toward the Ouachitas.

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Summary. The Johns Valley shale, with maximum thickness of 1,500-2,000 feet, occurs along the northwestern border of the Ouachita Mountains in west central Arkansas and southeastern Oklahoma. It lies with parallel structure on Jackfork sandstone below and is succeeded with apparent conformity of structure by the Atoka formation.

The Johns Valley shale contains many pebbles, cobbles and boulders, the latter up to a few hundred feet in diameter, all of which are derived from formations of the Arbuckle-Ozark type which are foreign to the geologic section of the Ouachita geosyncline. The erratic constituents range in age from Arbuckle (Cambro-Ordovician) to Morrow? (tentatively classed by me as latest Mississippian). To be included among the erratics are large masses of Late Mississippian Caney shale. It is these masses that mainly have led to confusion in determining the age of the Johns Valley formation.

Evidence is presented to show that in post-Morrow time an important uplift of Ozark-Arbuckle type rocks occurred along the region now occupied by the northwestern front of the Ouachita Mountains. This uplift, termed the Ancestral Ouachita Mountains, is presumed to have supplied "erratic materials" to a marine area of dark mud sedimentation lying to the south. After removal from the mountain uplift through agency of wave cutting, stream erosion or other agencies, probably including chiefly landslips along faults, it is suggested that the boulders were distributed through action of flowage or creep in the soft mud of the gently sloping sea-bottom.

GENESIS OF "HAYMOND BOULDER BEDS," MARATHON BASIN, WEST TEXAS

Hall, W. E.; *American Association of Petroleum Geologists, Bulletin,* 41:1633-1637, 1957.

The "Haymond boulder beds" have been described as sedimentary layers of Pennsylvanian age which crop out in the northeastern part of the Marathon Basin in West Texas. These outcrops have been recorded at two localities; one east of Haymond (near Housetop Mountain), and the other southeast of Gaptank (Old Clark Place). Sellards described the "boulders" as erratics, which he considered as evidence of mountain-making movements south and east of the Marathon region. He described the outcrop at the Old Clark Place as a conglomerate stratum, as did Baker. King, Baker, and Sellards referred to it as transported fault breccia indicative of diastrophism and uplift associated with the rise of highlands probably south of the "boulder bed" areas. The possible transporting processes which they suggested were: mud flowage, ice rafting, glaciation, and solifluction. Baker described the boulder-bed outcrops in great detail and discussed several possible theories of origin. He preferred the theory of glacial transportation during upper Haymond time. Carney also favored glacial transportation.

King described the "boulder-bed" fragments at the Housetop Mountain locality as: Precambrian granite, aplite, pegmatite, vein quartz, rhylite porphyry, and quartz conglomerate; sparse Maravillas (Upper Ordovician) chert; Caballos (Devonian) novaculite and coarse chert breccias; Tesnus quartzite sandstone; sparse Dimple limestone; and some fossiliferous Pennsylvanian limestone which he did not find in place in the Marathon Basin. He describes the fragments from the Old Clark Place as similar to the Housetop Mountain locality except that at the Old Clark Place fragments of Precambrian and fossiliferous Pennsylvanian limestone are rare. He considered that the "boulders" are part of a boulder-bed member of the upper part of the Haymond formation, and that the "boulder beds" are true sedimentary layers in a normal stratigraphic succession.

King described the "boulder bed" member of the Haymond as a complex group of interstratified, thin-bedded sandstones and shales, massive arkose, and boulder-bearing mudstone. He thought the "boulder beds" represented debris from faults and early growth of Pennsylvanian folds now exposed on the southwest. He did not indicate a preferred mode of transportation to the present locales. All writers seem agreed that the "boulders" were transported by surface agency and deposited as sedimentary layers during late Haymond time.

At Housetop Mountain the outcrop, partly covered by alluvium, is 8 miles long and up to 300 yards wide, extending northeastward parallel with the local steep folding. The strata exposed at the east are Tesnus, those at the west are Haymond. At the Old Clark Place the "boulder-bed" outcrop, partly concealed, is 4 miles long and narrow, and it parrallels the local steep folding. The adjoining deformed strata at the south are lower Tesnus, those at the north are Haymond.

A direct structural relationship between the "boulder beds" and the folds is indicated by the alignment of the "boulder beds" along the long axes of the folds, and parallel with the major faults. This relationship is further indicated by the outcrops west of the Old Clark Place and by structure shown by outcrops west of Housetop Mountain. At the southwest, in the central part of the Marathon Basin, are numerous similar faulted folds where the pre-Pennsylvanian cores have been exposed by erosion. King says that the "boulder-bed" breccias of Caballos age resemble breccias along some of the thrust faults in the novaculite (central Marathon basin) area. The writer believes that this faulting and folding occurred during the lower Wolfcamp orogeny.

A suggested geologic interpretation is provided by the outcrops west of the Old Clark Place. This is shown in section AA'. This sketch shows that the "boulders" are not transported and bedded, but are fault breccia and outcrops of Paleozoic strata brought to their present position by faulting and folding. Much of the "boulder" material has been disintegrated by weathering agencies; in fact, the dominant field evidence of these beds is widespread pre-Pennsylvanian residual debris. One of the fault surfaces is exposed with breccia and pre-Pennsylvanian cherts on the north side and Tesnus quartzite on the south side. The rather thin-bedded clastics on the north side of the faulted pre-Pennsylvanian are thought to be Haymond. The nearest outcrops of Dimple limestone are 3 miles east and south. Some of the breccia is itself brecciated, indicating earlier faulting. The sketch uses one part of the outcrop locality for the "boulder-bed" outcrop and adjoining Pennsylvanian strata on the south side, and another part of the outcrop locality (1/4 mile east) for the northern part of the figure. The critical evidence of these outcrops is the exposed fault contact between Tesnus and pre-Mississippian. (Figures omitted.)

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It is concluded: (1) that the "boulder beds" are not sedimentary layers of boulders, (2) that the "boulder beds" are the denuded cores of faulted folds, and (3) that the age of the folding and faulting is lower Wolfcamp (Permian).

PROBLEMS OF BOULDER BEDS OF HAYMOND FORMATION, MARATHON BASIN, TEXAS

King, Philip B.; *American Association of Petroleum Geologists, Bulletin,* 42:1731-1735, 1958.

The writer has read W. Ellis Hall's recent note, "Genesis of 'Haymond Boulder Beds,' Marathon Basin, West Texas," and feels obliged to present some personal geological observations which do not support the conclusion that these boulder beds are "the denuded cores of faulted folds." This writer has visited the Housetop Mountain and Bennett Ranch localities to collect samples of the igneous and metamorphic pebbles and cobbles found among fragments of recognizable Paleozoic rocks.

The igneous pebbles and cobbles are well rounded and composed mostly of muscovite granite, commonly rudely gneissic. The metamorphic pebbles and cobbles are also well rounded; the most common type is a highly sheared porphyry of intermediate composition, some samples of which are near mylonites. Sheared metaquartzite and one specimen of tourmaline-garnet gneiss were collected. In contrast to these more highly metamorphosed mostly cataclastic rocks, fragments were found of weakly metamorphosed silica-cemented sandstone showing reconstitution of intergranular material to sericite and chlorite. The latter are of a type common in the weakly metamorphosed parts of the Ouachita structural belt, of which the Marathon basin exposes a salient.

Although most of the pebbles, cobbles, and boulders of the Haymond boulder beds are found strewn about on the surface, a little digging discloses fragments in place in a shale or mudstone matrix. This is true for the round igneous and metamorphic pebbles and cobbles as well as the fragments of sedimentary rocks. The largest round granite cobble dug out of the matrix was 6 inches in diameter; smaller ones are more common.

At the Bennett Ranch locality the boulder-bearing unit is seen to be concordant within the stratigraphic sequence. The overall stratigraphic relationships and the presence of this mixed suite of rounded igneous and metamorphic pebbles and cobbles, clearly modified by one or more cycles of transportation, in close association with a suite of mixed angular to round pebbles, cobbles, and boulders of Paleozoic sedimentary rocks, some of them recognizable as to formation, do not support Hall's theory that these boulder beds are "the denuded cores of faulted folds." Mudflow transport from areas of active tectonism, as suggested by King, seems to be the most plausible explanation of their origin.

ICEBERG SEA ONCE COVERED ARKANSAS

Anonymous; *Science News Letter,* 14:364, 1928.

Icebergs similar in form and size to those that imperil the ship lanes of the North Atlantic Ocean were once carried by ocean currents into western Arkansas. This was many millions of years ago, in the Carboniferous period, when the sea covered much of the present area of Arkansas and adjoining states. Just as the icebergs of the North Atlantic are derived from the glaciers of Greenland, the icebergs that visited Arkansas in Carboniferous time were derived from an ancient ice and snow-clad range of mountains lying in Oklahoma and northeastern Texas, south of Ardmore, Okla. From these mountains ocean currents carried the bergs across southeastern Oklahoma into Arkansas.

That such frigid waters once spread into Arkansas is the conclusion of Hugh D. Miser, of the U. S. Geological Survey, from evidence he recently discovered at a locality half a mile east of the village of Boles, Scott County, Ark. There he found fragments of numerous boulders that had been transported by floating ice from the Oklahoma-Texas mountains. The boulders were dropped to the bottom of the sea when the rock-laden bergs melted, and they are now found in black shale which was mud at the time the boulders dropped to the ocean floor. The boulders are limestone of many different kinds and some of them are several feet in length. Only portions of the boulders were observed by Mr. Miser because farmers blasted and gathered up much of the limestone many years ago and burnt it into lime.

Although the Boles locality is the first occurrence of ice-transported boulders to be discovered in Arkansas, it is not unlike many such occurrences on the Ouachita mountains of southeastern Oklahoma. It is, however, 30 miles east of the easternmost Oklahoma occurrence, near the village of Stapp on the Kansas City Southern Railroad.

A noteworthy feature of many of these boulders is their enormous size. The huge stones range in size up to blocks measuring 30 feet across. Mr. Miser observed one block measuring 200 feet in length, another with revealed dimensions of 110 by 195 feet, and a third with revealed dimensions measuring 50 by 369 feet.

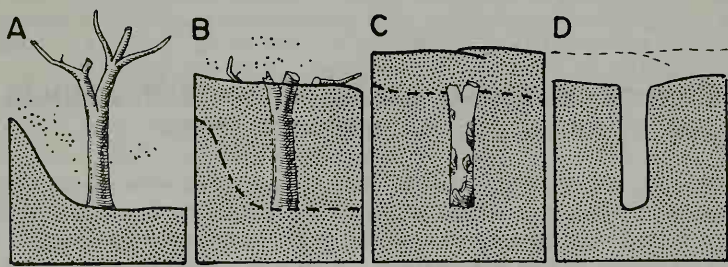
• Columnar Holes

THE ORIGIN OF COLUMNAR HOLES IN WANDERING DUNES
Harshberger, John W.; *Science,* 57:727-728, 1923.

The forests which existed on the New Jersey sand strands at Wildwood, Holly Beach, Peermont, South Atlantic City and South Seaside Park have been almost entirely destroyed, except at South Seaside Park and Peermont. The forest at the latter place has been invaded by wandering dunes, the highest of which are about forty feet, or the height of the tree tops. The formation of these dunes is due to the trees, which break the force of the wind, so that the sand accumulates on the seaward side of the forest. The accumulation of sand is followed by its encroachment on tree growth, so that the forest is narrowed gradually. The trees, which were buried by the advancing sand, have in some cases persisted without decay, especially the red cedars, and as dead trees they form a forest graveyard with the bleached stumps as monuments sticking through the dune sand, which has drifted away from such dead and buried trees with the action of the fickle wind. Fifty years hence little will remain of this forest of red cedars, hollies, post oaks, Spanish oaks, red mulberries, sour gum trees, hackberries, etc. The wandering dunes will have covered and destroyed the remaining trees. This forest destruction has been going on for a long time and between the highest dunes and the sea beach at Peermont, New Jersey, is the dune complex corresponding in area with the forest graveyard. (A).

The tops of the buried trees have decayed at the surface of the dune sand (B) and the branches have been broken off and have been carried away by the wind, or have been buried in situ by the drifting sand. The trunks of the trees have been covered with sand (C). If of destructible wood (the red cedars alone remaining without much decay), the tree trunks of such species disappear by decay and there is left a cylindrical cavity the exact height and other dimensions of the tree trunk, which before decay formerly filled it. Such decay is absolute, for when the columnar hole is uncovered there are found no remains of the tree which formed it. If there are any remains of the bark and the wood of the trees, they have dropped to the bottom of the hole and have been covered by the sand which has fallen from above into the depressions. These columnar cavities are roofed with compacted sand and with the removal of the sand by wind action, there is a change in the configuration of the dunes, and in the lowering of the dunes the columnar holes are uncovered. The upper edges of the holes slope inwardly (D) and leaves and blades of grasses and the tops of the tumble grasses (Eragrostis pectinacea) fall into the depressions, which are sometimes six to eight feet deep and a foot in diameter.

As far as the writer is aware the origin of these holes has never been described, although Dr. Seneca Egbert, of the University of Pennsylvania, has informed him that he had discovered them over thirty years ago at Peermont by breaking through the roof of one. The accompanying sketches will make clear the sequence of events in the formation of the columnar holes in the wandering dunes at Peermont, New Jersey.



Sequence illustrating how columnar holes may be formed in sand dunes.

• Quicksand Structures

QUICKSAND STRUCTURES IN THE BEDDED TUFTS OF GREAT LANGDALE.....

Parker, W. R.; *Nature*, 210:1247-1248, 1966.

Quicksand structures similar to those described by Selley abound in the bedded tuffs (Ordovician) of Great Langdale. These sediments appear to have been highly susceptible to the type of behavior suggested by Shearman and called by him "'quicksand' movement". These authors described examples in Torridonian and Devonian sandstones where this process, involving the repacking of sand grains and the expulsion of excess pore-water from the sediment, had, they assumed, operated "penecontemporaneously". It appears that both authors consider that this process took place below a thin (less than 1 m?) cover of sediment. (Figures omitted.)

Fig. 1 illustrates a structure in the bedded tuffs thought to have been produced by "quicksand" movement. Laminated mudstone rests on sandstone. A rectangular embayment projects upwards into the mudstone. Within this embayment, and also along the base of the laminated mudstone, angular, sharply bounded fragments of the laminated mudstone occur dispersed in the sandstone. Sand grains have not been pressed into the mudstone fragments.

From this structure it is concluded that: (a) the sand was mobilized after the laminated mud had been compacted to mudstone; (b) mobilization must, therefore, have occurred beneath a sediment overburden thick enough to have compacted the mud to mudstone. This overburden would also have provided the hydrostatic pressure which enabled the mobilized sand to penetrate into the mudstone.

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• Sandstone Dikes and Linear Bodies

SANDSTONE DIKES

Diller, J. S.; *Geological Society of America, Bulletin,* 1:411-442, 1890.

Summary. The sandstone dikes upon the forks of Cottonwood creek along the northwestern border of the Sacramento valley in California are over forty five in number, and crop out at about 112 exposures throughout an area fifteen miles in length from north to south and six miles in average width.

They are all approximately parallel, with an average strike throughout the whole area of N. 44^{o} E.

They are usually vertical, ranging from a mere film to 8 feet in thickness and from 200 yards to 9-1/3 miles in length.

They intersect the Cretaceous sandstones and shales along joints, without distortion or displacement of the strata, and occasionally include numerous fragments of the shale.

They are sometimes banded vertically parallel to their sides, and the scales of mica and other lamellar fragments usually stand on edge in the same plane.

The dikes are traversed by joints in two principal directions, parallel and transverse. Unlike the columnar jointing in igneous dikes, the groups of transverse joints in the sandstone dikes cross one another directly; and the principal group is usually parallel to the stratification of the adjoining shales.

The dike rock is an impure quartz sandstone containing considerable biotite. The structure of the rock is unquestionably fragmental, and shows no trace of crystallization in place of any material excepting the cement, which is carbonate of lime.

Much of the biotite is crushed in the direction of foliation, that is vertically in the dike, since the scales stand on edge and the distortion of the particles is such as to indicate that the sand moved upward in filling the fissure.

Filling fissures in the earth with sand from below is a common consequence of earthquakes---natural phenomena which are by no means rare in California.

The geologic structure of the region is such as to render it especially favorable for the production of sandstone dikes by means of earthquakes; and the evidence appears to be conclusive that these dikes record seismic movement during the Tertiary.

....

LIMESTONES AS ERUPTIVE ROCKS

Anonymous; *Nature*, 142:704-705, 1938.

The carbonate-rocks, especially limestones and dolomites, are so well known as sedimentary or metamorphosed sedimentary rocks that there may be some surprise that petrologists of Section C (Geology) of the British Association spent the greater part of a day during the recent Cambridge meeting in discussing the origin of carbonate-rocks associated with alkali-rich intrusions.

The occurrence of limestones in close association with alkali-rich rocks, such as nepheline-syenites, phonolites and related types, has been observed with great frequency and it has commonly been assumed that the limestones, where not clearly belonging to a sedimentary formation, were relics of sedimentary limestones assimilated in depth by the igneous magmas.

According to a widely accepted theory proposed by R. A. Daly in 1910, such assimilation of limestone by sub-alkaline magmas is the cause of the formation of the alkali-rich igneous rocks.

However, so early as 1892, some limestones occurring in the form of dykes and cutting the volcanic rocks of the Kaiserstuhl in Baden, were described by A. Knop, and three years later A. G. Hogbom described limestone dykes in a region of alkali-rich intrusives on the island of Alno in Sweden. Hogbom also recorded calcite as a primary mineral in some rocks at Alno, and there were other descriptions of primary calcite in alkali-eruptive rocks from Canada and India. In view of the readiness with which calcite dissociates on heating, geologists were reluctant to accept it as a primary mineral or to believe in limestone intrusions, but during the last few years much fresh evidence of apparently intrusive carbonate-rocks has been obtained.

The most convincing new evidence comes again from Alno, where the rocks are now far better exposed than they were at the time of Hogbom's visits forty-three years ago. They have been studied thoroughly by Dr. Harry von Eckermann, of Stockholm, who opened the discussion at Cambridge. A large area of alkali-intrusives---nepheline-syenites and ijolites---cuts the Precambrian gneisses and is probably late-Jotnian in age. Around the contact with the gneiss (which is altered) crystalline limestones appear, and outside the neck of intrusive rocks there are calcitic and dolomitic dykes which are shown to be cone-sheets dipping towards two deep central foci. From the inclination of the cone-sheets the focus of the calcite dykes can be shown to be at 1-2 km. below the present surface, and that for the dolomitic sheets at 6-7 km. The geology of the country near Alno is well known, and von Eckermann regards it as certain that for hundreds of miles around and to great depths there is no trace of sedimentary limestone in the Archaean rocks of earlier age than the alkali-intrusives. All the evidence points to a magmatic origin for these limestones at Alno.

Magmatic origin is also claimed by Dr. F. Dixey for the crystalline limestone associated with breccias filling remarkable vents of post-Karroo age in Southern Nyasaland. At one of the largest of these vents, Chilwa Island, limestone and orthoclase-breccias occupy a roughly circular area 1-1/2 miles across and form steep cliffs rising 1,400 ft. above the level of Chilwa Lake. Nine larger and seven smaller vents are known, and at most of them the limestones are cut by small bodies or dykes of alkali-rich rocks, nepheline-syenite, ijolite, phonolite, or nephelinite. The rocks surrounding the vents are altered and there are many resemblances with the rocks of Alno. As for the source of the limestone, Dr. Dixey finds that the small lenticles of limestone known to occur in the Basement Complex of the district are altogether too small and infrequent to have supplied the limestone for the great masses of the Chilwa vents, and the conclusion that they are in some way magmatic seems unavoidable.

Mr. S. I. Tomkeieff had visited Fen in Norway, where the rocks, closely comparable with those at Alno, were described in a classic paper by W. C. Brogger in 1921. He has no doubt about the dogmatic origin of the carbonate rocks in that district.

Prof. S. J. Shand claimed that the limestones at Alno and Fen, and at eight other localities which he listed, had been or ultimately would be proved to be derived from sedimentary or metamorphosed sedimentary limestones. He described two areas of alkali-rich rocks---Haliburton, Ontario, and Sekukuniland, Transvaal---where he regards it as demonstrable that carbonate-rocks associated with nepheline-syenite have been derived by the incorporation of sedimentary or metamorphic limestones by igneous magma.

Prof. C. E. Tilley admitted that the limestone-syntexis theory is applicable in certain places to a limited extent and he believes that the limestone 'intrusions' in the Haliburton and Bancroft areas present certain peculiarities differentiating them from the other occurrences, but he claimed magmatic origin for every other example of limestone associated with alkali-rich rocks in Prof. Shand's list. He mentioned especially Magnet Cove, Arkansas, and Palabora, Transvaal, and he added two new examples: Iron Hill, Colorado, and Kalossero at the head of the White Sea.

The claim for magmatic origin of some of these limestones seem to rest on good field evidence, but it needs to be supported by a credible explanation of how magmatic limestones can be formed and why they are associated with alkali-rich intrusions. To this task Dr. von Eckermann devoted the last half of his address. He outlined the possible processes which might have effected the formation at the base of the Jotnian sheet-intrusions of a nepheline-syenite magma rich in potash, carbon dioxide, fluorine and chlorine, and he traced the possible history of such a magma as it stoped its way upwards to a point at which the concentrated volatiles shattered the roof and more or less pure carbonates filled the conical fractures in the surrounding rock. Mr. Tomkeieff also was able to suggest a possible petrogenetic scheme for the rocks of Fen. He regards carbon dioxide as probably originally present in many rock magmas but lost by most during consolidation. Where it is retained, it must have a profound effect on the course of differentiation. While Dr. Eckermann made no claim that the explanation he had put forward applied outside Fennoscandia, Mr. Campbell Smith, referring to the rocks of the Chilwa Series of Southern Nyasaland, said that there are so many resemblances between them and the rocks at Alno and Fen that processes which were active in Fennoscandia in the Archaean must have been operative at the Chilwa vents in post-Karroo times. He said that in Nyasaland the problem is to explain the close connexion between the formation of pure orthoclase-rocks (remarkably rich in potash), their brecciation, the alteration of the country rocks, the supply of material for and the emplacement of the crystalline limestone, and the subsequent intrusion of alkali-rich rocks.

When the results of Dr. von Eckermann's work are published, it may be found that all these closely related events will find their places in the scheme of differentiation of which during the discussion he gave a brief description, but which lack of space here compels us to omit.

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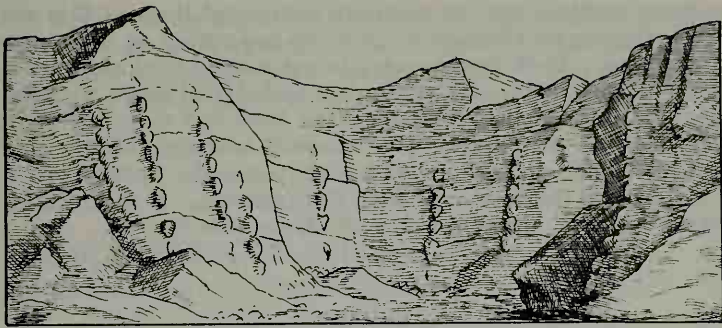
• Unusual Flint Bodies

ON THE ENIGMATIC FLINT BODIES.....

Charlesworth, Edward; *Victoria Institute, Journal of the Transactions,* 26:209-219, 1892.

Thus far I have been dealing with the great geological problem of flint as found in chalk. I now pass on to submit to the members of this Society the consideration of a most remarkable enigma connected with the chalk-flint story, which has been an enigma ever since when in the transactions of the Geological Society for 1816 it was brought under the notice of philosophers and men of science by the great geologist, Dr. Buckland. The title of Dr. Buckland's paper is "Description of the Paramoudra, a singular fossil body found in the chalk of the north of Ireland." These singular fossils, says Dr. Buckland, are found in many of the chalkpits from Moira. They are known at Belfast by the name Paramoudra, a word which I could trace to no authentic source, but shall adopt. They have, I believe, never yet been found in the chalk of England, except at Whitlingham near Norwich, whence there is a good specimen in the Geological Society equal in size to the largest I have seen in Ireland, being about two feet long and one foot in diameter. No two of these bodies are found exactly alike in all their proportions. Their length commonly varies from one to two feet, their thickness from six to twelve inches. Their substance in all cases is flint. These bodies have a central aperture passing through their long diameter. These apertures are always filled with chalk of the same nature as the chalk in which the flint masses are imbedded. Then Dr. Buckland



Chalk cliffs near Norfolk, England, containing vertical lines of flint bodies.

goes on with descriptive details which I pass over, but I quote the Doctor's account of the position of these bodies. The Paramoudras sometimes lie horizontally, sometimes inclined or erect. They are generally insulated, and altogether unconnected with the ordinary horizontal strata of flints which accompany them. Sometimes the extremities of two specimens are found in contact; but this seems to be the result of accidental juxtaposition, not of any original connexion. But I mention it because an idea used to prevail at Belfast that the Paramoudras are occasionally found linked together in a kind of chain.

....

It was not possible that so remarkable an incident in geological history as massive flint tubes occurring in the chalk of Antrim and Norfolk, and utterly unlike any mineral or organic forms of matter previously known, could be passed over by the lynx-eyed Sir Charles Lyell. Accordingly we find in the volume of the "Proceedings of the British Association" for the year 1838, that the following paper by Sir Charles was read before the Geological section.

"It has long been known that near Norwich the horizontal beds of flint nodules are crossed by perpendicular rows of much larger flints. These larger and vertical flints are locally called 'Potstones,' and are the same as those which ossur in the chalk of Ireland, and which have been described by Dr. Buckland under the name 'Paramoudra.' At Horstead, about six miles from Norwich, an excavation has been made nearly half a mile in length, through 26 feet of white chalk, covered by strata of sand, loam and shelly gravel to the thickness of about 20 feet. The rows of vertical 'Potstones' are remarkable for their number of continuity. It is affirmed by those who for more than twenty years have been engaged in quarrying the chalk, that every column of these vertical flints has been found to extend from the top to the bottom of the chalk, so far as the quarrying has been carried downwards. The columns occur at irregular distances from one-another, usually from 20 to 30 feet; and they are not portions of continuous flints in a vertical position, but piles of single flints. Few of the flints are perfectly symmetrical, and they are very unequal in size, usually from a foot to three feet in their vertical length. At the point of intersection between these vertical and the ordinary horizontal lines of flint there is no mutual interruption or shifting; but the two are united as if both were formed. at the same time. Each Paramoudra is not a solid flint as is the case with horizontal flints, but contains within it a cylindrical chalk nucleus, which when deprived of its flint envelope has the form and smooth surface of a tree when stripped of its bark. This internal mass of chalk is much harder than ordinary chalk, and does not crumble under the action of frost. It is seen at the top and the bottom of each Paramoudra. A ventriculite sponge was observed on one occasion in the chalk-nucleus."

....

THE DRIFT AND THE ICE AGES

The drift is a remarkable stratum of clay, sand, gravel, and far-from-source boulders seemingly flung by some careless hand over the northern portions of Europe and North America. Some of this debris has been moulded into distinctive ridges (moraines), rounded hills (drumlins), and long sinuous ridges (eskers). Any theory of drift formation must account for these singular accumulations as well as an immense family of scratches, lake basins, and sundry gougings.

The continental ice sheets of the Glacial Epoch are commonly credited with this colossal sculpturing. Although the Ice Ages have assumed the status of scientific dogma, some facts of the drift are not in accordance with the theory. It will be instructive to consider some of these seeming contradictions in this section. Some anomalous aspects of the drift are:

- Drift deposits and apparent glacial striations well south of the charted ice sheets
- Erratic blocks hundreds of feet above their quarrying points that call into question the motive force pushing the ice sheets and their mechanical strength
- Striations indicating northward motion of the supposed ice sheets
- The curious and difficult-to-explain distributions and internal structures of some drumlins and eskers
- Boulder trains and associated erosion that seem to demand cataclysmic flooding
- Puzzling enclaves devoid of drift.

These and other curious features of the drift are flaunted by some who wish to repeal the Ice Ages and substitute catastrophic events, particularly flooding. The catastrophists have made little headway because the Ice-Age theory does explain many aspects of the drift and is also compatible with uniformitarian thinking. The Ice Ages are amenable to scientific methodology. One can speculate about orbital changes, global heat budgets, the effects of volcanic dust veils, etc. In contrast cataclysmic flooding and other catastrophes invoke unpredictable cause-and-effect chains of events that transcend the scientific method. Geological convulsions indeed may have sculpted northern terrains; but the anomalies presented below have not significantly reduced the number of Ice Age believers.

(Incisive critiques of the Ice Age hypothesis are nonexistent in the recent mainstream geological literature, so we draw upon "creationist" journals, which are usually excluded from scientific debate. Most readers should find the following survey paper stimulating, comprehensive, and well-referenced. WRC)

PROBLEMS IN THE GLACIAL THEORY

Cox, Douglas E.; *Creation Research Society Quarterly*, 13:25-34, 1976.

Abstract. The drift phenomena around the world have been interpreted by modern geologists in terms of the Glacial Theory. A great many problems of a fundamental nature are involved in this interpretation. The cause for the ice ages has not been determined. The distribution of the drift has given rise to numerous complicated and unlikely theories of events in the earth's past. Movement of great ice-sheets, necessary for a theory of distribution of the drift by ice-sheets and for the formation of streamlined landforms in a glacial environment, is postulated through some unknown mechanism. Mysteries abound in the glacial explanations for drumlins, kames and eskers, the formation of stratified drift, and ice-disintegration features. Fossils of the Quaternary include mammals not usually associated with cold climate. All of these facts suggest that the reality of the ice ages has not been proved.

Evidence Commonly Cited for the Theory. The glacial theory is the presently accepted explanation for the layer of unconsolidated material that covers the solid sedimentary and igneous rocks in the temperate zones of Europe and North America. The material consists of gravel, sand and clay, with many large boulders of variable composition, and innumerable rounded stones and pebbles of all sizes. Often it is hundreds of feet thick. Frequently stratification exists, and it is usually present in the sand in the pattern of cross stratification.

A mantle of unconsolidated material similar to that of Europe and North America also occurs in parts of India, in South Africa, the tropical zones of South America, and in many mountainous areas of the world. Usually referred to as "drift", the material is also known as boulder-clay, diluvium, outwash deposits, glacial moraine, and till.

The surface of the mantle of drift is shaped into a wide variety of structures, that have been invariably associated with a glacial origin. Kames are conical mounds usually composed of sandy material, that are thought to have been caused by the dumping of glacial debris when the great ice-sheets of the glacial age melted. Eskers are long, winding ridges of gravel and sand, that are explained in the glacial theory as the debris of rivers formed in or on the glaciers, that was let down when the ice melted. Sometimes branching eskers occur. The eskers are known to stretch for great distances, go up and down hills, and disappear and occur again further on.

In the prairie regions of Canada and in the northern states of the United States there are various kinds of rimmed plateaux, composed of drift. Often these have central depressions containing clay sediments. The rims are often composed of stony material and contorted drift layers. Some of the rimmed plateaux or prairie mounds are of large size, with areas of several square miles, and may reach as much as 150 feet above the surrounding hummocky and pitted regions.

The rimmed plateaux and prairie mounds are explained in the glacial theory as landforms created during the melting of the great ice-sheets. The glaciers, it is believed, sometimes melted in such a way that isolated blocks of ice were formed, that wasted away and deposited their debris in various kinds of rimmed structures and plateaux.

Drumlins and flutings are streamlined landforms that are explained as the effects of the movement of the ice in the glacial theory. The ice-sheet flowing across the countryside shaped and moulded the rocks and previously deposited layers of glacial debris into these remarkable streamlined landforms, that occur in swarms sometimes covering thousands of square miles. In drumlin swarms the drumlins all have locally parallel orientation.

Drumlins are hills shaped like the inverted bowl of a spoon. Glacial flutings are similar, elongated parallel ridges and troughs. These may stretch for several miles in the prairies of Canada and parts of North Dakota and Montana. Drumlins and flutings are often composed of drift, but many are bedrock or partly bedrock. Some have a mass of bedrock at their upstream ends.

In general the landforms composed of drift have a remarkably fresh appearance. Although they contain loose material, the effects of erosion have been minimal, showing they could not be of great age but must have been formed recently. Geologists believe that the last of the ice disappeared only a few thousand years ago.

Striations are frequently present on the surface of the bedrock underlying the layer of drift. In some areas the bare rocks uncovered by drift are also scratched and grooved, as if by movement of stones across them, and this is attributed to the ice-sheets in the glacial theory. As the ice-sheet moved, it is supposed, there were large numbers of stones being carried along in its base, that gouged the bedrock as the ice-sheet went along.

Within the layers of gravel in the drift there are many rocks and boulders that are striated. These are thought to have been transported by ice and abraded in the process.

In the bedrock underneath the drift, and at many places where the bedrock is exposed, there are deep vertical potholes, that are often explained by reference to the glacial theory. These are attributed to glacial "moulins" or waterfalls tumbling down crevasses in the ice, that eroded the bedrock and caused these deep holes. Potholes are usually filled up with the drift material, sand and gravel and large boulders.

Large boulders are found in some regions with a composition quite different from that of the bedrock in the vicinity. In the drift there are stones and pebbles of varying composition and appearance, but most of the rocks reflect the composition of the bedrock underneath. The large boulders of quite different composition are known as "erratics", and are considered to have been transported from regions afar by the moving ice-sheets. These may sometimes be as large as houses, and are usually rounded, though some are of irregular shape.

Earlier Interpretations of the Evidence. The layer of drift was once attributed to the flood, rather than ice ages. The term "drift" goes back to the idea that the transported rocks, those with compositions differing greatly from that of the bedrock in the region, were thought to have been rafted about during the flood by icebergs. These rocks, it was supposed, dropped down through the waters when the ice-floes melted.

An American version of the theory that ice-floes transported the drift material during the Noachian deluge was proposed by Peter Dobson of Vernon, Connecticut in 1826. He reached his conclusions from observations of striated boulders found on the surface and at considerable depths in excavations of the drift.[1]

The Rise of the Glacial Theory. A leading exponent of the diluvial theory of the drift was William Buckland of Oxford, England. He was among the first, however, to abandon this idea in favor of the glacial theory of Louis Agassiz. Buckland supported Agassiz's claim that Britain and much of Europe had been inundated by land-ice after Agassiz visited Scotland and England in 1840. Charles Lyell, however, still favored the iceberg theory for most of the drift.

The Glacial Theory Accepted, but with Some Opposition. Agassiz came to America in 1846 and energetically proclaimed the glacial theory while teaching at Harvard University. Gradually the theory of a great glacial age gained acceptance, although strong opposition was voiced by geologists such as J. W. Dawson and Sir Henry Howorth. Howorth wrote numerous articles in opposition to the claims of glacialists that appeared in the Geological Magazine of London. He also wrote books such as The Glacial Nightmare and the Flood, and Ice or Water, a two-volume sequel arguing against the glacial interpretations and proposing instead a violent flood as the cause of the drift phenomena.

For many years a controversy raged about the reality of the Ice Ages, but Howorth's arguments were not taken very seriously by geologists who favored the glacial interpretation. His idea of a violent catastrophic origin of the drift was ridiculed. Referring to one of Howorth's books, Warren Upham wrote in 1894:

> The attention and general approval which have been accorded by English and Scottish reviewers to the recent book by Sir Henry H. Howorth, which sets aside the glacial theory, and substitutes for it the debacle theory, earliest thought out and long ago abandoned by geologists, seem surprising to American readers, since a most wonderful and unique but gentle agency of formation of the drift is by these authors discarded in favour of a still more strange and extravagantly violent hypothesis....they seek to revive an old opinion which had its day at the beginning of investigations of the glacial drift, but long ago became entirely obsolete.[2]

Howorth's Objections Considered Especially. No answer to Howorth's scientific objections to the possibility of the mechanisms involved in the glacial theory seems to have been published, however; and it would seem that the principles he appealed to have not become dulled over the years. Many of the assumptions involved in the glacial theory, Howorth argued, are contrary to physical laws and known facts about the properties of ice.

Howorth believed that the motivation of geologists who favored the glacial theory was their reluctance to accept a catastrophic alternative. He advocated a return to the older view, that the drift layers were the deposits of the Noachian flood, and that these materials had been transported by violent currents. In his book Ice or Water he discussed the reluctance of his contemporaries to accept this alternative:

> This alternative, I have always maintained, exists, and was

universally accepted before the world was dazzled by the factitious glamour of Agassiz's rhetoric, and especially by the escape it seemed to offer the fanatical adherents of the theory of uniformity as expounded by the disciples of Lyell, more especially Ramsay and Jukes. Their real inspiration has been the fervent hope embodied in the words with which Sir R. Ball concludes his ill-fated book on the Glacial Age. "The appeal to ice," he says, "removed the glacial period from the position of a 'catastrophic' phenomenon. It placed the ice-sheet as an implement at the disposal of the geological uniformitarian." That was the real basis and inspiration of the new theory. That was what gave it its hold upon the geologists of a generation ago. They did not stay to ask whether in their zeal in favour (not of a real doctrine of uniformity, but a bastard one) they were not giving themselves up to a Scholastic figment and appealing to a fictitious and imaginary instrument in order to save them from what they deemed the most pestilent of heresies, namely, catastrophism in any form.[3]

How the Present State of Opinion Arose. Whatever the reasons, most geologists slowly accepted the theory of ice ages and the idea of a world-wide flood was relegated to the limbo of having no geological effects whatsoever. And that is its present status, although there have been some voices in the wilderness all along proclaiming the faults inherent in the Geological Time Scale.

The intellectual climate at the end of the nineteenth century was overcast by the heated debates amongst the scholars about evolution. Intense opposition to Biblical teachings no doubt hindered a really objective attitude to the evidence for or against the glacial theory. There cannot be any doubt that geologists were aware of the many contradictions and seemingly impossible assumptions involved in the postulated ice-sheets.

It was thought that while the whole theory might eventually prove to be wrong, it was still a useful framework for observation. Perhaps because of the unsolved problems in Quaternary geology it has been the most studied of any of the geologic eras, but a progress report of the last century could still aptly apply to the state of affairs today. T. Mellard Reade wrote in 1896:

> The phenomena of the Glacial Period in Britain contain some of the most interesting problems it has yet been the lot of geologists to attempt to solve. It therefore behoves us to approach the subject in a spirit of humility. That such varied explanations have been proffered from time to time, that most contradictory conclusions should be drawn from well-ascertained and generally acknowledged facts, is curious and somewhat depressing. There is, however, this reflection to comfort us: however strange, however contradictory, however devoid of common-sense the various explanations and theories of the Glacial Period appear to the various observers and reasoners upon them, the total effect is, like that of the hypothetical Ice-Sheet, a push forward. Without opposition, observation stagnates, so that the first effect of enthusiasm, even if directed in lines that afterwards prove to be mistaken, is to advance the science we love so well. Even if a theory be utterly false, it may prove of great educational value, for, until every possible line of reasoning has been traversed, secure ground cannot be reached.[4]

With this rather uncertain foundation, the Glacial Theory became the backbone of geological research on the drift phenomena. As the most recent of the geological eras, the Quaternary forms the bridge from hypothetical geologic ages of the past to the present. As can well be expected, textbook writers have not emphasized too much the negative aspects of the theory.

Perhaps the background of doubt in the last century has even resulted in a defensive unanimity amongst geologists, that resists questions and ideas that do not conform to and support the basic framework of the geologic story of the earth's past. Variations within the superstructure are allowed, and these have proliferated. But it is not kosher to seek alternatives, or to deny the faith altogether by resorting to catastrophes.

Difficulties in the Glacial Theory. The layer of drift is the main body of evidence for the glacial theory. When one considers how this material is distributed, considerable difficulties arise in the notion that it has been caused by glaciers. It is not present in many areas where one would expect to find it, and it is present where one would least expect it. Thus in the northernmost parts of Greenland, and in the islands of northern Canada, no drift is present. But it is found in tropical areas such as the Amazon jungles. Regarding the tropics, right at the equator, no less an authority than Louis Agassiz wrote: "There were drift accumulations, and scratched rocks, and erratic boulders, and fluted valleys, and the smooth surface of tillite..."[5]

The presence of drift has been reported from such places as British Guinea, equatorial Africa, Madagascar, and India. Wherever the characteristic features of the drift are found, it seems necessary to postulate former glaciers to explain it. The theory of continental drift is partly an attempt to explain how the ice-sheets could have existed in these areas at various periods in the past.

The glaciers of mountain regions and the ice-sheets of the Antarctic and Greenland do not seem to be forming any deposits similar to the layer of drift that has been attributed to ice-sheets of the past. Present glacial moraines contain fragments of angular rocks unlike the boulders in the drift, which are rounded; and the glacial deposits of the present have none of the features of the structure of the drift, but are more aptly described as a heterogeneous muck.

The postulated ice-sheets of North America and Europe are also somewhat lop-sided, and do not conform to the polar regions as one would perhaps expect they should; and accounting for this has been a brain twister for the glacial theorists.

Charles H. Hapgood proposed that the continents were dislocated from time to time from their present relationship with the poles, as the earth's crust shifted over its interior. Hapgood's idea was that the north pole was located in the Yukon 80,000 years ago, shifted to a point northwest of Norway, from there migrated to Hudson Bay, and moved to its present location at the end of the last Ice Age.[6]

One reason why this idea has not been afforded very great favor amongst Quaternary geologists is that the structures composed of drift around the world are all very well preserved, and there does not seem to be good reason for attributing some to a much earlier period than others. All of the drift landforms actually must be quite recent, and of similar age, if the degree of erosion is considered as an indicator of age.

The Cause of an Ice Age Still Undetermined. The many astronomical theories proposed in the last century to account for the ice ages were discussed and refuted by Sir Henry Howorth in the first volume of Ice or Water. Today the problem is still much the same as then, no nearer a solution, and a statement by Coleman in 1929 is still valid:

> Scores of methods of accounting for ice ages have been proposed, and probably no other geological problem has been so seriously discussed, not only by glaciologists, but by meteorologists and biologists; yet no theory is generally accepted. The opinions of those who have written on the subject are hopelessly in contradiction with one another, and good authorities are arrayed on opposite sides...[7]

The problem in recent years has been restated. Rather than attempting to discover a cause for glaciation at various places around the world, emphasis should be placed on causes of climate change. On this "fundamental problem" R. F. Flint wrote in 1971: "Research in the impressively wide field of possibilities has not yet progressed sufficiently far to enable us to choose among the various published theories, many of them conflicting."[8]

Conflict is perhaps all-pervasive in the glacial theory. But it is generally assumed that the ice-sheets in various parts of the world existed, the problem of causes being inconsequential to the evidence that they did not occur. So attention should rightly be directed to the geologic evidence, the drift layer and the landforms composed of drift and other features associated with it, that have been attributed to glacial action; and to the properties of ice.

Problems About the Motion of the Ice. In considering the layer of drift and its origin, the basic assumption in the glacial theory is that material was formed by ice-sheets, and that rocks and stones from various places were ground up by the movement of the ice, transported in its lower parts and redeposited when the ice-sheets melted. The presence of erratics in the drift, scratched surfaces of the stones and the bedrock underneath, and other facts are considered to be proof of the involvement of ice. Inherent in this assumption is the notion that a great ice-sheet would actually move, and that it could carry along the material it over-rode and deposit the glacial debris in layers like those characteristic of the drift.

The motion of the postulated ice-sheets is a necessary assumption for a glacial explanation of transport of erratic boulders by the ice, and for the streamlining of the surface of the drift into flutings and drumlins. The physics of ice would lead one to expect that ice-sheets of the past would move under the influence of gravity, once the ice had obtained a sufficient thickness; and that the direction of this movement would be from higher to lower ground.

It would be a viscous flow, and would be controlled by topography and the slope of the upper surface of the ice-sheet. This would mean that there would be flow over level country only in the upper layers of the ice, while movement of the base of the ice-sheet should be limited to downhill gradients in the topography underlying the ice.

Movement of the ice-sheets of the past, that are proposed in the glacial theory, does not seem to have obeyed the normal rules, as the erratics are found in areas hundreds of miles from their supposed sources. This would require transport of the base of the ice-sheets over irregular country without any downhill slope indicated by present topography. Writing about the difficulty in explaining the required motion of the ice-sheets of the glacial theory, Howorth commented:

> A more important and far-reaching difficulty which the glacial champions have to face is the proved incapacity of glacier ice, as of any other viscous body, to travel over enormous stretches of level country, and up and down long hills, as it must have done if the glacial theory is to become the final and effective explanation of a large part of the drift phenomena.[9]

To get the debris of the base of the ice-sheets moved over sufficient distances, the idea of sliding of the base of the ice-sheet over the countryside, due to an unknown factor in the ice-sheets has been conceived. It is pointed out that the bases of the ice-sheets and glaciers existing today are rather inaccessible for study, and this has resulted in a lack of understanding of the processes that were involved in former ice-sheets. Flint suggested that basal sliding of these ice-sheets possibly exceeded the flow due to viscosity that would be confined mainly to the upper layers of the ice-sheets. Flint wrote:

> The mechanics of the process is not yet understood, partly because the base of a glacier is far less accessible to study than its upper surface. Apparently the sliding process consists partly of relegation (pressure melting of ice followed by refreezing), in which, therefore, transport of water is involved. In some glaciers, at least at some times, basal sliding may possibly account for most of the motion that occurs.[10]

The need for some mechanism for sliding of the ice-sheets over their beds, sometimes for great distances, up and down irregular country, is indicated by the presence of erratics in areas far from their supposed sources. The erratics, or boulders different in composition from the bedrock of the areas in which they are found, really constitute a minority of the boulders in the drift. Most boulders resemble the bedrock of the vicinity. Flint reported:

> A small proportion of the rock matter picked up does, nevertheless, travel long distances. Stones and boulders from Scandinavia and Finland were carried in the Scandinavian Ice Sheet through hundreds of kilometers to points in Britain, Germany, and Poland, and (1250 km) to Russia. Stones from Ontario were carried by the Laurentide Ice Sheet as much as 1000 km to positions in Missouri. Most such stones consist of durable rock types containing hard, resistant minerals, and with few joints or other surfaces of weakness. They may have survived long-distance travel in the base of the ice at the expense of considerable loss of size by attrition, or may have traveled in englacial positions where there were few other rock fragments to abrade them.[11]

The theory that these stones and boulders have been transported by the sliding of the ice-sheet at its base rests on an assumed process the mechanics of which is not yet understood. It is not known how the movement of the ice was accomplished, but geologists accept as a fact that somehow basal sliding of the ice-sheets over vast distances occurred. Perhaps it is less difficult to attribute unexplained properties to a vanished ice-sheet than to imagine a different explanation for erratic boulders that are obviously real.

Howorth claimed that the movement of ice-sheets is viscous flow and that there could be no "unknown" or mysterious properties in the ice of the glacial theory, that could cause movement in ways not evident in the ice known today. In this he appealed to true uniformity, and causes in line with those existing at the present time.

To postulate that causes in the past were different to those of present experience is quite contrary to the principle of uniformity that geologists claim to uphold. Regarding the possibility of a basal motion of the ice-sheets, apart from the viscous flow of the upper layers, Howorth wrote:

> If there be any such motion en masse it cannot be great, nor can it exceed a certain amount without the force inducing it becoming dissipated. This seems plain, as I showed before from some simple considerations. Every solid known to us will crush and disintegrate under a sufficient pressure, and it does not matter whether this pressure is applied perpendicularly downwards, or laterally. It follows, therefore, that if a solid be so heavy and so big that it requires more than a certain force to move it, it will crush rather than move, that is to say, the whole thrust will be dissipated by the object being reduced to pulp, or even liquid, which will flow away rather than move en masse.
>
> This argument applies to all solids, and notably to what is almost a solid, i.e., to ice. The crushing point of ice has been roughly ascertained. It enables us positively to say that a mass of ice which is longer than (according to Oldham in his paper on the modulus of ice) about seven miles cannot be moved en bloc along a flat surface without crushing. If the ice has to move up-hill, and therefore to overcome gravity, the difficulty of moving it en masse will, a fortiori, be increased, and the length of the column of ice capable of being moved will be proportionately lessened. If it is on a slope and gravity gives its assistance, this motion will be reversed, and the greater the slope the greater the distance to which the mass can be moved. This is of course treating the problem apart from friction. There is also evidence that when glaciers reach level ground their motion, however caused, rapidly ceases.[12]

Not only is it necessary to assume that the base of the ice in the great ice-sheets of the glacial period was capable of moving for great distances, over irregular country, and frequently uphill, but the boulders it transported are thought to have been lifted upwards by the ice, so that now they are often found at altitudes much higher than those of the source beds from which the erratics are supposed to have been derived.

Flint provides a table of some examples of uplifted erratics, citing the following examples: (1) In Maine, erratics on Mount Katahdin have been transported at least 18 km and uplifted 1000 meters. (2) Erratics in the Adirondack Mountains, New York, have been transported at least 100 km and uplifted 900 meters. (3) On the Allegheny Plateau, central New York, rocks are supposed to have been moved 160 km and lifted 500 meters vertically. (4) On Killington Peak, Green Mountains, Vermont, rocks have been transported possibly 80 km and lifted 900 meters, apparently, by the ice. (5) In the Rocky Mountains of Alberta rocks have been moved a distance of 1,300 km and uplifted 1,300 meters. Other similar examples are cited from Alberta, Manitoba, Northwest Territories, and from Eire, Wales and Northern Germany.[13]

These erratics perched higher than their sources, if they are to be attributed to ice, would require that the direction of the flow of the ice was opposite to the slope of the land. Flint suggested that the stones were carried in the base of the ice, which flowed uphill, rather than that they somehow migrated upwards through the ice.

Discussing the notion that stones have been transported upwards by glaciers, Howorth accused the glacialists of departing from the principles of physics and appealing to "transcendental causes". Howorth wrote:

> The question is one of mechanics, to be dealt with by mechanical arguments, and it seems to me to be the height of rashness for geologists who are quite guiltless of any training or knowledge as physicists to appeal to transcendental causes, whose potency they have not tested, and which are treated as contrary to the laws of physics by those specially familiar with the latter.
>
> They habitually argue in a circle. Finding a big stone on a mountain many hundreds of feet above its bed rock, <u>and having made up their minds, a priori, like the schoolmen in the dark ages, that</u> their <u>deus ex machina</u>, ice and ice alone, did it all, they have to attribute to ice qualities which it not only does not possess, but which are contrary to the very elementary laws of matter.[14]

<u>How Could the Ice Move Uphill</u>? Far from actually proving the reality of ice ages, erratic boulders in fact pose a perplexing problem for this theory to explain. The ice not only has to be capable of basal movement over very great distances, it also has to move uphill for distances of hundreds of miles, which is contrary to any experience we have of glaciers and ice-sheets today.

Ice-sheets that are known from present experience tend to obtain a fairly uniform slope at which they are in equilibrium. The thicker they are the more quickly this equilibrium will be obtained. The ice will spread and thin out, by viscous flow confined to its upper layers, as long as thickness is sufficient to cause a flow.

No cause for upwards sliding of the base of ice-sheets is apparent from the study of present-day ice-sheets. No reason for the motion of ice over great distance is known. Yet this movement of the ice is a basic assumption of the glacial theory, and it must be supposed that ice in the past would act in the same way that ice acts today.

Any other ice will not do; the properties of ice that we know from experience set bounds and limits to scientific hypotheses about the ice of the glacial theory. If a transcendental ice is appealed to, such as is not observed today, then the glacial theory should be relegated to philosophy, and placed in the category of the celestial spheres of the astronomers of antiquity.

As Sir Henry Howorth insisted, ice as we know it moved downhill, under the influence of gravity. Motion of the base of the ice has no foundation in present day experience, particularly uphill motion, such as the glacial theory requires for the explanation of the distribution of the drift. Howorth complained:

> It is, however, I know, useless to quote glaciers to the ice men. They repudiate glaciers as tests altogether, just as they repudiate laboratory experiments upon ice. With them all indictive

> methods and arguments fail, since they always reply that the ice they appeal to is something entirely different to the ice of glaciers. It is ice-sheets they rely upon, portentous ice-sheets, such as no longer exist anywhere. A Saturnian postulate, in fact, is their platform, and not a mundane one. Yet it ought to be a condition even of such a transcendental postulate as this that the ice in an ice-sheet should act in accordance with, and not contrary to, the nature and the physical qualities of ice. If it does not, the appeal ceases to be a scientific appeal, and it is, in fact, very largely an unscientific appeal which is continually being made by this noisy, clamorous school of writers, who never verify their premises and make assumptions as readily as they abandon them.
>
> An ice-sheet is only a great mass of ice after all; a mass of ice which, instead of lying on a mountain slope or being embayed in a valley or on a plane surface, is supposed to have smothered and covered a stretch of uneven country and swathed it in a continuous mantle. Such a mass of ice cannot acquire properties not possessed by other ice. If it moves it must move according to the mechanics of ice, and, as we have seen, ice moves in no other fashion than by the influence of gravity.[15]

Basal movement of the ice-sheets is also a necessary assumption in the glacial explanation of the formation of drumlins and flutings. Again, the cause for all this motion is a mystery. The drumlins are streamlined, their form giving a clear indication of the direction of the streamlined flow that formed them. Paradoxically, this flow must have been frequently uphill.

In northern New York the drumlins are oriented north-south and the direction of flow was uphill from Lake Ontario; and in Northern Ireland, the pattern of the drumlins in one region indicates the flow was from out of the sea in Belfast Lough, and overland to Dundrum Bay.

If the drumlins were shaped by ice, the flow would have to be uphill, requiring a cause that is quite outside the forces of present experience. In an attempt to explain the nature of the forces that caused an ice-sheet to flow uphill in the New York region, Fairchild wrote:

> The drumlins were shaped by the sliding movement of the lowest ice, that in contact with the land surface. This fact implies that the whole thickness of the ice-sheet participated in the motion. Such motion was not due to gravitational stress on the ice over the drumlin area, but to effective thrust on the marginal ice by the gravitational pressure of the rearward mass. As the margin of the ice-sheet thinned by ablation, there came a time when the drift-loaded ice in contact with the ground was subjected to less vertical pressure by the deep ice in the rear, and was pushed forward bodily. In this fact is believed to lie the key to drumlin formation.[16]

It is postulated that "gravitational pressure of the rearward mass" caused the ice to flow uphill, but why would this presumably thicker mass of ice not have simply spread in the upper layers, instead of pushing the southward ice bodily and forcing it to slide over its bed, across high hills of rock? The trends in the shape of the New York drumlins do not confirm a theory of pushing bodily from the north, for the drumlins at higher altitudes to the south become more intricately streamlined, smaller and having steep sides and narrow crests.

Drumlins in the vicinity of Lake Ontario are large, flat topped and poorly streamlined.[17] Trends in the form of the drumlins indicate that streamlined flow of the agent that caused them was faster at higher altitudes to the south, and so a bodily push from the north, which could only cause motion as fast as the ice-mass causing the pressure, is incompetent as a cause.

More Mechanical Difficulties: Ice not Strong Enough. Sir Henry Howorth pointed out that there is a limit to the size of an ice mass that could be pushed bodily. If the extent of the ice-sheets were greater than seven miles, he claimed, the ice would crush and dissipate the forces causing the horizontal push.

The ice-sheet causing the New York drumlins must have extended at least 50 miles from the shores of Lake Ontario, while the drumlins of the region were being formed. That they were formed contemporaneously is proved by the patterns of orientation over wide areas. A cause for the uphill movement of the ice-sheets is once again a missing ingredient of the glacial theory.

When one considers the pattern of the drumlins over broad areas of the North American continent, the vast areas over which streamlining occurs precludes the transfer of a force within the ice-sheet that could cause movement of its base over the countryside. Howorth wrote:

> ....it is not possible to pile up a mass of ice to an indefinite height, or to force a mass of ice of greater length than about seven miles along a level surface by any pressure, however obtained, without its crushing, and without, therefore, the thrusting force being dissipated.[18]

Not only is the cause for the movement of the ice-sheets over vast areas of irregular and uphill country unexplained, but the streamlined landforms are frequently composed of drift, which is supposed to have been deposited when the ice-sheets melted. Streamlining of the surface of the drift requires the existence of moving ice after it had melted!

This seems to be a contradiction within the glacial theory, and one that requires the utmost of ingenuity to explain away. Drumlins and flutings are thought to have been formed by movement of the ice, that over-rode the material left behind when the ice-sheets melted.

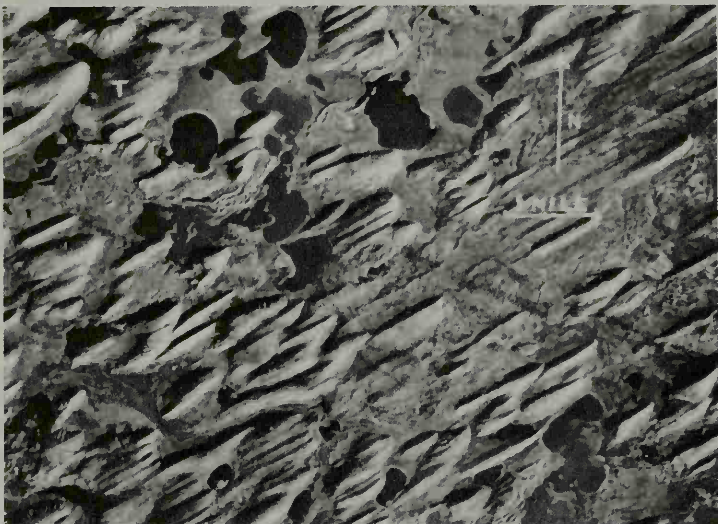
How Could the Ice Have Melted, and Still be at Work? How could the ice carve the surface of the drift, after it had melted? Somehow the ice must have returned to do its mysterious work of streamlining the drift, and when this resurgence of ice melted, it failed to deposit any debris. The streamlined surfaces are undisturbed by deposits of this last ice-sheet. Even drumlins and flutings that are explained by erosion, bedrock drumlins and those containing stratified material, evidently contributed no debris to the glacier. For when the ice disappeared no layer of debris was left behind on the streamlined topography.

These are paradoxical facts inherent in the glacial explanation of the drumlins, and streamlined landforms do not in any way support the idea that ice ages have occurred. They are actually objections to the idea of great ice-sheets, that ought to have planed off the country they over-rode rather than moulding it into streamlined forms. This was admitted by Warren Upham, who wrote:

> Instead of amassing the till in such prominent accumulations, we should expect that the ice-sheet would tend constantly to wear away the hill tops and leave thick deposits of subglacial drift only in depressions of the country and on low or nearly level land.[19]

Both the drift phenomena and the glacial theory would indicate that the possibility of ice eroding drumlins from drift deposits and bedrock alike is doubtful. The moving ice would have destroyed every trace of stratification in the material it over-rode, especially when this was unconsolidated sandy material.

Yet drumlins are composed of sand and gravel with the pattern of cross stratification in an excellent state of preservation, as well as other types of drift such as clay and till. How could moving ice have carved these



Drumlin field near Snare Lake, Saskatchewan. (Douglas E. Cox and Canadian Government)

drumlins, without even disturbing the delicate patterns in the material comprising them?

Erosion of the surface of the drift by an advancing glacier has been proposed by Grovenor as the explanation for drumlins. He supposed that if the glacier advanced in an irregular fashion, halting and starting up again, the drift could have been deposited just prior to its streamlining by the advancing glacier. In effect, the glacier laid down for itself a carpet of drift in its path, which became streamlined as the glacier advanced. Grovenor wrote:

> Since some drumlins are made of pre-existing materials, it is known that erosion can produce a drumlin. It is believed that

halts or a slow advance during the forward movement of a glacier can give rise to a wide irregular surface of drift which would be shaped into drumlins by the advancing ice.[20]

In this environment of drumlin formation the layer of drift is assumed to have been deposited during the advance of the ice-sheet, and if this were so there must have been a growth of the ice-sheet at the same time that it was being melted. One would expect, however, that the time of advance of the ice-sheets could hardly be the time of melting and deposition of their drift load.

If drift was deposited even while the glacier was advancing, how much more could we expect to find a thick accumulation of drift above the streamlined surface that could have resulted from the ice-sheets' melting! But no layer of drift occurs above the streamlined surface. In order to account for drumlins with internal stratification the glacial theory requires numerous conflicting and unlikely hypotheses.

Equally improbable is the idea that bedrock drumlins and flutings that occur in rocks harder than ice could have been eroded by the ice-sheets. On the one hand the great ice-sheets are supposed to have carved drumlins from loose drift materials without disturbing the pattern of stratification evident in the sand, and in other regions the same ice-sheet became much more competent than rocks of the hardest varieties; and shaped them into hills of the same dimensions.

In the process the ice-sheets apparently failed to accumulate a load of debris that had to be deposited on the drumlinized surface as the ice melted. What happened to the debris contained on the ice-sheet that eroded the drumlins? Rather than confirming the reality of the ice-sheets, the drumlins have so far proved inexplicable in terms of the glacial theory.

Could Ice Have Carved the Rocks? According to the glacial theory the layer of drift on the continents was formed during the melting of the ice-sheets. The gravel and stratified sand in the drift was deposited by "outwash" streams flowing from the melting ice. The unstratified material, known as "till", is thought to be the direct deposit of the ice. Till materials became stratified as they were transported and redeposited by the outwash streams, according to the glacial theory.

These conditions are considered sufficient to explain the characteristics of the stratified sand and gravel of the drift, with the pattern of cross stratification, rounded stones and pebbles and "sharp" sand. The stones of different composition are thought to have originated from widely separated source areas.

The ice flowing over various kinds of bedrock broke off bits of bedrock as it went along, which became embedded in the base of the glacier. As it passed over other territory, and areas where different kinds of bedrock predominated, it broke off other rocks that became embedded in the ice, and mixed in with other varieties of stones. Sir Henry Howorth objected to the assumption that the ice-sheets could have broken up their beds as they moved. He wrote:

> Ice is much softer and more easily crushed than the great majority of rocks, and would itself be crushed and reduced to slush by its own pressure long before the rock upon which it stands could itself be broken.... We must always remember the kinds of materials upon which the supposed crushing was effected. These are not

> lumps of soft rock showing crushed outlines, but clean broken and shattered masses with their surfaces still raw and unhealed, consisting of the hardest crystalline rocks such as granites, syenites, porphyries, etc., as well as limestones, sandstones and chalk, and we are asked to believe that the same ice-sheets which thus shattered such intractable materials in situ after passing on a few yards travelled over beds of laminated and stratified sand and loam with such a gentle touch as not to disturb the laminations....
>
> The word impossible is not a favourite one of mine, but I am bound to say that, if it is to be applied to any physical operation, I know of none where it seems so applicable as to the process appealed to by the ultra-glacialists for the manufacture of drift by an ice-sheet smashing its own bed.[21]

If it is admitted that an ice-sheet could have moved over sufficient distances to accumulate a load of drift of variable composition, and broken up underlying rock by some process, would these conditions cause the surfaces of the stones to become rounded and smooth? The glacial theory requires that the stones, once broken off from the bedrock, would be rounded by abrasion in the process of transportation in the ice or in the streams that flowed from the ice when it melted.

Of course it is unlikely that stones would be mobile enough while embedded in the ice for them to have been rounded very much. But when we examine the till, the unstratified drift gravel and so forth, the stones are rounded. Supposedly these must have been rounded by a previous erosional environment before they became embedded in the ice.

Effects of Contemporary Glaciers Different. In mountain glaciers today there are examples of stones and boulders being deposited after transportation from their source areas by moving ice. These mountain glaciers form end moraines and lateral moraines composed of this debris once embedded in the ice or lying on top of it.

In glacial moraines of mountain areas, the fragments are angular in shape. They are not rounded and smooth like the stones and boulders of the drift on the continental lowlands. The glacial theory must assume once again that conditions in the past were quite different, contrary to the principle of uniformity.

The sand in which the stones of the drift are often embedded is explained in the glacial theory as originated in the environment of the melting of the ice at the end of the ice ages. However, in contrast with the stones of the gravel, the sand is composed of tiny grains of angular shape. Describing the characteristics of this sand, Reineck and Singh wrote:

> An important feature of glacial sediments is the presence of numerous labile minerals, e.g. feldspar, ferromagnesium minerals as unaltered, angular grains even in silt and clay-sized fractions. The sand fraction is characterized by extremely angular sediment grains....Sand grains of glacial sediments show characteristic surface features if studied by the electron microscope. Such surfaces show abundantly conchoidal fractures, minor striations, imbricate breakage blocks, and small-scale indentations.[22]

The presence of the fragile particles in the sand and clay of the drift has been interpreted by glacial geologists as evidence that the ice-sheet eroded fresh rock rather than decomposed or weathered material. The angular shape of the particles is interpreted as evidence of crushing and shattering processes at the ice-bedrock contact.

These fragile particles could not have been transported in outwash streams for any great distance, since they would be easily broken apart. The disintegrated boulders in the drift likewise cannot have been rolled great distances.

On the other hand, particles of fine size are thought to have been deposited quickly, while on the other, large stones with composition much different from that of the bedrock are thought to have been abraded and striated, moved great distances and finally deposited in swift-flowing outwash streams. Paradoxically, conditions of sedimentation would lead one to expect the opposite effects: the larger stones ought to have been deposited <u>before</u> the finer sized particles.

<u>Why is the Sand so Different from the Stones</u>? The contrast between angular sand grains and rounded stones and boulders, referred to as "clasts", in the drift is problematic for the environment proposed for its deposition in the glacial theory. In conditions where rocks can be rounded by abrasion it would seem that sand particles also would become rounded and the fragile particles disintegrated.

<u>Problems Concerning Cross Stratification</u>. Stratified material in the drift usually exhibits the pattern of cross stratification, regarded as evidence for sedimentary deposition in rivers. However, a sedimentary environment for the formation of cross stratification has not been demonstrated by experiment. In the cross stratified materials stones and boulders are embedded in such a way that bedding does not wrap around them. No turbulence effects are present that could indicate currents aided in depositing the stones.

The direction of inclination of the strata in the pattern of cross stratification is variable, making the actual mechanism of formation of the stratified drift a mystery. However, in the glacial theory the drift is assumed to have been formed in a glacial environment.

<u>Difficulties About Kames and Eskers</u>. Another enigmatic topic in the glacial theory is the origin of kames and eskers. According to the glacial theory the eskers were formerly river courses in the ice-sheets, and these may have been either surface rivers or rivers flowing in tunnels underneath the ice. The river beds became chock full of sand and gravel, that was deposited when the ice disappeared.

Kames are thought to be related structures, since they frequently occur in association with eskers. They are interpreted in the glacial theory as accumulations of debris from the melting ice-sheets, at the perimeter of the ice or in crevasses. They are composed of stratified drift, usually with abundant sand and gravel, and form irregular or conical mounds of various sizes.

Kames and eskers are apparently confined to thick accumulations of drift, and have not been reported from areas where a cover of unconsolidated material is absent. In a glacial environment, it would seem that rivers may have been present in the ice even where the ice over-rode bedrock, and one would expect that kames and eskers may have been deposited on all kinds of terrain, whether or not a layer of drift was present.

To account for the drumlins, the ice is postulated to have been moving in the glacial theory, and yet the eskers are thought to have been formed during the melting of the ice. The drift of the drumlins appears to be continuous with the material comprising the eskers. The eskers have not been let down on top of the drift that has been streamlined, but appear to be continuous with the drift of the vicinity.

Studies of the internal structure of eskers have not clarified the problems of accounting for them in the glacial theory. Some contain vertical clay walls parallel to the axis of the esker. The direction of inclination of the cross stratification within eskers has led some investigators to the conclusion that the river that formed one esker flowed sideways, across the axis of the esker![23]

Flint suggested that most eskers have been formed in tunnels underneath the ice, or in open canals near the perimeter of the ice-sheet. The ice was stagnant and the ice-sheet was thin. Meltwaters flowing from the surface of the glacier sought the lowest channels, and thus topography influenced the course of the esker. Flint wrote:

> Most large eskers do not trend indiscriminately across country, as they should do if superposed from upon or within the ice. They are highly selective, following valleys through long distances and crossing divides at conspicuous low points. This could happen only if they were built on the ground, under the guidance of the local topography. Indeed the englacial hypothesis is an attempt at a compromise by keeping the ice tunnel close enough to the ground to be influenced by the terrain.[24]

However, the difficulty of the eskers following courses that go up and down hills is unexplained. It seems that for the common phenomenon of a sinuous ridge winding over the countryside many different theories are required, including (1) squeezing up of the drift by weight of the ice on either side, (2) deposition of sediments in crevasses, (3) deposition from rivers flowing in tunnels underneath, (4) deposition from rivers flowing in tunnels within the glacier, and (5) dumping of debris at the glaciers' snout as it melted away. Eskers are actually enigmas in the glacial theory, as the variety of hypotheses proposed to account for them shows.

Prairie Mounds and Related Structures. Prairie mounds, rimmed plateaux, and a wide variety of landforms known as "ice disintegration features" and interpreted in the glacial theory as the effects of stagnating ice during the melting of the ice-sheets. According to the glacial theory ice sheets sometimes disintegrated in isolated blocks, that wasted away in place. In some regions these caused hollows such as kettles, and in other places raised mounds and plateaux resulted.

One of the most complex areas of investigation in the glacial theory involves the interpretation of events at the close of the ice ages in places where ice disintegration features predominate. The wide variety of these structures that may be present has given rise to conflicting interpretations for many areas. Quaternary geologists argue about how the ice melted, whether the debris was deposited underneath, or if rivers in the ice were responsible for intersecting ridges, etc.

In general the basic assumption that ice would disintegrate in isolated blocks, rather than the ice-sheet melting at its perimeter and gradually shrinking, seems essential for the glacial interpretation of the vast numbers of mounds, hollows and plateaux over the Great Plains of Canada. Yet this assumption is not confirmed by present experience with ice in glaciers and ice-sheets.

Actually melting ice influences the temperature of the environment in such a way that isolation of various blocks would be most unlikely. The glaciers melt at their perimeters, and one would expect that an ice-sheet would do the same. Studies of the so-called ice disintegration features only add to the mysteries of the glacial theory.

Anomalous Fossils in Supposed Glacial Deposits. Another area of difficulty in the glacial theory involves the types of fossils that occur in the drift. If the Quarternary was a time of glaciers, one should expect that the fossils of the period would be restricted to life forms associated with cold climate.

A wide variety of life forms seem to have been present at the time of the deposition of the drift, which is interpreted as the material deposited during the melting of the ice-sheets, and which has been modified at its surface by the melting and movement of the ice.

The remains of the Cohoes mastodon were discovered in 1866 in the Pleistocene deposits of New York. Woolly mammoth and woolly rhinocerous bones have been found in many parts of the United States. A cave lion, one third bigger than the African lion of today, is representative of the middle Pleistocene of Europe. The strata containing abundant fossils of the Quaternary are interpreted as Interglacial deposits in the glacial theory.

Multiple ice-sheets are required for the interpretation of the fossils contained in the drift. In some instances these fossils seem to be more tropical than representative of cold climate. The kinds of fossils present do not really provide confirmation of an Arctic environment. Describing the variety of fossils present in the Quaternary of Alaska, Flint wrote:

> The extensive silty alluvium, now frozen, in central Alaska contains a numerous mammal fauna. The stratigraphic position of the alluvium is not well known, although C^{14} dates show that the sediment antedates, at least in part, the Late Wisconsin drift. Freezing has preserved the skin and tissue of some of the mammals. The faunal list includes dog, wolf, fox, badger, wolverine, a large cat, lynx, woolly mammoth, mastadon, horses, camel, saiga antelope, bison, caribou, moose, stag-moose, elk, mountain sheep, musk-ox, musk-ox and yak types, ground sloth, beaver, and other rodents. The number of individuals is so great that the assemblage as a whole must represent a rather long time. The large cats and the ground sloth may seem surprising in a cold country, but their significance must remain unexplained until their stratigraphic significance is better known. The general rarity of fossil mammals in glaciated as compared with nonglaciated North America suggests that the rich Alaskan faunas are probably interglacial.[25]

Certainly the list of mammals does not confirm the idea that the Quaternary was really a time of cold climate. As with the many other topics involved in the glacial theory, unsolved problems, contradictions and mystery surrounds the question of the fossils of the glacial period.

Is it Time for a New Explanation? Inconsistencies in scientific theory, and poor correlation between theory and observational data, sometimes are indicative of a wrong approach or a fundamental error in assumptions. Perhaps the data that have been interpreted in terms of the effects of ice ages can actually be explained in a completely different way.

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• Drift South of the Ice Sheets

GLACIAL PEBBLES IN EASTERN KENTUCKY

Jillson, Willard R.; *Science,* 60:101-102, 1924.

Within the last year (1923-24) the discovery of erratic pebbles of apparent glacial origin widely distributed throughout northeastern Kentucky has provided the first concrete evidence in support of a hypothesis of Pleistocene glacial ponding in a part of Kentucky heretofore thought to be without glacial characteristic. The occurrence of old elevated stream channels along the Ohio, notably at Huntington, West Virginia; Ashland, Kentucky; Ironton, Wheelersburg and Portsmouth, Ohio, has been known for some time, having been described by Leverett and Tight. These abandoned channels occur at elevations ranging from 680 feet to 690 feet above sea level. While they contain gravels chiefly composed of quartzite and chert of stream origin, possibly more remotely glacial, they are not to be confused with the pebbles which are now being found in remote parts of eastern Kentucky at much higher elevations.

In the course of non-glacial field work geologists on the Kentucky Geological Survey, including the writer, have found 18 pebbles varying in size from a few ounces to 13 pounds, consisting principally of quartzites, but with an occasional granite, gneiss or other crystalline or metamorphic rock. These pebbles range in elevation from 720 feet on the Big Sandy River to 850 feet on the North Fork of the Licking River, and have been found in Lawrence, Elliott, Lewis, Morgan, Carter and Boyd counties. Field evidence indicates that similar pebbles may also be found at similar elevations in parts of Menifee, Greenup and Rowan counties, though these are not a certainty. The drainage systems involved in these discoveries include the Big Sandy River, Little Sandy River and Tygarts Creek, and the North and Elk Forks of the Licking River.

Based on evidence now in hand, which will be supplemented this year by further investigations, the following hypothesis is advanced:

The general accordance of elevations of these pebbles coupled with their certain extraneous origin and decidedly glacial characteristic suggests their invasion into Kentucky by means of floating ice. It is held that they probably represent a complex assortment derived from both river and glacial front sources during the period of readjustment of the northward flowing drainage of this portion of the Cumberland plateau, while cols were being degraded to form the present course of the Ohio River at points just above (1) Ironton, (2) Portsmouth and (3) Manchester, Ohio, and possibly just above Cincinnati. It is thought that the higher and more remote pebbles (800 to 850 feet) represent invasions by floating ice at the time of the first cutting of the Manchester col, which may have been originally about 850 or 900 feet. Ridges in the vicinity of Manchester now show elevations ranging up to 1,000 feet above sea level. Pebbles occurring in Kentucky at points near to the major drainage at elevations ranging from 720 to 750 feet are taken to represent subsequent ponding during the latter cutting of the Manchester col, and possibly those at Ironton, Portsmouth and Cincinnati. Ridge elevations at Ironton now range between 800 and 850 feet; at Portsmouth between 900 and 950 feet; and at Cincinnati (Dayton, Kentucky-Walnut Hills, Ohio) between 850 and 860 feet.

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ON GLACIERS OF THE GLACIAL ERA IN VIRGINIA

Stevens, R. P.; *American Journal of Science*, 3:6:371-373, 1873.

In a late visit to the Richmond, Va., coal field, my attention was drawn to palpable signs of glacial action, in long and narrow trains of pebbles and small boulders: one train I traced for more than five miles. These trains in the vicinity are called "ancient river beds." Their general direction was north and south.

Other than these signs were seen at the new opening upon the middle vein, on lands of the James River Coal Co., lying north of the James River. I found the northeastern outcrop of the Coal-measures, including the lower vein of coal, had in many places been removed, and, with the debris of associated strata, had been carried over the deposited upon the northerly slope of the hill holding the upper vein of coal, making a true drift deposit, composed of Coal-measure materials mingled with material from gneissoid rocks. I was able to follow the line of removed outcrop up to the northern limit of the coal field. I had previously noticed similar phenomena south of James River. That the Richmond coal field had been struck by a moving glacier was quite as palpable as the northern fields of Pennsylvania. Richmond is in latitude 37° 30' S.

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STRIATED BOULDERS ON THE SOUTHERN COASTAL PLAIN OF VIRGINIA

Wentworth, Chester K.; *Geological Society of America, Bulletin,* 38:150-151, 1927.

Abstract. Large striated and faceted boulders occurring in the Columbia terrace gravels of the Coastal Plain of Maryland and the District of Columbia have been known for many years. Studies by the writer in 1921 and 1922 extended the known occurrence of these boulders westward up the Potomac River, through the Harpers Ferry gap, and finally to the margin of the Allegheny Plateau at Cumberland. Scores of localities west of the fall line are now known.

Recent studies of the Coastal Plain of Virginia for the State Survey show that these boulders are not confined to the basin of the Potomac River, but are numerous in the Pleistocene terrace deposits of the James River and are to be found within 15 miles of the North Carolina line. In the James basin they are especially numerous in some of the intermediate terraces at Richmond in situations strikingly analogous to those in which they are found on the Potomac at Washington. No examination has been made of the basin of the Roanoke, the next trans-Blue Ridge River southward from the James, and no southern limit has yet been established for these boulders.

Boulders of foreign materials up to 4 feet in diameter are found near the fall line and up to 2 and 3 feet in diameter within a few miles of Chesapeake Bay, near Point Lookout, on the Northern Neck of Virginia, and in the Hampton Roads district, at the mouth of the James. Many of the more characteristically striated boulders are smaller than the sizes mentioned, but the association and common origin of all these boulders are evident.

That these boulders were ice-borne is strongly suggested by their distribution and by the occasional presence not only of large blocks, but also of blocks of especially fragile material. That they have been striated and faceted by true glacial action the writer is not as yet ready to assert, though he believes that the striations are accomplished through the agency of ice, possibly in rivers under severer conditions than those of the present. Similar striated boulders have not been observed in the load of the present rivers, except as immediately derived from the terrace

gravels. Some of the boulders show but a few sporadic scratches, but others are planed and precisely scored in one or several systems of striae, which seem quite indistinguishable from true glacial work.

It is desired here to call attention to the character and distribution of these boulders rather than to offer a solution for the important problem they present, and it is to be hoped that the interest of geologists will be directed to these boulders, and that the entire extent of their occurrence southward may be learned through the observations of students in other districts.

STRIATED COBBLES IN SOUTHERN STATES

Wentworth, Chester K.; *Geological Society of America, Bulletin,* 39:941-954, 1928.

Abstract. Striated and faceted cobbles similar to those found in glacial drift have been known for many years to occur in the Columbia terrace deposits of Maryland and the District of Columbia. They had been interpreted as having been deposited from stranded ice-blocks and derived from glaciated territory to the north. The presence of these cobbles in terraces along the Potomac River from Washington westward to a point beyond Cumberland and over 700 feet above present sealevel was reported by the writer in 1922 and renders the above hypothesis untenable. In 1926 the striated cobbles were found at many places on the Coastal Plain of Virginia adjacent to the Potomac and James rivers and extending to the North Carolina State line.

During the past season cobbles in every way identical with those of the Atlantic Columbia terraces and occurring in similar poorly sorted terrace gravels have been found at a score or more of localities in the Tennessee River basin. Their range is from Paducah along the whole length of the Tennessee and includes localities on French Broad, Holston, Nolichucky. Big Pigeon rivers. Thus the area of their occurrence is extended to include the States of Tennessee, North Carolina, Alabama, Mississippi, and Kentucky. To date, though considerable parts of the lower courses of the Powell and Clinch rivers have been visited, none of the cobbles or this type of gravel has been found, and it is thought that the processes responsible for them may not have operated on the northwest side of the Tennessee basin.

The entire extent of these cobbles and their true significance is yet to be worked out, but the tentative conclusion is reached that they are not the result of true glaciation, but are more probably the product of a somewhat more intense and potent action of river ice during one or more of the Pleistocene glacial stages.

POSSIBLE EVIDENCE OF PLEISTOCENE ICE ACTION IN SOUTH-EAST TEXAS

Reed, Lyman C.; *American Journal of Science,* 215:520-521, 1929.

At Munsen shoals about a mile below Pitts Bridge on the Brazos River separating Burleson and Brazos Counties, Texas, there are numerous boulders of Eocene, Cretaceous, and Paleozoic rock. These boulders are from 50 to 250 miles removed from their outcrop. No mention is made of this phenomenon in the literature, although William Kennedy, of the State survey, described sections from this locality.

So far as can be ascertained this is the only place on the Brazos River where rocks of this type are found. At this point, which is a sand bar and shoals, there is evidence that the river has changed its course and probably only recently uncovered the rocks from an old channel. This is concluded from the overflow channels and the fact that the country rock is exposed on either side of the river. The outcropping formation is Yegua in age. The boulders of the foreign material are angular, usually in slabs such as would be broken off by weathering at the outcrop, and show relatively little wear by water. Some are at least three feet across and weigh over one hundred pounds. They lie on the shoals, riverbed, and for at least ten feet up the bank. Terrace gravel is cemented to a few of the boulders, showing some stratigraphic relation between the two. This is thought to be the number one terrace, the slabs occurring in the upper part or on top, but their relation cannot be determined. In the bank on the opposite side of the river consolidated gravel, presumably the lower part, outcrops with apparently none of the foreign rocks. The size of the pebbles is from about one to two inches in diameter.

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One large slab and at least two smaller ones found at Munsen shoals were seen to be striated, not such as formed by glaciation but fine etched-like grooves from two to four inches long and trending in a somewhat parallel direction. These are striations such as would result from blocks of ice being shoved together. Further investigation may also show the gravel to be marked in this manner.

It is highly improbable that these boulders were transported by human agencies during any past civilization because of their weight and especially because of the wide range of the formations represented by the specimens and the great distance between their outcrops. Their presence by structual deformation is not within reason.

The most plausable explanation is that the slabs were transported down the Brazos River by some physical agency, such as ice or water. The distance is too great and the gradient of the river too low for them to have rolled down even by flood waters without showing more wear than is evident. In the past history of the Brazos as revealed by its terraces, there is nothing to indicate that it ever had what may be called a steep gradient. It is estimated that the Midway was transported 50 miles, the Upper Cretaceous 75 to 90 miles, the Comanchean 90 to 200 miles and the Pennsylvanian 200 to 250 miles by an air line course which in reality would be nearly doubled by the meanders of the river. It is possible for rocks as large as these to have been uprooted with trees and borne downstream by floods to a log jam, but the great numbers of the boulders representing widely separated localities would appear to make this mode of transportation far-fetched.

The means of transportation, with evidence upon which to base the assumption, appears to be by ice blocks which incased the boulders and deposited them at this certain point in an ice jam. During the latter part of the Pleistocene there must have prevailed, even this far south, a cold climate sufficient to form ice of considerable thickness in quiet water.

It is therefore believed quite probable that Munsen shoals is the site of an ancient ice jam where the rocks belonging to the formations traversed by the Brazos River were deposited. Other such rocks may have been stranded along the course of the river, but they have not been reported and it is likely that it would not take long for them to be worn down by the action of the water. The reason the great boulders at this point are preserved may be that the Brazos is now in a new channel which has probably not been traversed since the stranding of the rocks by the supposed ice jam.

GLACIAL PHENOMENA IN NICARAGUA

Belt, Thomas; *American Journal of Science,* 3:7:594-595, 1874.

Mr. Thomas Belt, in his "Naturalist in Nicaragua," published in London early the present year, describes, as follows, Drift deposits in the valley of the Depilto, one of the head streams of a river (Rio Wanks or the Segovian) that rises among the highest mountains of northern Nicaragua, and reaches the Atlantic near Cape Gracias a Dios.

"Going down the valley of the Depilto the massive beds of quartz and gneiss are soon succeeded by overlying, highly inclined and contorted schists, and, as far as where the road from Ocotal to Totagalpa crosses the river, the exposures of bed rock were invariably these contorted schists, with many small veins of quartz running between the laminae of rock. On the banks of the river, from about a mile below Depilto, unstratified beds of gravel are exposed in numerous natural sections. These beds deepen as the river is descended, until at Ocotal they reach a thickness of between two and three hundred feet, and the undulating plain on which Ocotal is built is seen in sections near the river to be composed entirely of them. These unstratified deposits consist mostly of quartz sand, with numerous angular and subangular blocks of quartz and talcose schist. Many of the bowlders are very large, and in some parts great numbers have been accumulated in the bed of the river by the washing away of the smaller stones and sand. Some of these huge boulders were fifteen feet across, the largest of them lying in the bed of the river two miles below Depilto. Most of them were of the Depilto quartz rock and gneiss, and I saw many in the unstratified gravel near Ocotal fully eight miles from their parent rock. Near Ocotal this unstratified formation is nearly level, excepting where worn into deep gulches by the existing streams. The river has cut through to a depth of over two hundred feet, and there are long precipices of it on both sides, similar to those near streams in the north of England that cut through thick beds of bowlder clay. The evidences of glacial action between Depilto and Ocotal were, with one exception, as clear as in any Welsh or Highland valley. There were the same rounded and smoothed masses of rock, the same moraine-like accumulations of unstratified sand and gravel, the same transported bowlders that could be traced to parent rocks several miles distant."

***"The transported boulders, near Ocotal, are about three thousand feet above the sea, those near Libertad about two thousand feet"

Mr. Belt infers, from the facts, that the ice of the Glacial era stretched on uninterruptedly from the northern regions of North America through Central America, and probably over South America. But observers have shown that the glacial phenomena occurring on a grand scale about the higher mountains of California and of the summit region of the Rocky Mountains, within the United States, are those of local glaciers, and that there is there no northern drift. This being so, it is certain that the facts described by Mr. Bent indicate the existence only of local glaciers---those of the mountains of northern Nicaragua. They are still of very great interest, as they give a much more southern limit in North America to the local glaciers of the Glacial era than had been before suspected.

GLACIER SCRATCHES SOUTH OF THE "TERMINAL MORAINE"....

Anonymous; *American Journal of Science,* 3:42:172, 1891.

Messrs. P. M. Foshay and R. R. Hice, in a paper in the 2d volume of the Bulletin of the Geological Society of America, describe and figure glacial scratches observed by them on the western bluff of the rock gorge of the Beaver, near the mouth of the Connoquenessig, "two miles or more south" of the "terminal moraine" as located by Lewis and Wright. Some of the grooves are 5 feet wide and 18 inches deep. The authors remark that the grooves may be within "the fringe" of scattered erratics south of the line of the moraine, described by Lewis, but observe that they are as much glacier-made as those of Kelly Island in Lake Erie. For an article by Mr. Foshay on the pot-holes and pre-Glacial drainage of the same region, with a map, see vol. xl of this Journal, p. 397, 1890.

THE TERMINAL MORAINE NEAR LOUISVILLE

Bryson, John; *American Geologist,* 4:125-126, 1889.

Having lived for more than seventeen years on the "backbone" of Long Island, N. Y. before coming to Louisville, Ky., I was naturally attracted by the clayey deposits of this region, so similar in character to the glacial deposits of Long Island.

I was aware that the line of the terminal moraine of the great continental ice-sheet was drawn farther to the north through central Indiana, but the more I studied the matter the more I became convinced that the glacier had something to do with the clay and cherty formations of Kentucky. This opinion has been confirmed by Profs. Newberry and Collett. Instead of a lobe of ice, however, flowing down a glacial river through central Indiana to the Ohio, as described by Prof. Collett, there is evidence that the whole eastern part of the state was covered by the great ice-sheet.

While the glacier seems to have taken a southeast trend, the streams under it flowed in a southwest direction. Crossing the Ohio river at Louisville these subglacial streams seem to ramify very much the same as those of Long Island. The limestone ridge east of Louisville is very much broken, especially toward the south. In places it entirely disappears, or exists only in little round isolated hummocks as it nears the knobs. Here a vast basin was formed which is now known as "the wetwoods." The present outlet of the Ohio, through the knobs, could not have been sufficient to carry off the great flood of waters, and so they became dammed up behind the Kentucky hills, or cut their way through forming them into the peculiar contour which they now present. If we follow up one of the old subglacial depressions as far as the knobs we find it connecting with a corresponding depression in the hills, showing that at one time there must have been some relation between them, although water alone could hardly have produced such results as are here presented. The summits of the highest knobs are not only worn into pot-holes, but there are well defined kettle-holes, and boulders of granite are often met with in the clay. It is true that these boulders are small and have the appearance of being water worn, and the floods may have reached the height of four or five hundred feet, but the writer has found boulders of sandstone and granite lying together several miles up the river from the knobs at the height of ninety feet above the present level of the stream. These certainly could not have been deposited by water unless the water ran up hill. The boulders referred to, lay exactly in the path of the glacier as it crossed the river from New Albany, Ind. knobs.

It is well to be careful in coming to any definite conclusion in regard to these phenomena, but they are certainly worthy of scientific attention.

Long years of careful study of the drift formations have convinced the writer that the glacial area in America is more extensive than has been imagined, and that no well defined terminal moraine can wall in its extreme southern limits.

Striae here and there may guide us in determining the general flow of the glacier, but they are not an infallible guide as to its extent, as it has been demonstrated that glaciers move over surfaces without eroding or leaving scratches of any kind; yet to maintain that none of these signs are produced by the motion of glaciers would be very absurd. It would be equally so to say that there were no terminal moraines because they cannot always be well defined. The "backbone" of Long Island is very much broken and disjointed, but it would hardly be just to say that it had no vertebral column at all. There are wide gaps to be filled in along the line of the terminal moraine of the great American continental ice-sheet, and prudent geologists will be careful in drawing the line until more of the facts are known in relation to glaciers, especially one so startling and confounding as that which covered more than half of the north American continent.

• Unusual Erratics

ERRATICS AT HIGH LEVELS IN NORTH-WESTERN AMERICA

Dawson, George M.; *Geological Magazine,* 15:209-212, 1878.

In the vicinity of the forty-ninth parallel, boulders from the Laurentian Axis, a great highland plateau, are distributed westward or south-westward across the whole breadth of the Great Plains to within twenty-five miles of the Rocky Mountains, where the country has an elevation of about 4,200 feet. Debris from the Rocky Mountains at the same time passes far eastward across the plains, the drifts of diverse origin overlapping to the extent of several hundred miles. The general inclination of the plain is eastward, or north-eastward, toward the foot of the Laurentian Axis, along which Winnipeg and associated great lakes lie, with an elevation of about 700 feet only. The higher parts of the Laurentian Axis have an average height of about 1600 feet.

If it be supposed that the western boulders were deposited in their present position by glacier-ice formed on the Laurentian Axis, or flowing over it from the north (as Mr. Geikie thinks most probable), the ice-sheet must have been pushed up-hill for a distance---measured from the Laurentian Axis---of about 700 miles. Many facts stated in the paper above referred to, but which cannot here be detailed, lead me to believe that the boulders in question reached their present position attached to sea-borne ice. Mr. Geikie, in objecting to this hypothesis, writes:---"When we remember, however, that the maximum height of the latter (Laurentian Axis) is only some 1600 feet, we may well ask how these boulders could possibly have been carried by floating-ice; for, when the sea stood at the level of 4200 feet, the Laurentian Axis, from which the boulders have come, must have been drowned to a depth of 2,400 feet, at least!"

This difficulty, though at first sight a very grave one, was not ignored. I believe the evidence to be conclusive, that the western portion at least, of the Laurentian region, was covered by a confluent glacier, guided in the direction of its motion by that of the general slope of the surface, but impelled chiefly by the pressure resulting from the continual addition of snow and ice to its central and higher portion. Pre-supposing this, I have written: "The occurence of Laurentian fragments at a stage in the subsidence, when, making every allowance for subsequent degradation, the Laurentian Axis must have been far below water, would tend to show that the weight and mass of the ice-cap was such as to enable it to remain as a glacier, till submergence was very deep." By this it was intended to suggest that a ponderous ice-cap, several thousand feet in thickness, continually reinforced by abundant snow-fall, might continue to act as a glacier till the surrounding water gained on it to such an extent as to float it bodily away. To this I might have added as an additional, and perhaps more probable suggestion, that adopted by Principal Dawson to explain the transport of blocks of sandstone from the Cumberland plains of Nova Scotia to the summits of the Cobequid Hills, viz. that the ice-fields of successive years may have raised these erratics and deposited them at higher and higher levels, during a more or less rapid subsidence of the land. This process is at least competent to effect the result, and wherever coast-ice surrounds a sinking shore, the materials of the beach must thus be gradually warped up, though but a small proportion of the material from below could ever reach a great height.

It is probably to action of this kind that Darwin wishes to appeal in endeavouring to explain the positions of erratics in some parts of England, though I only know his views by a reference to them by Mr. Geikie, in a note on the same subject read by him before the Geological Society of Glasgow in 1873, and in part reprinted in the Great Ice Age; in which it is endeavoured to explain the facts by the forcing up in the mass of a glacier, owing to "frontal resistance" of stones included in it.

To my mind, many facts seem to show the impossibility of the westward extension of a vast ice-sheet from the Laurentian Axis across the plains. The most striking of these is perhaps the existence of the great escarpment of soft Cretaceous rocks, which runs parallel with the south-western base of the Laurentian, at an average distance of 130 miles from it; the Winnipeg group of lakes occupying the intervening low ground. There are gaps in this escarpment, the most extensive being the valley of the Assineboine; but, in the main, it extends from near the Saskatchewan River to the forty-ninth parallel, with a bold north-eastern front, and a height in some places of 900 feet above the low country occupied by the lakes. That any mass of glacier-ice should have been forced across this escarpment without destroying it, seems incredible; though that the Laurentian Glacier may have reached its base in places appears not improbable.

The wide valley occupied by the Winnipeg group of lakes and Red River has doubtless, in the first instance, been formed by river-erosion. A great stream at one time probably flowed southward in it, gradually cutting downward, and shifting its channel westward on the sloping surface of the hard Laurentian rocks, at the expense at first of the soft Cretaceous strata, and later of the Devonian and Silurian limestones. The valley is pre-glacial, and, with the escarpment, has been produced in this way precisely in the manner explained by Professor Ramsay in describing the formation of the Weald of Kent and Sussex. A like process may also account, to a great extent, for the production of the valleys now occupied by the Great Canadian lakes, and of those of Athabasca, Great Slave, and Great Bear Lakes in the far North-west; all of which hold a similar position with regard to the Laurentian region, and overlying newer and little-disturbed rocks.

Quite lately, Prof. E. W. Claypole, of Antioch College, Ohio, in connexion with the theory of an all-powerful ice-sheet, has drawn attention to the well-known great Silurian escarpment, which bears a similar relation to the Laurentian Highlands in the Peninsula of Ontario, and northern part of Lake Huron, and consists of a range of cliffs in some places 200 to 300 feet high. Prof. Claypole writes: "It appears as if geologists who advocate the excavation of the basins of the great lakes by the action of northern ice flowing off the Laurentian Highlands are somewhat oblivious of the existence of this escarpment. If the ice possessed the enormous eroding power on rocks and cliffs so often attributed to it, it must certainly have cut away and destroyed this gigantic barrier to its advance before proceeding to scoop out deep basins to the southward."

In discussing these points it is necessary to assume that the relative elevation of different parts of the continent have remained unchanged during and since the Glacial period. This is probably not strictly true, and may be so far from correct in some cases as to invalidate arguments based on the assumption. Unequal elevation, great in amount, must have occurred in the west toward the close of the Tertiary, and may have continued in progress in Glacial, or even in post-Glacial times.

THE ICE AGE AND ITS WORK

Wallace, Alfred R.; *Popular Science Monthly,* 44:781-791, 1894.

The case of the bowlders in the Isle of Man, which have been carried nearly eight hundred feet above their source, has already been mentioned, but there are many other examples of this phenomenon in our islands; and as they are of great importance in regard to the general theory of glacial motion a few of them may be noted here. So early as 1818 Mr. Weaver described a granite block on the top of Cronebane, a slate hill in Ireland, and several hundred feet higher than any place where similar granite was to be found in situ; and he also noticed several deposits of limestone gravel in places from three to four hundred feet higher than the beds of limestone rock which are from two to ten miles off. Debris of red sandstone is also found much higher than the parent rock. Bowlders of Shap granite, Mr. Kendal tells us, have passed over Stainmoor by tens of thousands, and in doing so have been carried about two hundred feet above their source; and the curious Permian rock, "Brockram," has been carried in the same direction no less than a thousand feet higher than its highest point of origin. In Scandinavia there are still more striking examples, erratic blocks having been found at an elevation of forty-five hundred feet which could not possibly have come from any place higher than eighteen hundred feet. We thus find clear and absolute demonstration of glacier ice moving up-hill and dragging with it rocks from lower levels to elevations varying from two hundred to twenty-seven hundred feet above their origin. In Switzerland we have proof of the same general fact in the terminal moraine of the northern branch of the Rhone glacier being about two hundred feet higher than the Lake of Geneva, with very much higher intervening ground. As it is universally admitted that the glacier of the Rhone did extend to beyond Soleure, all the a priori objections to the various cases of rocks carried much higher than their origin, in America, the British Isles, and Scandinavia, fall to the ground. We must either deny the existence of the ice-sheet in the great Swiss valley, and find some other means of accounting for the traveled blocks on the Jura between Geneva and Soleure, or admit that the lower strata of a great glacier can travel up-hill and over hill and valley, and that the ice-sheets of the British Isles, of Scandinavia, and of North America merely exhibit the very same characteristics as those of Switzerland, but sometimes on a larger scale. We may not be yet able to explain fully how it thus moves, or what slope of the upper surface is required in order that the bottom of the ice may move up a given ascent, but the fact of such motion can not any longer be denied. (pp. 788-789)

• Boulder Trains

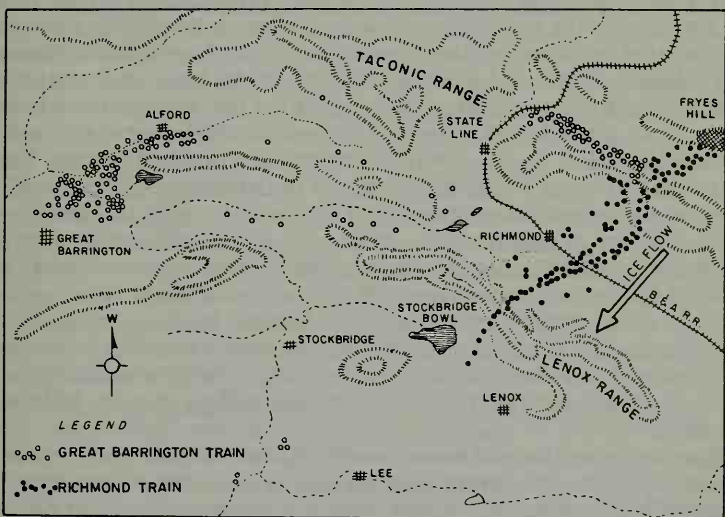
RICHMOND AND GREAT BARRINGTON BOWLDER TRAINS

Taylor, F. B.; *Geological Society of America, Bulletin,* 21:747-752, 1910.

Location and Characteristics of Richmond Train. The Richmond train extends from Fryes Hill, otherwise known as "The Knob," which stands on the line between the towns of New Lebanon and New Canaan, in the northeastern part of Columbia County, New York. A small area on the top of the knob is composed of chloritic or amphibolite schist. The exposure of this rock is about half a mile long and a quarter of a mile wide and forms the lightest knob of the Canaan and Lebanon range.

The principal train, concerning which so much has been written, extendsin a nearly straightline from Fryes Hill about south 40 degrees east. It is easily traced for 7 or 8 miles into Berkshire County, Massachusetts, and is faintly traceable for about twice this distance. The bowlders are quite numerous and many of them are large in the first 7 miles, but beyond this they grow scattered and of smaller size.

The most remarkable characteristic of this train is the nearly straight course which it takes diagonally across a region of mountain ridges and valleys. From Fryes Hill the train crosses Shaker Valley, then over the summit of the Taconic Mountain range, then over the wider Richmond Valley, then over the Lenox Mountain range, thinning out in the neighborhood of the Stockbridge Bowl and in the Housatonic Valley beyond. The accompanying sketch map shows the course of the Richmond train, and also the distribution of the Great Barrington bowlders so far as now mapped.



Map of the Richmond and Great Barrington boulder trains in Massachusetts.

Benton, who has written the most detailed description of the Richmond trains, recognizes several separate lines. On his map he shows two lines near Fryes Hill and four in Richmond.

The less prominent lines are composed mainly of metamorphic limestone and sandstone from other parts of Canaan and Lebanon range than that in which the amphibolite is situated, but they are weak and poorly defined, and the chief interest centers in the principal train, composed of amphibolite blocks.

The writer's study of the bowlders of this region was incidental to other work and was not so thorough as could be wished. But it was found that, besides the bowlder trains previously described, there is apparently another which takes a different direction from Fryes Hill, and that the bowlders composing it, although of the same rock as the Richmond train, are very different in their appearance and condition. The whole line of the newly found train has not yet been studied in detail, so that the results presented are somewhat incomplete and the conclusions in some degree tentative.

As stated above, the Richmond train runs in a direction about south 40 degrees east from Fryes Hill. All the bowlders of this train are sharply angular in their forms and fresh in their appearance. They seem to show no weathering nor any rounding off of corners and edges, but have the appearance of freshly quarried blocks. Many of them are of large size, especially some of those in Shaker Valley and on the flanks of Perry Peak. The one most often described is the great bowlder in a pasture lot west of the road 2 miles north of Richmond station. This stands about 8 feet high, 14 feet long, and 10 feet wide, and a considerable part is under ground.

Location and Characteristics of the Great Barrington Train. The train recently found appears to begin in Shaker Valley southeast of Fryes Hill on the slope east of Queechy Lake, and from this place runs southward along the western flank of the Tatonic Range to the base of Cunningham Hill, 2 miles northwest of State Line station on the Boston and Albany Railroad. In all probability it continues south and southeast through the gap at State Line, and thence southward toward Alford and Great Barrington, for in the valley of Seekonk Brook, in the vicinity of Alford, which is 5 miles northwest of Great Barrington, Bowlders of this same amphibolite schist occur in considerable numbers, and their number increases southeastward toward Great Barrington, where they seem to have been concentrated by the ice movement. This interval of about 8 miles between the two parts of the train as now reported has not been examined in detail. From the few observations made, it is not believed that the bowlders are so numerous in it nor the train so well defined. For some distance north of Alford comparatively few were found in the valley, but the hills were not examined.

The form and condition of these bowlders, both in that part of the train near Fryes Hill and near Great Barrington, is strongly contrasted with those of the Richmond train. Every bowlder found in this southward train is well rounded and shows marked effects of weathering. Not only is the surface discolored by oxidation to a grayish green in place of the clear, dark green of the fresh, angular surfaces of the Richmond blocks, but some of the effects of weathering have penetrated beneath the surface a quarter to half an inch, and deeper in diminishing strength. Among these bowlders none of great size were found, the largest being about 4 feet in diameter, but a great many were found with diameters of 1-1/2 to 2 feet. In certain places in the valley of the Seekonk below Alford and among the drumlins back of Great Barrington, as many as thirty or forty of these bowlders were found built into 200 feet of ordinary stone wall along the roadside, and there still remains a sprinkling of them in the fields. There are also in the same walls rounded and weathered bowlders of several other varieties of rock. Among these is one which must be carefully distinguished from the amphibolite on account of its close resemblance in color and hardness. This is the green Rensselaer grit. It is many times more common, but is readily distinguished by characteristics of a freshly fractured surface. So far as observed, the bowlders along the base of the hill south of Queechy Lake are mostly smaller and not so many as near Great Barrington, but they are of the same rounded, weathered character, entirely unlike the angular blocks of the Richmond train.

The bowlders near Great Barrington are 16 to 17 miles from Fryes Hill and nearly straight south of it. On account of this distance and direction, there is, perhaps, some reason to doubt whether they were derived from that hill. But on this point it may be said that the bowlders south of Queechy Lake, being of the same character, suggest the beginning of a train leading southward, and occasional bowlders of the same kind occur between State Line and Great Barrington, both in the valley of Seekonk Brook and of Williams River, farther east, although particular search for them has not been made in this interval.

It is, of course, possible that the Great Barrington bowlders were derived from some other nearer source than Fryes Hill, but no other outcrop of amphibolite schist is known in the region north and northwest of Great Barrington. Smaller bowlders of the same rock in the same condition were found occasionally on a line running south-southeast from Great Barrington nearly to the south line of Massachusetts. Several were found occasionally on a line running south-southeast from Great Barrington nearly to the south line of Massachusetts. Several were found where this line crosses Konkapot Valley 2 or 3 miles south of Mill River. Two or three small bowlders of this same rock were found about 3 miles south of Tolland, Massachusetts. The latter seem likely to belong to the Richmond train, for they lie in line of its trend produced.

Amphibolite schist occurs also on Haystack Mountain north of Norfolk, Connecticut, and at points from 1 to 2 miles farther north, but none of the bowlders mentioned, neither those in the Konkapot Valley, north of Haystack Mountain, nor those south of Tolland, can be supposed to come from these outcrops by glacial transportation, for the trend of the ice movement was toward this mountain from Konkapot Valley, and they would have to be carried 10 miles a little north of east to reach the locality south of Tolland.

Probable History of Bowlders of the Great Barrington Train. The rounded, weathered condition of all the bowlders of the Great Barrington train bespeaks a very different history from that of the Richmond train. The Richmond blocks appear to have been plucked from the summit of Frye's Hill by the last ice-sheet, carried on or in the upper part of the ice and strewn across the country on the line of ice movement. They appear to have been deposited or let down on the surface. The Great Barrington bowlders, on the other hand, are water worn and weathered and more intimately associated with the till, as if they had been transported in the dirt-laden basal part of the ice.

These bowlders were in all probability detached from Fryes Hill in preglacial or interglacial times and were water worn and weathered before the coming of the Wisconsin ice-sheet. These characteristics must have been acquired by them before they were finally incorporated into the drift and deposited where they are now found.

There are also some amphibolite bowlders in this condition in the line of the Richmond train, for Benton says: "In a cut on the Boston and Albany Railroad, three-quarters of a mile northeast of Richmond station, are completely rounded and polished bowlders, some of which have a length of

4 or 5 feet. They are composed of limestone and of chlorite schist, and a few exhibit well marked parallel striae." That there was a pre-Wisconsin ice invasion of this region is not open to doubt, for a deep, indurated bed of bowldery till, plainly older than the Wisconsin, is well exposed in the excavation for the new water power plant on the Housatonic River just below Glendale. The Great Barrington bowlders, however, may not constitute a train of the same character as the Richmond train. It seems probable that their immediate source was a great weathered talus around Fryes Hill, and perhaps also from bowlder paved river beds near it. It seems difficult to account otherwise for the rounded, weathered condition of these bowlders.

THE NATURE OF THE ENGLACIAL DRIFT OF THE MISSISSIPPI BASIN

Chamberlain, T. C.; *Journal of Geology,* 1:47-60, 1893.

One of the most remarkable expressions of the drift phenomena of the Upper Mississippi region consists of belts of boulders stretching for great distances over the face of the country, and disposing themselves in great loops after the fashion of the terminal moraines of the region with which they are intimately connected. Besides this, there are numerous patches of boulders of more or less irregular form and uncertain relations. The whole of these have not been studied in detail, but a sufficient portion of them have received careful examination to justify the drawing of certain conclusions from them. Those which have been most studied lie in Ohio, Indiana, Illinois, Michigan, Wisconsin, Iowa and Dakota. Those of the first three States have been most carefully traced and their constitution is such as to give them the greatest discriminative value. To these our discussion will be limited chiefly.

Emerging from the dunes at a point north of the Iroquois river in Jasper county, northwestern Indiana, a well characterized belt of surface boulders stretches westward to the State line, just beyond which it curves about to the south and then to the east, and re-enters Indiana a little south of the northwest corner of Benton county. It soon turns abruptly to the south and reaches the Wabash river near the centre of Warren county. The immediate valley of the Wabash is thickly strewn with boulders from the point where the belt reaches it to the vicinity of West Point on the western line of Tippecanoe county. The uplands, however, do not give any clear indication of the continuity of the belt, and the connection is not altogether certain. There is an inner well-marked belt that branches away from this in the central part of Benton county and runs southeasterly into the northwestern quarter of Tippecanoe county, beyond which only scattered boulders occur, which leaves its precise connections also in doubt. But starting from West Point, which is less than a dozen miles from the point where the two belts cease to be traceable with certainty, a well-defined belt, one or two miles wide, runs southeasterly across the southwestern corner of Tippecanoe county and the northeastern quarter of Montgomery county to the vicinity of Darlington, beyond which its connection is again obscure, although boulders occur frequently between this point and the northwestern corner of Brown county, where boulders are very abundant. So also, patches of exceptionally abundant boulders occur in the west central part of Clinton county. These may be entitled to be regarded as a connecting link between the train which enters northwestern Tippecanoe county and that of northwestern Boone county, as scattered boulders of the surface type, but of not very exceptionally frequent occurrence, lie between them. However this may be, a belt of much more than usually frequent surface boulders stretches southeasterly to the vicinity of Indianapolis, and probably connects with a very well-marked belt lying near the south line of the southeast quarter of Marion county and in the northeastern part of Johnson county. There is also a well-defined tract in southeastern Hendricks county, running east and west, without evident connection with the foregoing tracts, though it may be the equivalent of the Darlington belt. There is also a somewhat unusual aggregation in the form of irregular belts in southeastern Johnson county, in the vicinity of Nineveh, and in southern Shelby county. The belt south of Indianapolis is probably to be correlated by scattered boulders only slightly more abundant than those of the adjacent region, but of the surface type, stretching northeasterly to near the center of the west half of Henry county, where a well-marked belt again sets in. From this point the tract runs northeasterly nearly to the north limit of the county, where it turns easterly and runs in the vicinity of the line between Randolph and Wayne counties to near the Ohio line, where it curves to the southeast entering Ohio near the northwest corner of Preble county. In its southeasterly course across that county it is phenomenally developed as has been well shown by the descriptions of Professor Orton. Soon after entering Montgomery county it curves about to a northeasterly course, and crossing the great Miami river, a few miles above Dayton, holds its northeast course across the southeastern part of Miami county, the northwestern part of Champaign county, and thence on to about the center of Logan county, where it curves about and runs in a direction a little east of south to near the southeast corner of Champaign county, beyond which it ceases to be a specially notable phenomenon.

In the region between the Wabash and Kankakee rivers, in northern Indiana, there are numerous tracts of irregular form over which surface boulders in phenomenal abundance are scattered. These are particularly noticeable in southern Jasper county; in the vicinity of Wolcott, Monon and Chalmers in White county; near Star City in Pulaski county; in the southeastern corner of Stark county, and very generally along the great interlobate moraines, lying parallel with the Eel river, and some others of the Saginaw glacial lobe. These are so associated with the inter-tangled morainic phenomena of that region as not to admit of convenient and brief description in their genetic relationships.

The well-defined tracts have a most significant distribution. The first part described is associated with the terminal moraine that marked the margin of a lobe of ice that moved westward along the axis of the Iroquois basin to a point a few miles beyond the Indiana-Illinois line. The portion that runs southward to the Wabash is associated with the moraine that follows the same course, and runs at right angles over the older moraines of the Lake Michigan lobe. The tract in Tippecanoe and Montgomery counties, that in south Marion county, and that in Henry and Randolph counties, in the eastern part of the state, are associated with the terminal moraines that form a broad loop with the West White river basin lying in its axis. In western Ohio the belt is intimately associated with a moraine that bordered the Miami lobe of the ice sheet, and the south-trending portion in eastern Logan and Champaign counties lies on the western margin of the Scioto lobe.

The relationship of these tracts to terminal moraines is very clear and specific. They constitute marginal phenomena of the ancient ice sheet. Their distribution completely excludes their reference to floating ice, for they not only undulate over the surface utterly negligent of any horizontal distribution, but they are disposed in loops in crossing the basins of the region, and the convexities of these loops are turned down stream. These basins for the most part open out in southerly or westerly directions which makes it improbable that ice-bearing bodies of water occupied them. But if this were not fatal, certainly the fact that the convexities of the boulder belts are turned down stream and cross the centers of the basins is precisely contrary to the distribution they must have assumed if they were due to floating ice in bodies of water occupying the basins, I hold it, therefore, to be beyond rational question that these tracts were deposited as we find them by the margins of the glacial lobes that invaded the region.

If these boulder belts were of the same nature as the average boulders of the till-sheets beneath them, then the simple fact of unusual aggregation might be plausibly referred to the accidents of gathering and deposition. But they are very clearly distinguished from the average boulders of the till by several characteristics.

1. They are superficial. Sometimes they rest completely on the surface, sometimes they are very slightly imbedded, sometimes half buried, sometimes they protrude but a slight portion, and sometimes they are entirely concealed, but lie immediately at the surface. In all cases the aggregation is distinctly superficial. Where they are buried, the burying material is usually of different texture and composition from the subjacent till, and appears to be distinct in origin from it. The superficiality of the tract is very obvious almost everywhere, and is especially so in regions where the subjacent till is of the pebble-clay rather than boulder-clay order, for the comparative absence of boulders below emphasizes the contrast. Throughout most of the region the subjacent till is not of a very bouldery type, so that the distinction is generally a marked one.

2. The boulders of the belts are almost without exception derivatives from the crystalline terranes of Canada. Those of the great tract especially under consideration were derived from the typical Huronian rocks of the region north of Lake Huron, and from granitic and gneissoid rocks referable to the Laurentian series of the same region. These last, however, cannot be sharply distinguished from the granitic rocks derived from other parts of the Laurentian terrane. The Huronian rocks are very easily identified because of the peculiarities of some of the species. Among these the one most conspicuously characterized is a quartz-and-jasper conglomerate. The matrix is usually a whitish quartzite. This is studded with pebbles of typical red jasper and of duller rocks of jasperoid nature, which grade thence into typical quartzite pebbles. With these are mingled crystalline pebbles of other varieties. Another peculiar erratic comes from the "slate conglomerate" of Logan. It consists of a slaty matrix through which are scattered rather distantly pebbles of granitic, quartzitic and other crystalline rocks. This is one of the forms of the "basal conglomerate" of Irving. Other varieties of this "basal conglomerate" are present. In addition to these very peculiar rocks, a quartzite of a very light greenish semi-translucent hue has a wide distribution along the tract. It is readily distinguishable from the numerous other quartzites

of the drift of the interior. Some years since, on returning from my first field examination of a portion of this belt, I sent a typical series of chips from the characteristic erratics to Professor Irving, who had recently returned from the study of the original Huronian region. He returned a suite of chippings that matched them perfectly throughout, all of which were taken in situ in the region north of Lake Huron.

Among the boulders of the belt are occasionally found specimens of impure limestone or of limy sandstone that might perhaps be referred doubtfully to some member of the paleozoic series; but on the other hand, might with equal or greater probability perhaps be referred to the similar rocks of the Huronian series. These are quite rare, never forming, so far as my observations go, as much as one per cent. of the series. In the several definite enumerations made to determine the percentage of the doubtful specimens, the result never exceeded a fraction of one per cent. In the most extensive enumeration the result was about one-half of one per cent. Aside from these doubtful specimens there are practically no boulders in the belts that can be referred to any of the paleozoic rocks that intervene in the 500 miles between the parent series north of Lake Huron and the tract over which the boulders are now strewn. Occasionally there may be seen erratics from the paleozoic series at or near the surface, but they are not usually so disposed on the surface as to appear to be true members of the superficial boulder tract. There is, therefore, the amplest ground for the assertion that these boulder tracts are of distant derivation, and that they are essentially uncommingled with derivatives from the intermediate region.

3. The boulders of this series are much more angular than those of the typical till sheets. Some of them, indeed, are rounded, but the rounding is generally of the type which boulders derived by surface degradation and exfoliation present. They rarely have the forms that are distinctively glacial. Quite a large percentage are notably angular, and have neither suffered glacial rounding nor spherical exfoliation. Some few are glacially worn and scratched, but the percentage of these is small.

The tracts therefore present these four salient characteristics: (1) the boulders are derived from distant crystalline terranes (400 to 500 miles) and are essentially uncommingled with rock from the intervening paleozoic terranes; (2) they are essentially superficial, and the associated earthy material has a texture differing from that of the subglacial tills; (3) they are notably angular and free from glacial abrasion, except in minor degree; (4) the tracts are so associated with terminal moraines and so related to the topography of the region, that there is no rational ground for doubt that the boulders were borne to their present places by the glaciers that produced the correlative moraines.

In contrast to these superficial boulder formations, the till sheets below are made up of a very large percentage of glacial clay whose constitution shows that it was produced in part by the grinding down of the paleozoic series. In this are imbedded boulders and pebbles that were derived from the paleozoic series as indicated by their petrological character, and, in many instances, demonstrated by contained fossils. While a small part of the boulders contained in the till are angular or but slightly worn, the larger part are blunted, bruised, scratched and polished by typical glacial action. This obvious grinding of the boulders, taken in connection with the clay product resulting from the grinding, affords a clear demonstration that the deposit was produced at the base of the ice by its pushing, dragging, rolling action.

The two formations, therefore, stand in sharp contrast; the one indicating the passive transporting action of the ice in bearing from their distant homes north of the lakes the crystalline boulders and dropping them quietly on the surface, the other indicating the active dynamic function of the ice in rubbing, bruising and scoring the material at its base. The one seems to me a clear instance of englacial and superglacial transportation; the other an equally clear example of subglacial push, drag and kneading.

Now if it were the habit of an ice-sheet of this kind to carry material from its bottom to the surface by internal movement, it would seem that the distance of 400 to 500 miles which intervened between the source of the crystallines and the place of their deposit would have furnished ample opportunity for its exercise, and that there would have been commingled with the englacial and superglacial material many derivatives from the intermediate region, and these derivatives should have borne the characteristic markings received by them while at the base of the ice. The very conspicuous absence of such commingling, and the absence or phenomenal rarity of anything that even looks like such a commingling, appears to me to testify in quite unmistakable terms to the distinctness of the methods of transportation. In view of the great territory over which this particular belt is spread, and the greater territory which is embraced in the other tracts not here specially considered, there is left little ground for doubt that this distinctness of englacial from basal transportation was a prevailing fact and not an exceptional one. This is supported by concurrent evidence derived from the territory west of Lake Michigan. This territory unfortunately does not bear erratics that have equally distinct characteristics, but, so far as my observation goes, the phenomena are alike throughout. I am therefore brought to the conclusion that, in the interior at least, there was no habitual lifting of boulders from the base of the ice sheets to the surface, nor any habitual commingling of basal with englacial and superglacial material, except, of course, as it took place by virtue of the falling of the latter through crevasses to the base, and by mechanical intermixture of the two at the edge of the ice. (pp. 52-60)

CATASTROPHIC TERMINATION OF THE LAST WISCONSIN ICE ADVANCE.....

Hunt, C. Warren; *Bulletin of Canadian Petroleum Geology,* 25:456-467, 1977.

Abstract. A theory that catastrophe emplaced the Erratics Train of Alberta, Canada, and filled the basin of Lake Bonneville of the western interior United States with sea water, is examined and found consistent with both field evidence collected by the author and published information (Stalker, 1956; Tharin, 1962; Broecker and Orr, 1958; Morrison and Frye, 1965; Mountjoy, 1958). The evidence is found to favour tidal inundation to account for both phenomena, although this explanation has heretofore been wholly overlooked.

Setting of the Erratics Train of Alberta. The frontal edges of two enormous glaciers, the Keewatin (continental) and Cordilleran (montane) glaciers, faced each other some 11,000 years ago just to the east of the Rocky Mountain front in Alberta. The gap between them was an ice-walled valley 20 mi or so (32 km) wide, which carried the combined meltwaters southeastward into the Mississippi River system (Stalker, 1956; Tharin, 1962).

The 11,000-year date is derived from carbon dating of mammalian fossils collected by the writer from terrace gravels at Cochrane, Alberta on the west edge of the interglacial valley. These specimens were dated by the Geological Survey of Canada (Churcher, 1968) and are believed to be approximate age equivalents of the youngest tills in the area (Tharin, 1962).

Above the bone-bearing terraces and the latest tills of the interglacial valley area there was laid a thick layer of poorly stratified brown silt, which Tharin named the Calgary silt. Its deposition he attributed to a body of water for which he proposed the name, "Lake Calgary."

Wherever the writer has observed this formation, it lacks varves, coarse sand or gravel. Its appearance suggests deposition after suspension in turbulent flow such as in a tumultuous flood. It resembles neither the coarse clastic sedimentary discharge of the mountain rivers that flow east from the Canadian Rockies nor the chloritic glacier-derived rock flour and silt of the western Rocky Mountains at this latitude. Its character does not suggest derivation from the nearby cordillera in any respect.

Nestled into the top layers of the Calgary silt and depressing its faintly expressed bedding lines are occasional boulders of quartzite. They are the Erratics Train of Alberta boulders (Rutherford, 1941; Stalker, 1956; Mountjoy, 1958; Tharin, 1962). Comprising quartzite blocks of Cambrian and late Precambrian age, they were carried to their present locations without being striated, rounded or visibly altered in the process. There are enough of them to map; and their course, which Mountjoy, Tharin, and Stalker all have mapped in part, leads from the valley of the Athabaska River where it debouches from the mountains upon the western Alberta plain and proceeds southeastward to the area of Calgary and thence into Montana northwest of Great Falls. The length of this course is more than 400 mi (643 km). The erratics rest variously on youngest glacial tills, Calgary silt, and older strata, their distribution defining approximately the interglacial valley, which Tharin refers to as the "Calgary River" valley.

This "river valley" is a phenomenal one. It progressed southeastward transverse to all present rivers, over hill and dale, so to speak, only locally leaving relatively narrow, relict channels to certify its existence. Tharin calculates its grade as 12 ft/mi (2.3 m/km) from the Athabaska River to the Montana border. It never achieved grade over most of its width or length, the only deposits definitely attributed to it being the Calgary silt and the erratics. As previously noted, neither of these deposits is characteristic of a river.

The topology of the Cochrane bone-bearing terrace gravels illustrates the anomaly with respect to the gradient of the "Calgary River". The Bow River was already incised when the bone beds were deposited along its east-flowing course. Although there has been some post-bone bed incision of the Bow River at Cochrane, and slightly more at Calgary, the main Bow valley development was pre-bone bed in age. If the bone bed terraces had been laid down in part of the "Calgary River" valley system, they should be found continuing southeastward with that system; that is to say, taking off as a separate river course clearly departing from the present Bow River course somewhere in the 20 mi (32 km) downstream from Cochrane.

They do not do this, which suggests that their deposition is not truly part of the "Calgary River" deposition but was a deposit of the Bow River either before the existence of the "Calgary River" or after it.

The age of the bone beds precludes deposition before the last Wisconsin ice advance. The suggestion that the bone beds are younger than the last ice advance is not untenable. But it requires acceptance of the deepening of the Bow Valley from the bone-bed levels to the present position in even less time than the 11, 000 suggested years. And, since the bone beds are below the rim of the major incision of the Bow, all the incising down to their level must have occurred subsequent to "Calgary River" time, along with obliteration of almost all evidence for the "Calgary River" itself. To make use of this interpretation would require pushing back the date of the last ice retreat, the emplacement of the Erratics Train, and the deposition of the Calgary silt. This solution is wholly unacceptable if one contemplates the fragile nature of the Calgary silt and the larger erratics, which would have had to be preserved while entire land forms were destroyed and created. Of course, this solution also entails a special interpretation as to why there was a different glacial chronology in this area from that of most of the continent.

Thus, the fact seems to be forced upon us that the "Calgary River" was about the same age as the bone beds, which were laid down in a normal mountain-derived river capable of incising its channel. But the fact is also evident that the "Calgary River" never incised a channel commensurate with its great width or presumed water load derived from the entire Saskatchewan and Athabaska River systems. Neither did it develop terraces, benches, or recognizable flood plains, at least some of which would be expected to have been preserved as the Cochrane terraces, the Erratics Train and the Calgary silts are preserved.

The implications are that the Cochrane terraces, the Erratics Train and the Calgary silt are not products of a normal river and that there was no channel developed by this ephemeral waterway. We are, nevertheless, compelled to recognize that Keewatin ice did block the flow of water on its present courses, so that the "Calgary River" indeed must have existed as a regional watercourse, but perhaps one of very short life.

The size of some of the erratics deposited on the course of the "Calgary River" is impressive. The "Big Rock" Erratic is calculated by Stalker to weigh 20, 000 tons. The source of these rocks as established by Mountjoy in the Athabaska Valley above Jasper, Alberta is not disputed, so far as the author is aware. Neither is there any dispute as to the absence on the erratics of flutings, striae or polish that would suggest glacial transport as a means of emplacement. And no rationale can be developed with any degree of plausibility to attribute transport of the erratics to overthrusting, gravity sliding or fluvial processes active at present.

A Possible Solution. The only conceivable transportation mechanism that can explain the transportation of the erratics while also preserving their fresh nature is ice rafting. This idea was first proposed by Rutherford in 1941 but was never popular because of the two problems inherent in it: the requirement of a large body of water to float great ice rafts and to allow them to be floated for over 400 mi (643 km), and the requirement of a mechanism that could overcome the geologically awkward problem of loading and launching rafts with fresh mountain rock in fragments of up to 20, 000 tons.

Stalker has calculated that the ice volume necessary just to float the

A small section of the Big Rock, Alberta, erratics train. (C. Warren Hunt)

largest of the erratics would be about 5.5 million cubic feet---a large iceberg, indeed, for an inland sea!

The solution to the problem of a body of water is inherent in the solution to the loading problem. The fresh condition of the rock making up the erratics is the key, as it requires that the rock have ridden on top of the ice of the raft, not within it as glacial boulders normally travel. To have carried the erratics on top, the ice raft would have needed to be much larger than would suffice for flotation---perhaps ten or twenty times the minimum size. A slab shape would be necessary, to prevent overturning. A slab of 200 ft (60 m) thickness and 600 ft (180 m) diameter might have floated the "Big Rock" Erratic.

Ice rafts of this size cannot occur by calving from mountain glaciers. Present-day floes of this type originate only by detachment from polar ice packs. But such ice floes could result if a glacial valley was flooded and the tongue of a glacier floated. Such a mechanism, in which a great tide inundated the "Calgary River" valley, could have produced the floes that acted as ice rafts for the Erratics Train. Only floes developed in a mountain valley in this way could have received mountain rock, a fact which Stalker noted.

To produce the number of rafts and the quantity of rock represented by The Alberta Erratics Train required that a considerable length of glacier be loaded with similar rock. As no glacier rives and plucks 20,000-ton boulders by its usual mechanisms, the loading of the erratics required an avalanche. Perhaps peaks and shoulders of the mountains for tens of miles along the Athabaska valley collapsed in a great earthquake and avalanched out upon the surface of the glacier. Once the loading was complete, the glacier must have been gently floated, in the process of which it would have broken up because of various factors such as differential rock load, differential ice thickness, or simple turbulence of tidal waters surging up the valley and driving the glacier back along its course. The floes so developed could then have sailed with their rock loads on the ebbing tide like a flotilla of great ships.

If such a tide had come in through an estuary between the two great glacier systems and inundated the Athabaska valley up to 5000 ft (1823 m) or so above present sea level, it could have floated the glacier in the 50 or so mi (80 km) comprising the probable rock source. That such a phenomenon could have happened and, in fact, probably did happen, is the thesis of this paper.

Violent earthquaking would have been the first event, perhaps due to proximal passage of a cosmic body. Seismicity is conceived to have caused collapse of mountains and ridges with consequent avalanching out upon the surface of the Athabaska valley glacier. That event was followed by a great tide from the Gulf of Mexico, which churned up silt as it came. This silt was deposited in the Calgary area as the Calgary silt; and its quantity suggests that the tide was either repetitious or of some duration. Duration might have resulted from slow passage of a large, distant, cosmic body. Repetition might have resulted from a smaller body returning periodically. In both cases, the turning of the earth would have given diurnal tidal repetition, with maximum flood tide occurring at closest passage, after which the flotilla of ice rafts would have proceeded to string out along the estuary course, grounding, foundering and melting, on their way toward the Gulf of Mexico.

As a lake 2,000 ft (600 m) deep in which one entire shore is ice does not appear to be possible, the "Lake Calgary" concept as proposed by Tharin is rejected in favour of the tidal concept. Only the tidal concept offers a means to adequate water depth; and only the earthquaking which would have resulted from the gravity effects that caused the tide would have delivered the rock load to the ice surface at the right time for the flotation. Even a few years' difference between the timing of tide and earthquake would have aborted the complete program necessary to emplace the Erratics Train. The entire scenario is essential.

Another possibility for the earthquaking and inundation sequence would be foundering of the entire cordilleran region. This sort of event would have required a similar gravity disturbance, which, however, might have been the negative response to gravity attraction to other parts of the earth. This suggestion, thus, does not seem to add anything to the concept as proposed.

The idea of catastrophe originating with gravitational interference and resulting in tidal inundation is proposed by the author to be convincing and unchallengeable. Avalanche loading of the Athabaska glacier and tidal flotation seem to be both necessary and sufficient to explain the situation. That such an event was also the terminal event to the most recent ice advance of the Pleistocene may be adduced if the youngest tills, the Calgary silts, and the bone-bearing gravel beds of the Cochrane area are contemporaneous among themselves and with the termination of the ice advance.

Consideration of Lake Bonneville. Looking farther afield, to Lake Bonneville, the studies of Broecker and Orr (1958) and of Morrison and Frye (1965) have demonstrated that the relict beaches reached elevations of more than 5,200 ft (1,600 m) during the last 25,000 years, the last culmination being at 11,500 according to the former and at 10,000 according to the latter authors. Broecker and Walton (1959) and Eardley, Grosdetsky and Marsell (1957) studied the chloride content of the waters of the residual lake, recognized the excessive proportion of chloride ion for a continental environment, and attempted to explain it as wind-blown from the Pacific Ocean. Feth (1959) commented adversely on the need to invoke eolian transport.

The author regards the aforesaid studies as sources of valuable data, but insofar as they purport to explain either the chloride content of the Bonneville basin or the high beach cutting, which is 461 ft (140 m) above the present low point on the drainage divide to the Snake River---Columbia River system, they are wholly unsatisfactory.

If the Alberta interpretation of inundation is valid, the waters of the Pacific Ocean would simultaneously have inundated the Columbia-Snake estuary and thence entered Lake Bonneville over Red Rock Pass (Elev. 4,789 ft, 1,460 m). The Lake Bonneville beaches on the pass and even to the <u>north</u> of the pass, as found by the writer at elevations high above the pass, contain rounded pebbles, grotto features and water-worn rock surfaces indicative of some duration for their development by wave energy and current action.

Despite the fact that the beaches are well developed above pass level, all previous students of the problem seem to have regarded Red Rock Pass only as an "outlet." One might have expected an overflow spillway to be active seasonally and, therefore, to have features showing the effects of flow only in one direction, northward; one might also reasonably have expected it to be a gorge with a few preserved benches cut when the spill point was higher. Instead, one finds a 10-mi (16-km) river-like depression with a flat floor, well-preserved benches, and vertical polished surfaces facing <u>north</u>. The surfaces are the product of gravel carried by a current <u>from</u> the north against the impeding surface. The pass looks much more like a <u>strait</u>, and the polished surfaces show <u>southward flow into</u> the Bonneville depression. The strait can be thought of equally well as having accommodated a north-flowing ebb tide or a south-flowing flood tide. But at no time would north flow have exceeded south flow, because of the high evaporation rates of the Bonneville basin; and the many beach levels show all too well the repeated drying up of the basin when tidal replenishment failed.

Concerning salinity, Broecker and Walton and Eardley <u>et al</u>. attempt to show that the chlorine could have arrived by wind from the ocean. Their rationale is most erudite and intriguing, but the explanation is superfluous. Feth gives the sodium-to-chlorine ratio as .92 and points out its similarity to that of the Pacific Ocean, which he gives as .86. The .92 ratio may be above the Pacific figure because of post-Bonneville contributions of local salts. That is what would be expected, in any case, as much higher ratios characterize indigenous waters of the cordilleran region. Interior drainage and evaporation give rise to gypsiferous and carbonate deposits rather than to halite.

Broecker and Walton as well as the author of this paper consider an oceanic source essential to explain the presence of the quantity of chlorine found in the surface environment of the Bonneville basin. This paper suggests that direct oceanic contribution is a far better choice of mechanism for the chloride emplacement than the wind-borne hypothesis. This proposal is believed to be much enhanced by the high probability of inundation having occurred at approximately the same time in Alberta.

Turning to the estuary of Lake Bonneville, we may observe an interesting further clue to inundation. In the Snake River valley 10 mi (16 km) west of the town of Bliss, Idaho, situated beside the highway on a terrace 100 ft (30 m) or so above the river and continuing downstream for approximately 4 mi (6 km), is a deposit of very well rounded basalt boulders up to 7 ft (2 m) in diameter. ("Melon gravels" See H. E. Malde, USGS Prof. Paper 596, 1968.) They are distributed evenly over a level depositional plain in the manner of a tidal-flat deposit. They are not in heaps, as they would be if deposited by a raging torrent in a spring flood, but have

The Bliss boulder field.

been worked over until they nestle "shoulder to shoulder" in a one-boulder-thick mat at the top of a mixed sand and smaller boulder bed.

Development of round boulders of this size is attributable to the upstream occurrence of 50 mi (80 km) or so of canyons with gradient averaging 18 ft per mi (3.4 m per km). There is not enough energy in the present Snake River to discharge boulders like this and spread them evenly over a 4 mi (6.4 km) distributary plain. Attesting to this lack of energy is the absence of such large boulders a mere 3 mi (5 km) downstream, even though the river has cut through the boulder deposit. Thus, it appears necessary that a much greater energy source have been available to distribute and winnow the Bliss boulder deposit. This energy source could have been a tumultuous roiling tide, its flood and ebb cycle filling the Snake River Canyon to brimming and higher. The flushing action under these conditions might have discharged the pre-existing boulders out of the canyon on to a fan at its mouth. Subsequent flood and ebb cycles could have spread the boulders and jostled them into the even blanket in which they are now found.

Summation. The conception of a celestial body interfering with earth gravity to cause great tides is not alien to the theory of uniformitarianism.

Earth scars from known meteorites, and scars that appear attributable to meteorite impact include depressions up to 300 mi (483 km) diameter (e.g., Belcher Island depression, southeast Hudson's Bay). A cosmic body that could cause such a large depression on impact might be expected to have caused a great tide if, instead of striking, it had passed close to earth.

That the frequency of such phenomena is adequate to assure an acceptable probability is inferred from the frequency of meteorite occurrence. Considering that a sphere the size of the moon's orbit has 478 times the surface area of the earth, we may deduce that there are 477 times as many near misses within that distance as there are hits. Inferring, from the rate of erosion of residual effects, that such a strike is unlikely to remain longer than one million years, and assuming that three-quarters of the strikes hit oceans, we may be within the right order of magnitude of the truth if we estimate 4 x 477 near misses of Belcher Island meteorite size per million years. This number suggests that there are ample opportunities for tide-inducing passages of cosmic bodies.

A more difficult stricture arising from the evidence is the need for a duration sufficient to allow development of beaches and deposition of thick silt beds. Required would be either a very slowly passing, perhaps large and distant, cosmic mass, or a smaller, faster-moving mass that travelled in comet-like fashion within the solar system on an elliptical orbit.

This paper suggests that the evidence for cosmic interference has greatly increased within the last decade, during which we have had the opportunity to observe the great extent to which impact effects have modified the surfaces of the moon and Mars. It also suggests that there is now known to be ample opportunity for both impacts and near and distant misses ---sufficient, in fact, for these phenomena to be regarded as frequent contributors to the geological environment.

The author concludes, then, in summary, that the gravity of a passing celestial body caused a 5,000 ft (1,700 m) ocean tide and violent crustal motion; that both of these events were necessary for creation of the Alberta Erratics Train, but that the tide alone would explain the salinity of Lake Bonneville, its beach features (some of which are located above the Red Rock Pass strait) and the Bliss boulder deposit. If tidal inundation was the only direct causative mechanism, it must have recurred over the period 25,000 y.B.P. to 10,000 y.B.P., according to the radiocarbon dates of the high Bonneville beaches. But if all or some of the observed features were caused by foundering of the entire region of the North American cordillera, then fewer celestial passages might have sufficed, because the foundering would have persisted longer than a tide.

The scenario might have been one of foundering at one or more dates in the period from 25,000 to 11,000 y.B.P., caused by a reverse effect of a tide which might have been high in the Arctic and Antarctic while at the same time depressed in the equatorial regions. Recovery of the crust from such a severe distortion might have taken a long time---long enough, we might speculate, for polished rock surfaces and deep beach cuts to be created by the usual water erosion processes. In a later passage near 11,000 y.B.P., a great tide may have filled Lake Bonneville for the last time and emplaced the Erratics Train.

The synchroneity between available radiocarbon dates for the Alberta and Idaho events, and for the similarity of elevations of the implied water levels, gives good support to the idea of commonality of cause. Radiocarbon dates as well as paleosol dating by various workers indicate that the common event occurred between 11,500 and 10,000 y.B.P. It is hypothesized that this event terminated the last Wisconsin ice advance through the floating of glacial peripheries up to the 5,000 ft (1,700 m) level. Such floating would have made the entire central glacial regimen unstable. Internal stress would have caused slippage of large masses in the manner of earth landsliding. Thus decimated, much of their volumes having been floated away as icebergs, the great glaciers might not have had enough residual weather-modifying capability to preserve themselves, and their demise under astatic conditions would have been assured.

The relative ease with which evidence for the inundation hypothesis has been found in widely separated areas suggests that tidal inundation may be a much more important factor in the development of land forms than has been heretofore recognized. The possibility for gathering additional evidence is very great. Lake Agassiz' beaches, the Bliss boulder deposit, and the Spokane Flood materials may all yield carbon dates. Some studies of the energy requirements and time represented by the carbing of the flat North American prairies east of the Rockies to leave extremely gentle slopes such as we now find, with Miocene-capped hill masses elevated several thousand feet above "river" valleys 100 mi (160 km) wide, may succeed in proving that not enough time has elapsed for such erosion by present fluvial processes, and that tidal erosion might have been an agent. This paper merely broaches an intriguing subject.

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• Anomalous Grooves, Striations, and Furrows

STRANGE ASPECTS OF THE DRIFT

Donnelly, Ignatius; *Ragnarok: The Age of Fire and Gravel,* University Books, New York, 1970. (Originally published 1883)

And here is another perplexity: It might naturally be supposed that the smoothed, scratched, and smashed appearance of the underlying rocks was due to the rubbing and rolling of the stones under the ice of the glaciers; but, strange to say, we find that---

"The scratched and polished rock-surfaces are by no means confined to till-covered districts. They are met with everywhere and at all levels throughout the country, from the sea-coast up to near the tops of some of our higher mountains. The lower hill-ranges, such as the Sidlaws, the Ochils, the Pentlands, the Kilbarchan and Paisley Hills, and others, exhibit polished and smoothed rock-surfaces on their very crest. Similar markings streak and score the rocks up to a great height in the deep valleys of the Highlands." (Geike: The Great Ice Age)

We can realize, in our imagination, the glacier of the mountain-valley crushing and marking the bed in which it moves, or even the plain on which it discharges itself; but it is impossible to conceive of a glacier upon the bare top of a mountain, without walls to restrain it or direct its flow, or higher ice accumulations to feed it.

Again:

"If glaciers descended, as they did, on both sides of the great Alpine ranges, then we would expect to find the same results on the plains of Northern Italy that present themselves on the low grounds of Switzerland. But this is not the case. On the plains of Italy there are no traces of the stony clay found in Switzerland and all over Europe. Neither are any of the stones of the drift of Italy scratched or striated." (Ibid)

But, strange to say, while, as Geikie admits, no true "till" or Drift is now being formed by or under the glaciers of Switzerland, nevertheless "till" is found in that country dissociated from the glaciers. Geikie says:

"In the low grounds of Switzerland we get a dark, tough clay, packed with scratched and well-rubbed stones, and containing here and there some admixture of sand and irregular beds and patches of earthy gravel. This clay is quite unstratified, and the strata upon which it rests frequently exhibit much confusion, being turned up on end and bent over, exactly as in this country the rocks are sometimes broken and disturbed below till. The whole deposit has experienced much denudation, but even yet it covers considerable areas, and attains a thickness varying from a few feet up to not less than thirty feet in thickness." (Ibid)

Here, then, are the objections to this theory of the glacier-origin of the Drift:

I. The glaciers do not produce striated stones.
II. The glaciers do not produce drift-clay.
III. The glaciers could not have formed continental sheets of "till."
IV. The glaciers could not have existed upon, and consequently could

not have striated, the mountain-tops.

V. The glaciers could not have reached to the great plains of the continents far remote from valleys, where we still find the Drift and drift-markings.

VI. The glaciers are limited in number and confined in their operations, and were utterly inadequate to have produced the thousands of square miles of drift-debris which we find enfolding the world. (pp. 21-22)

GLACIAL MARKINGS OF UNUSUAL FORMS IN THE LAURENTIAN HILLS

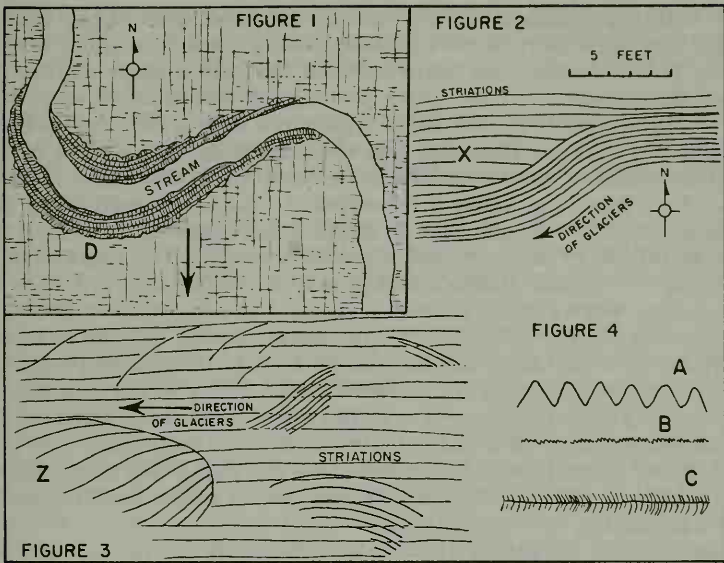
Andrews, Edmund; *American Journal of Science,* 3:26:99-105, 1883.

Two summer vacations spent in camps and canoes where the Laurentian Hills skirt the northeast shore of Lake Huron have brought to my notice some glacial phenomena of very unusual forms.

These hills are for the most part ranges of hard metamorphic rock, which, at the bowlder drift period, were scraped bare and washed clean of all earthy covering, so that the present forests grow mostly in a thin stratum of vegetable mold of later origin. The irregular and knobby eminences, as the country slopes gradually beneath the level of Lake Huron, project their countless summits above the water in a wide belt of wooded islands, which extend along the coast some two hundred and fifty miles. The British chart (Bayfield's original) marked fifty-two thousand of these islands. The rocks along the coast are mostly white quartzite and gneiss, and are everywhere covered with glacial markings, which are often of peculiar forms. North and northeast of Grand Manitoulin Island, the Cloche Mountains stretch east and west about thirty miles along the coast. These mountains are of white quartzite and the strata are nearly perpendicular, with their striae parallel to the range, that is, east and west. They are covered everywhere with striations, which, owing to the intense hardness of the material, retain their forms with beautiful distinctness.

Curved Striae. Among the interesting phenomena of the region are the thousands of curved striations. Fig. 1 is from the stream that comes down by the Hudson's Bay Post, about fifteen rods above the cascade. There is a broad gap here in the Cloche Range through which some fine lakes, lying behind the mountains, send their surplus waters to Lake Huron. The stream apparently ran in the same bed before the drift period, for the little gorge at D (indicated in the figure by shading), scarcely ten feet deep, is well scored to the very bottom with glacial striae following all the sinuosities of the stream. The general course of the striae of the gap is southward. The perpendicular lines in the figure indicate this general direction, while the curved lines in the shading of the gorge D show how the striae bend abruptly in order to follow around the hard quartzite banks of the stream, and in doing so even run a little contrary to the main course of the glaciation.

The crest of the Cloche Mountains is crossed by a multitude of giant grooves, some of which reach a depth of six feet, and are twenty feet across. These markings run southward, rounding slightly over the summit of the range and down its slopes, until they reach the crests of its southern precipices where they terminate abruptly, as it were, sailing



away into the air and not forming any grooves down its face.

Sixty miles southeast of the Cloche gap and off the mouth of French River, there lies, outside of the general insular belt, a beautiful cluster of wooded islets, the Bustard Isles. The group consists of about two hundred great roches moutonnees, upon which sufficient vegetable mold has accumulated to support a thick growth of trees. Wherever this soil has been washed away by the waves the striae come to view.

Fig. 2 was sketched from a sample of curved markings near one of my camps on the north side of the group. The sketch represents about fifteen feet of the length of the marks. It is not easy to see any reason for the curve, as there was no prominence of rock in the direction of X to turn the ice. In fact the islet was highest on the side toward which the ice turned at the first curve. The compass mark is approximately, but not precisely correct.

Fig. 3 is copied from my notes of observation on striae found at Negaunee, in northern Michigan. A knob of rock uncovered by iron miners was of such material that it showed on its irregular surface the finest markings, even to hair lines. There were upon this rock some curves which were evidently deflections caused by knobs and bosses on its surface, as for instance at Z. While other markings were erratic and curved without obvious cause, as though the ice had been swayed by swirling currents as the waters moved about it. The most of the glaciation was in the direction shown by the horizontal lines. The curved lines in the figure were selected from hundreds of others on a surface of about two rods square. They were generally short, and some of the curves were of less than one foot radius.

Serrated Striae. Behind the Cloche Mountains the Spanish River runs westward into Lake Huron. A branch of this stream, called the Sable, coming down from the hills on the north, presents near its mouth five cataracts within a distance of eight miles. At the lowest of the falls the river runs through a sort of rock flume, having upon both sides walls about forty feet in height, not quite vertical but with a slight inclination away from the stream. These cliffs are smooth and striated in every part parallel to the stream. At the falls, which are only a few feet in height, the striae curve with the descent, and also laterally with a bend of the cliff. On the walls of the gorge are to be seen a few examples of the marks A and B. Fig. 4 and the mark A is serrated, the serrations being perhaps twelve inches high. It is not easy to explain the cause of these striae in a perfectly satisfactory manner, but it would seem that ice must have been driven through the flume with a rocking motion so that the bowlders on its lateral margins were caused to take a zigzag course, scoring the walls in a corresponding form. In B, fig. 4, is represented a section of certain marks produced in the same manner as those cuts of a stone planing engine where the tool trembles or vibrates in the grasp of the machine so as to cut a finely serrated groove. In the specimens found the serrations were about one-quarter of a centimeter from crest to crest. It is possible that the regular vibrations thus recorded on the rocks had some fixed mathematical relation to the velocity of the ice, which might possibly be determined by calculation or experiment.

New Index of the Direction of Motion. The mark C, fig. 4, was copied from a granitic roche moutonee at the fishing hamlet of Killarney near some quartzite ranges named "Killarney Mountains." Striae of this type show a multitude of minute cracks extending laterally and curved so as to present their points forward in the direction of the glacial movements. Only large grooves and scratches show this peculiarity. It is a very convenient mode of determining the direction of the motion, for the pressure of the bowlders which made the scratches as they moved forward caused the transverse cracks to present their concave sides always forward. It is well known to engineers that in brittle substances the forms assumed by fractures vary with the velocity of the impact, so that there is probably a time relation involved here also which would make it possible to determine the approximate velocity of the ice which carried the bowlders. Such a calculation, if based upon carefully repeated experiments, might prove an important contribution to our scanty knowledge of the Drift Period.

Scoop Marks. These are singular phenomena and very difficult of explanation. They are of two varieties, the striated and the unstriated. Fig. 5 is a diagram intended to illustrate a typical form of the striated variety. The marks consist of shallow elongated excavations or troughs which may be many feet in width. They run nearly in the direction of the general striation of the locality, and look as though a huge flour scoop had been inserted into the rock and had cut out enough of its substance to make a smooth and rather shallow concave channel. The end toward the east, or northeast from whence the drift action came, is abrupt, sharply-defined, and although the angle of junction with the general surface is obtuse, yet this line of junction is a sharp and clearly cut edge and not a gradual sloping or rounding into the general level. The interior of the concavity is well striated in the direction of its own length, but the scratches are never continuous with those of the general surface northeast of the head of the scoop mark; and, conversely, the striae of the general glaciated surface are all cut off abruptly at the head of the scoop and never descend at all into it.

The tail of the channel grows shallower as it runs west or southwestward, and its thin extremity merges imperceptibly into the glaciated surrounding surface. A few of the scoop-marks are nearly flat in contour and are only recognizable where they cut abruptly through at an obtuse angle into the general face of the rock.

The interpretation of these anomalous scoop-marks is somewhat perplexing; at least, after considerable study of them, I am quite unable to frame a plausible theory of their origin other than the general one, that ice was the agent.

The unstriated scoop-marks differ considerably from the others in form, and on the average are smaller, seldom exceeding two feet in breadth. There are no glacial markings in their smooth but unpolished concavities.

Whether they never contained any striations or whether the markings have been erased by sand and water driven through them before the Drift Period closed is not easily determined. These channels generally are crooked without obvious reason (see fig. 6), and are narrowest at the end toward the northeast, from which direction the drift came. Toward the opposite extremity they grow wider and more shallow, disappearing finally and vaguely into the general ice-marked surface of the locality. The specimen shown in fig. 6 is perhaps six feet long, sunk in granite, without any crevice-vein or visible irregularity in the rock face to account for its excavation at that spot. These channels often differ pretty widely in direction from the adjacent striation, and the end nearest the northeast commences as a rounded depression without the clear cut edge presented by the striated scoop-marks. The darkly shaded spot in fig. 6 was deeper than the rest, as if from a species of "pot-hole" action.

Most of the striated scoop-marks are not independent phenomena, like fig. 6, but evidently are appendages to adjacent knobs and projections of rock. The type of such cases is represented in fig. 7, which is a diagram of the plan of numerous specimens seen along the eastern shore from Killarney to Parry Sound, a distance of about one hundred miles. K is a boss or knob of rock projecting above the general glaciated surface in an oval form---in fact, a <u>roche moutonnee</u>. The specimen in fig. 7 is about four feet high, fifteen wide and thirty long; but all sizes and irregular forms are common. The observed specimens are mostly in gneiss.

FIGURE 5

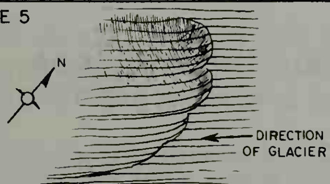


FIGURE 6

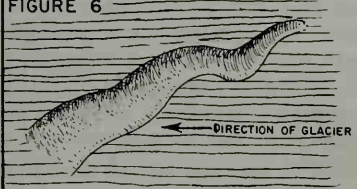
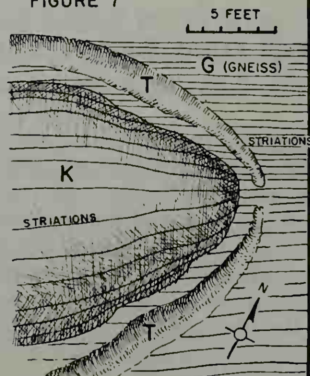


FIGURE 7



The horizontal lines in the diagram show the general direction of the striation in the locality---nearly west-southwest, as shown by the arrow. It will be seen that as the striae approach and rise upon the surface of the knob they are deflected to the right and left and sweep over it in an oblique course. This sort of curved deflection, partly over and partly around obstacles is common to the whole coast, so that in many places almost all the striae are curved by the influence of the knobby surfaces of the gneiss and quartzite.

TT are two unstriated scoop-marks having a length of about ten feet and a width of twelve inches. They begin vaguely near to each other, but not in contact, close to the northeast end of the knob, and rapidly deepen to six inches or more as they curve about its two sides, after which they grow wider and more shallow until they become lost in the general glaciation along the sides of the rocky buttress. There are no striae in these concavities and their inner borders do not touch the base of the knob but keep a foot or more away from it, leaving a narrow strip of level striated rock between the margins of the troughs and the eminence.

In a multitude of cases like this it is sufficiently clear that the resistance offered by knobs of rocks to the progress of the drift agencies in some way determined the presence and direction of these scoop-marks.

The great belt of fifty-two thousand islands, above referred to, varies from three to fifteen miles in width and is about two hundred and fifty miles long. Beginning at the St. Marie River it first outlines the north channel by the great Manitoulin group, and thence, passing southeast through Frazer Bay, continues along the whole east coast of Georgian Bay and terminates near Collingwood. Near the main land the islands are mostly metamorphic with a very distorted stratification, but a few of those on the lakeward border of the belt are of Silurian limestone with the strata dipping gently away from the nearest metamorphic hills.

This almost untrodden solitude, which has lain forgotten by the crowds of summer pleasure seekers, is well worthy of a visit by the lover of nature. The magnificent panoramas of the island-belt as viewed from the summits of the La Cloche and Killarney ranges are unique and in themselves well worth the journey to the region. Fortunately they are as yet almost unknown to sight-seers and still remain in their original freshness and silence.

GIANT GLACIAL GROOVES IN NORTHWEST CANADA

Smith, H. T. U.; *American Journal of Science,* 246:503-514, 1948.

Abstract. In the Mackenzie Valley area west of Great Bear Lake, the bedrock on many ridges and mountain slopes is furrowed by glacial grooves of unusually large size. Individual grooves range up to about 100 feet in depth and upwards of one mile in length. The grooves are approximately straight and parallel, and occur closely spaced in zones reflecting the influence both of the erodibility of bedrock and of topographic position. The trend of the grooves in the various zones is indifferent to structural axes and to drainage lines, and conforms to a systematic regional pattern which records the advance of an ice sheet west to and then northwest along the Mackenzie valley.

GIANT GLACIAL GROOVES AND THEIR SIGNIFICANCE IN THE JACKSON HOLE AREA, WYOMING

de la Montagne, John, and Love, J. D.; *Geological Society of America, Bulletin,* 68:1861, 1957.

Abstract. Piedmont lobes of pre-Wisconsin(?) Buffalo ice flowed southward and westward into Jackson Hole. Giant grooves cut into bedrock along channelways, as far south as Snake River Canyon, indicate extent of ice and direction of movement. A real study of grooves and associated features shows:

(1) Ice covered more than 1300 square miles in Jackson Hole and was 2500 feet thick in places.

(2) Some grooves extend beneath the alluvium-covered floor of Jackson Hole, thus indicating little or no erosion in broad valley areas after this glacial stage.

(3) Grooves were cut in hard and soft bedrock ranging in age from Precambrian to Pliocene.

(4) Orientation of grooves is not necessarily related to bedrock structure.

(5) Grooves range in size from minor fluting to U-shaped valleys 400 feet deep and 1500 feet wide.

(6) Longitudinally median points are commonly higher than ends of grooves, indicating they could not be stream channels.

(7) Thin deposits of Buffalo till veneer most grooves; ends of those grooves extending across Flat Creek are buried by a moraine of Bull Lake (?) age.

(8) Difference in elevation between highest and lowest grooves 2 miles apart along the Gros Ventre River is 2000 feet.

(9) Groove swarms occur where principal channelway narrowed, and where ice impinged against moderately sloping valley sides; swarms are not necessarily localized in lee of sources of rock that could have served as abrasive tool.

(10) Most extensive ice sources were Yellowstone Park, Absaroka, and Wind River mountains.

PLEISTOCENE GLACIATION IN THE BLUE RIDGE PROVINCE, ...

Berkland, James O., and Raymond, Loren, A.; *Science*, 181:651-653, 1973.

Abstract. Glacial polish, grooves, and striations discovered at an elevation of 1370 meters in the headwaters of Boone Fork on Grandfather Mountain, North Carolina, indicate the former existence of alpine glaciation at a latitude of 36°07'N. The Boone Fork glacier was located 890 kilometers south of the previously recognized southern limit of alpine glaciation in the Appalachian Mountains, and 350 kilometers southeast of the nearest point on the Laurentide ice sheet. This find has significant implications for studies of Pleistocene geomorphology, paleobiology, and paleoclimatology in the eastern United States.

NORTHWARD MOVING ICE IN THE THETFORD MINES AREA.....

Lamarche, Robert V.; *American Journal of Science,* 271:383-388, 1971.

Abstract. Evidence of northward moving ice in the Thetford Mines area of southern Quebec is based exclusively on crag-and-tail glacial striations measured on horizontal or sub-horizontal bedrock surfaces. The northward movement of glacier ice proposed herein is thought to represent a somewhat local deviation in late-glacial time from the more regional southeastward ice direction as the ice sheet thinned due to melting.

• Peculiarities of Eskers

THE ASAR OR OSAR OF SCANDANAVIA AND FINLAND

Howorth, Henry H.; *Geological Magazine,* 35:195-206, 1898.

The asar are such a notable feature in the landscape of Sweden that it is not surprising they should have been observed and their peculiarities described at an early period. Their main features were, in fact, pointed out by Swedenborg at the beginning of the last century, and have been enlarged upon by every succeeding explorer. The Swedish geologists divide the asar into two classes---the asar properly so called, built up of masses of rolled stones, and the sand-asar, composed chiefly of sand. While it is easy to find specimens of each of these, it is also very easy to find others where masses of rolled stones and beds of sand or of tough clay or brick-earth pass into each other very much as they do in the Cromer cliffs. A good example is the fine as upon which Upsala is built, and in which we can study the internal structure admirably, since it has been recently excavated right through. There we can see in the course of a few yards the passage from a mass of rounded boulders into sand. The sand in some places is almost continuous, and in others has banks of clay intercalated in it. The contour of the asar, as Swedenborg long ago pointed out, differs with the nature of their contents, the stony asar having steep sides, while the sandy ones have much rounder outlines. The stones which form such a great part of the asar (except certain specimens occurring in their upper parts) are invariably rounded and waterworn, and would be well described by the phrase applied to some of the Eastern Anglian gravels, viz. "cannon-shot gravel." The asar are found in all parts of Sweden from Scania to Norland, and in Finland and Northern Russia they form, as is well known, huge banks and ramparts. In some cases they run with great uniformity in shape and breadth for long distances, their direction being wonderfully continuous. So uniform are they that, as Brongniart pointed out, the roads in some places, as from Upsala to

Wendel, from Enkoping to Nora, from Hubbo to Moklinta, etc., run along their crest. Sometimes they spread and widen out a little, forming nodes like so many knots on a cord. Frequently the continuous line is interrupted by a gap or a series of gaps, so that instead of a uniform bank there are a number of huge circular or oval mounds. They consist generally of a main trunk, with a number of small subsidiary lateral branches running into them like the affluents of a river, and sometimes they have satellites attached to them in the shape of eskers and kame-like mounds. They are as sharply marked off from the adjoining plain on either side as a railway embankment is. In some cases, notably in Finland, they do not run in parallel lines, but vary in direction, sometimes even crossing each other, but in Sweden their direction is singularly parallel, as may be seen from the admirable maps published by the Swedish geologists, notably that by Tornebohm. The enormous size and cubical contents of these gigantic mounds can only be appreciated by those who have seen them on the spot and followed them for miles.

According to Erdmann, the well-known Upsala as, which runs from the mouth of the Dalelf to Sodertom, south of Stockholm, is about 200 kilometres long. The as of Koping, as far as it is at present traced, from Nykoping to the Dalelf, is about 240 kilometres in length. The as of Enkoping runs from near Trosa in Sudermannia to Loos in Helsingland, and is from 300 to 340 kilometres long, while the as of Badelunda, running from Nykoping in Sudermannia to the parish of Rattvik in Dalecarlia, is about 300 kilometres long. According to Erdmann, the asar west of the watershed between Lake Wenern and Lake Wettern run N. N. E.-S. S. W., while east of that line they run from N. N. W. to S. S. E.

Erdmann also gives the elevation at which some of the principal asar have been traced. "In Jemteland, N. and N. W. of Storojo, to 1,000 or 1,200 feet; in Herjeadal, near Hede, to 1,300 or 1,400 feet; in Dalecarlia, in the parishes of Malung and Idre, to between 1,000 and 1,300 feet; in the government of Elfsborg, in Vestrogothland and east of Ulricehamm, to 1,100 feet; at Jonkoping, in Smaland, near to Lake Almesakra, to about 1,000 feet; but Tornebohm informed Mr. Geikie that in the northern parts of the country they occur at an elevation of 2,000 feet." Their height varies, the average being about 50 or 100 feet high, but in many places they run up to 100 metres or more, while they sometimes sink to 20 or 30 feet. Their breadth, too, varies, the normal breadth being from 30 to 50 paces, but in some cases, as at Upsala, where there is a spreading node, their breadth runs to 200 or 250 yards. From these facts the cubical contents of the asar may be guessed. They are often somewhat wider and higher at their northern end, that is, at their inception, than further on. In the low flat country their contour is very uniform, but in the upper and more hilly districts, where they chiefly abound, they have a tendency to become broken up into strings of separate mounds and kame-like masses. Their materials, in so far as they consist of boulders, have in every case where they have travelled, and we can trace the mother rock _in situ_, moved from north to south, and were never in the reverse direction.

One of their most important features, and one which has been a great deal too little noticed in the various theories which have been forthcoming to explain them, is the fact that they traverse the country quite irrespective of its contour, going uphill and downhill, and athwart the natural drainage. On this point I will quote the language of a first-rate authority, Erdmann. After saying that they sometimes run along the valleys, sometimes on the mountain flanks, and sometimes on the plateaux, he adds (in italics) the words: "C'est ainsi qu'elles continuent leur cours lointain, franchissant les plateaux, les vallees, et les plaines, et ne semblant en aucune maniere s'inquieter des reliefs divers actuels du pays." ("Expose," etc., p. 41.) This is a conclusion drawn from the Swedish asar. The Finnish ones are quite as remarkable, traversing lakes and watersheds without any hesitation.

As I have said, a large portion of the asar consist of masses of rounded stones of various sizes up to 2 feet in diameter. These rounded stones are not mixed with angular erratics. The latter, when they occur, do so in the upper and more sandy and loamy layers, or scattered over the asar's backs, nor, so far as I could observe, do they contain stones of exceptional size. These, again, chiefly occur in the sandy beds or on the banks of the asar. Their contents are not sorted according to their size, but the stones generally lie with their longer axes parallel to the direction of the as in which they are found. The beds of sand and the sandy asar are in nearly all cases more or less stratified. They are frequently false-bedded, and the beds which show the false-bedding have their lines very pronounced, the angular wedges of sand and the lenticular masses being on a large scale and very marked. The uppermost layers of the asar often consist of stiff blue clay or of finely sifted and laminated brickearths, containing in places numbers of diatoms and marine shells, but never, so far as I know, fresh-water debris or land molluscs. These beds of brick-earth and clay occur only at the top of the asar, where they are often intercalated with sand beds very irregularly disposed, just as they are in the beds of contorted drifts in the Cromer cliffs, and they are generally continuous with the mantle of similar loam that covers the intervening country. I cannot follow Erdmann and Geikie in separating these superficial layers in the asar from the beds below. So far as I can judge (and here, again, the present condition of the cutting at Upsala is very pregnant with meaning), they pass continuously down into them, and are merely later phases of one deposit, just like the similar phases we see in the drift beds of East Anglia. Lyell, Murchison, and others, who examined the asar with care and skill, and whose judgment was in this case unwarped by a priori theories of the origin of the asar, treated the superficial beds containing marine shells as belonging to the same period as the lower beds, which are barren and consist largely of boulders. (pp. 198-200)

• Drumlins and Kindred Formations

THE ORIGIN OF DRUMLINS

Gravenor, Conrad P.; *American Journal of Science,* 251:674-681, 1953.

Introduction. Although several theories have been advanced to account for drumlin formation, there is still difference of opinion on their origin.

Essentially there are two ideas: first, drumlins are formed by the erosion of pre-existing drift; second, they are depositional in origin. Recently the latter theory has gained much favor even though it does not explain fully drumlins of extreme composition. The depositional theory has been applied to only those drumlins which are made up almost entirely of till, and the erosional theory is left to explain those drumlins which clearly have been formed from pre-existing drift or rock.

The purpose of this paper is to review briefly some of the better-known theories and to sum up the facts known about drumlins. It is considered that a modification of the erosional theory best fits the known facts.

Depositional Theory. In general the depositional theory states that drumlins are formed by the progressive deposition of drift. However, there is a lack of agreement on the factors that determine the start of accumulation. Russell suggested that since ice under pressure behaves as a plastic solid the introduction of debris into this plastic mass will decrease the rate of flow. At certain points excessive amounts of debris stop ice flowage, and hence nuclei are formed. Ice, containing smaller amounts of debris, which passes over these nuclei will deposit material and form drumlins. An examination of the excellent drumlin sections on the south shore of Lake Ontario led Slater to believe that in this case a till core initiated the drumlin accumulation. Chamberlin found that some drumlins have rock cores and from this intimates that a deeply hidden rock boss is usually and perhaps universally the determining cause of the accumulation. Crosby concluded that some of the drumlins in the Boston basin area have rock cores. From a study of the drumlins of central British Columbia Armstrong inferred that the nuclei were knobs of frozen till and the drumlins were built up from these knobs. Alden found that few of the drumlins of Wisconsin have rock cores and consequently suggested that the radial spreading of ice developed transverse stresses which, although not actually creating longitudinal crevasses, may have induced localized piles or ridges of drift which were later shaped into drumlins.

The concentric layering of material found in a few drumlins has led many geologists to believe that drumlins have been built up by successive additions of clayey till. Fairchild suggested that "the accretion was because of the greater friction between clay and clay than between clay and ice."

The theories of Millis and Upham differ from the accretion theory, but fall into the depositional class. Millis suggested that material accumulated in crevasses which were enlarged by melting. Then as the remaining ice melted, drumlins were left. Upham believed that as the ice melted by ablation, englacial drift would appear at the surface in depression areas. When the ice "re-livened," this superglacial material again would become englacial as a stratum of drift. This englacial drift would be shaped into lenticular masses by ice movement and then let down either as a completed drumlin or as an accumulation point.

Erosional Theory. From an examination of the materials which form drumlins it is evident that many of them were formed from materials which were present prior to the ice advance. This has led to the belief that all drumlins were formed by erosion. Shaler thought that the drumlins of New England were formed by two glaciations. The first glaciation provided an irregular till surface and the second scoured this surface leaving the drumlins. Tarr found that rock drumlins and till drumlins have the same shape, and consequently he concluded that the same erosive process produced both types.

Objections to the Depositional Theory. Although drumlins with cores of bedrock or pre-existing drift are found, more often a central core is absent. While this fact demonstrates that for a drumlin to accumulate no pre-existing core is necessary, it does not disprove the depositional theory. Contrary to Alden's theory, Hollingworth found that drumlins were formed in regions where there was no radial spreading of the ice.

The presence of stratified materials in drumlins constitutes a more serious objection to the depositional hypothesis. Drumlins containing stratified materials have been recorded in most drumlin fields both in North America and Europe. Although drumlins containing stratified materials have been described by many geologists, for the most part their origin has been ignored. Deane suggested that stratified materials in drumlins indicate a readvance of the ice after each layer of stratified material was deposited. Tarr pointed out that flowing water could not exist under the great thickness of ice necessary to form drumlins. It seems reasonable that deep within an active glacier any openings which would give access to meltwater would be closed by plastic flow. If eskers and associated deposits are evidence of stagnation, then the time when meltwaters are flowing at the base of the ice is not the time of drumlin formation.

Although it has been suggested by Fairchild that accretion takes place because of the greater friction between clay and clay than between clay and ice, the writer has been unable to find quantitative data which would substantiate this conclusion. Many drumlins have been described which contain little or no clay. The drumlins of northern Saskatchewan, described by Sproule, are made up largely of sand. Mechanical analyses made by Goldthwait of drumlin materials in New Hampshire show that the drumlins of that region contain an average of about 10 per cent clay and in one case the clay content was as low as 5 per cent. In southern Ontario, Chapman has found that the drumlins are more numerous in loamy till than in clay till. Mechanical analyses of drumlin materials of southern Ontario give an average of about 12 per cent clay. Indeed most published analyses indicate that drumlins are sand-rich rather than clay-rich. In the states of Indiana and Illinois, where the tills generally contain more clay than those of southern Ontario and New England, no drumlins are found. Therefore it appears that clay is not necessary for drumlin formation.

Concentric banding, found in some drumlins, has been an important factor in the formulation of the depositional theory. However, it seems that this concentric banding is a rarity. Fairchild thought that the banding in the drumlins on the south shore of Lake Ontario was evidence of accretion, but Slater found that these bands consist largely of stratified materials. In many areas where the internal structure of drumlins has been investigated banding is absent. Alden suggested that a definite cleavage found in certain drumlins in Wisconsin could be accounted for either by accretion or by pressure effects.

The alignment of drumlins and their streamlined shape seems sufficient to discount the theory proposed by Millis. Tarr has objected to Upham's theory on the grounds that no evidence of shearing is found in drumlins. Another objection is the presence of so much englacial material in an ice sheet.

Objections to the Erosional Theory. Objections to this theory have been outlined by Thwaites, but certain of these objections do not appear valid. Thwaites suggested that drumlins of the erosional type should be shaped like roches moutonnees; yet it is well known that drumlins formed from pre-existing materials have the same shape as till drumlins. Other objections advanced by Thwaites include the following:

(1) The stratified materials found in drumlins is unlike that found in kames.

(2) The width of drumlin belts (10-20 miles) exceeds that of most moraines.

(3) The drift in drumlins is apparently the same age as the surrounding drift.

While the second objection holds for most moraines of the Mississippi basin area it is not true of the wide morainic belts found over much of western Canada. The third objection is perhaps the most valid since in many areas where there are till drumlins there is no evidence of readvance of the ice.

Modified Erosion Theory. It is known that rock drumlins and drumlins carved from pre-existing materials are found in the same drumlin fields as those made of till. Consequently it is reasonable to suppose that all these drumlins were formed at the same time and by the same process. During the past 80 years many facts have been learned about drumlins and any one theory should satisfy the following conditions:

(1) Drumlins may consist of (a) clay till, (b) sandy or loamy till, (c) rock, (d) pre-existing drift.

(2) They frequently have lenses and layers of stratified materials which sometimes are faulted and folded.

(3) Rock drumlins are found side by side with other varieties and have the same shape.

(4) Many glaciated regions do not support drumlins.

(5) They exist in fields wider than most moraines and rarely occur singly.

(6) They have a streamlined shape with the stoss end usually pointing upstream.

(7) Lamination may or may not be present.

(8) Some drumlins have cores but most do not.

(9) They are found behind terminal moraines which mark approximately the outer limit of the ice advance.

(10) Their long axes parallel the direction of ice movement.

Generally it is agreed that drumlins are formed under actively flowing ice and their form is one which offers the least resistance to ice movement. This assumption seems valid since it accounts for the position of the drumlins with respect to moraines, their alignment and streamlined shape.

The usual interpretation of the erosional theory is that during a retreat of the ice moraines are formed which are shaped by a later advance. It is the writer's belief that this retreat is not necessary. Upon the retreat of an ice sheet moraines are formed which mark stationary positions of the ice. Is it not possible that during the advance of an ice sheet the rate of movement would vary? If this were the case there should be evidence of "moraines of advance." However, such surface irregularities would be shaped by the over-riding ice and would not be recognizable as moraines.

Where the ice advance is more rapid and the material distributed homogeneously throughout the ice a relatively flat till plain is formed. Chapman found that the flat till surfaces of southern Ontario are scored with shallow grooves or "flutings." These flutings may result from the same process as that which formed the drumlins.

The complete process of drumlin formation can be outlined as follows:

(1) Masses of till and stratified materials would be deposited at the front of an advancing glacier if there was a temporary halt during the ice advance.

(2) Ice riding over this drift would erode and shape it and thereby produce drumlins.

Debris derived from this erosion and shaping eventually could move to the front of the ice and be redeposited either as "moraine of advance" or as terminal moraine. It is known that the second part of this theory is feasible since drumlins of erosional origin are found. Consequently all that is needed is an irregular surface of till with or without stratified materials. It is believed that such a surface can be formed during an ice advance.

Obviously, one other prerequisite to drumlin formation is a supply of drift. Consequently drumlins form best in the softer materials, such as shales and limestones, which are removed readily by glacial erosion.

Objections to the previously outlined erosional and depositional theories can be explained by this modification of the erosional theory.

(1) The absence of drumlins from certain regions of clay till can be explained by a relatively rapid ice advance.

(2) The lamination found in a few drumlins could be the result of ice pressure. Any clay minerals which are present would have preferred orientation as a consequence of the applied pressure, and this would give rise to a rough fissility in the till.

(3) Meltwater action at the front of the advancing ice would give rise to stratified materials.

(4) Although Thwaites pointed out that drumlin belts are much wider than most moraines, it should be realized that the nature of retreat is quite different from that of advance. During a retreat, wide intermorainal areas, covered by eskers, superglacial till, and related deposits, are left by the downwasting process. An advance would not produce these ablation areas since wasting would take place mainly at the front of the ice, and wider morainic belts would result.

(5) Thwaites also stated that the stratified material found in drumlins is unlike that found in kames. It may be pointed out that the bedded material in drumlins is quite similar to the stratified material found in ground moraine. It is thought that the origin of the stratified material found in ground moraine is similar to that postulated for drumlins.

(6) Where drumlins have been found with cores it is possible that during a slow advance any pre-existing irregularities would have a layer of till deposited on top of the obstruction and thus present the type of surface necessary for drumlin formation.

Summary. Since some drumlins are made of pre-existing materials, it is known that erosion can produce a drumlin. It is believed that halts or a slow advance during the forward movement of a glacier can give rise to a wide irregular surface of drift which would be shaped into drumlins by the advancing ice.

This modification of the erosion theory is less intricate in its mechanics than those previously described. It avoids the necessity for two theories and offers adequate explanations for the known facts on drumlins.

The erosional theory is not acceptable in its present form because of the following objections:

(1) In many areas where there are till drumlins there is no evidence of readvance of the ice.

(2) Morainic belts usually are not as wide as drumlin fields.

(3) The stratified materials found in drumlins is unlike that found in kames.

The currently accepted depositional theory is untenable because of the following objections:

(1) Stratified materials found in drumlins could not have been deposited under a thick ice sheet.

(2) The accretion theory hinges on the idea that drumlins are clay-rich; however, descriptions and mechanical analyses show that many drumlins contain little or no clay.

(3) Many areas of clay-rich till do not support drumlins.

(4) The absence of nuclei and concentric banding from most drumlins.

NARROW LINEAR DRUMLINS NEAR VELVA, NORTH DAKOTA

Lemke, Richard W.; *American Journal of Science,* 256:270-283, 1958.

Abstract. Remarkably straight and narrow parallel ridges, which are interpreted to be an elongated type of drumlin, trend southeasterly across an area of ground moraine in the vicinity of Velva in north-central North Dakota. The drumlins are paralleled by shallow grooves in the intervening ground moraine; arcuate recessional washboard moraines lie transverse to them. The drumlins are commonly 1 to 3 miles long, 5 to 15 feet high, and have even crestlines. The longest, however, is 13-1/2 miles long and 15 to 30 feet high. The higher and wider drumlins consist mostly of stratified sand and incorporated bodies of till; those less than 5 feet high consist almost entirely of till. It is tentatively postulated that the drumlins were formed in part by glacial erosion of preexisting stratified deposits and in part by till deposition at the base of the ice. * Publication authorized by the Director, U.S. Geological Survey.

Introduction. Remarkably straight and narrow parallel ridges trend southeasterly across an area in north-central North Dakota. The purpose of this paper is to discuss the morphology and composition of these ridges, to present reasons why the writer believes that they are an elongated type of drumlin, and to discuss their origin.

The ridges trend southeastward across the Velva area of about 300 square miles in southern McHenry County. All are confined to the area south of the Souris River valley.

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Morphological Characteristics of the Linear Ridges. Most of the linear ridges are 1 to 3 miles long, 150 to 200 feet wide at their base, 5 to 15 feet high, steep-sided and sharp-crested. The average length to width ratio is about 60 to 1. They are only slightly asymmetrical in longitudinal profile (highest at their northwest ends) and are symmetrical in transverse profile. Those less than 5 feet high are scarcely discernible in the field. However, even the lowest ridges are plainly visible on aerial photographs where their crests show as light-gray lines. In cross section, the lowest ridges have gentle, sloping sides and tops whereas the higher ones are proportionately narrower and more conspicuous.

The longest and most conspicuous ridge extends southeast for a distance of 13-1/2 miles from the south valley wall of the Souris River at the town of Verendrye. It is breached in two places near Verendrye by gaps eroded by meltwater flowing down the Verendrye outwash channel and in one place by a small tunnel valley cut by a sub-glacial stream that formed an esker along one segment of its course. The ridge decreases in height from about 50 feet near its northwest terminus to less than 5 feet near its southeast end. Throughout much of its length it is about 30 feet high, is even and sharp crested, and has a remarkable symmetrical cross profile. It resembles nothing so much as a large railroad or highway grade. Its average base width is about 300 feet, which makes its length to width ratio about 240 to 1. At the southeast end of the ridge and slightly en echelon to it is a second ridge, about 3 miles long, which extends to a point about 1-1/2 miles southeast of Balfour.

The highest and widest ridge occupies the middle part of the head of Lake Hester outwash channel. It is about 60 feet high at its northwest end. Southeastward, it diminishes to about 30 feet in height in a distance of slightly less than one mile where it is breached by meltwater that flowed down the outwash channel. A fairly even-crested segment southeast of the breach is nearly 2 miles long. This linear ridge and several others are well shown on the shaded relief topographic map of the Voltaire 7-1/2-minute quadrangle.

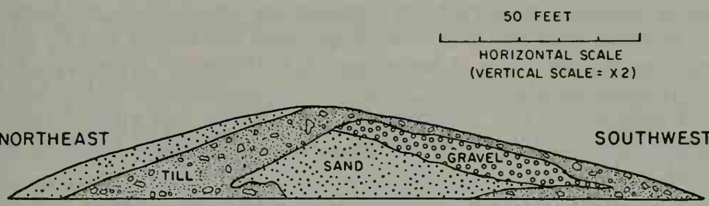
Most of the linear ridges trend about S. 50° E. A few bend slightly along their courses. An individual ridge commonly tapers to extinction along its southeast trend, but in many places another ridge is aligned with it or is parallel to it in en echelon fashion. As denoted by figure 2, the smaller linear ridges tend to occur in localized swarms in areas where the linear grooves are also most abundant. However, the larger ridges tend to be more isolated. (Fig. 2 omitted.)

Composition of the Linear Ridges. The larger ridges consist predominantly of stratified sand and incorporated irregular bodies of till. Till also commonly forms the flanks of the ridges and in some segments the upper 2 or 3 feet of their crests. The incorporated till bodies and the till forming the surface deposits range from compact till similar to the adjacent ground moraine to a predominantly sandy till that contains just enough clay to bind it. Some of the till has an indistinct fissility or platy structure.

Ridges less than 5 feet high consist chiefly of till. This till appears to be identical to the till composing the adjacent ground moraine.

The ridges probably vary considerably in composition and internal structure along different segments of their lengths. As shown in figure 4, the southeast side of a roadcut across a ridge near Balfour exposes a central body of fine gravel and a body of sand flanked and partly underlain by till. The northwest side of the roadcut, although poorly exposed, appears to consist almost entirely of sand. Numerous auger holes drilled in the larger ridges also indicate considerable variability in composition and structure.

No evidence has been noted that the ridges were deposited in the lee of bedrock knobs, boulders, or pre-existing masses of frozen till or blocks of ice or that they have bedrock cores. An auger hole drilled in the northwest end of the large ridge at the head of Lake Hester outwash channel shows that the bedrock surface is no higher under the ridge than under the surrounding terrain and that the composition is typical to that found through-



Cross section of a typical drumlin.

out the lengths of the other larger ridges. Similar stratigraphic relations are believed to exist for the other ridges except for one segment of a ridge in the southeast part of the Velva area where bedrock (considerably tilted and deformed) exposed in a roadcut forms the core of the ridge.

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• Boulder Fields

THE HICKORY RUN BOULDER FIELD.....

Smith, H. T. U.; *American Journal of Science*, 251:625-642, 1953.

Abstract. The Hickory Run boulder field is located in the Pocono Plateau region of northern Carbon County, northeastern Pennsylvania, along a valley flat near the headwaters of Hickory Run. It lies within an area mapped as Illinoian drift, just beyond the border of the Wisconsin drift. The boulder field is irregular in outline and roughly 400 by 1800 feet in extent. The surface of the field is a bare expanse of unsorted, loosely packed boulders up to 20 feet or more in length. Despite minor irregularities, the overall appearance of the field is one of striking flatness, and the surface gradient is close to 1°. The boulders are composed of quartzitic sandstone and conglomerate of local derivation. Many boulders show splitting, pitting, rounding, and discoloration by weathering in place. Scattered excavations show a complete absence of any finer interstitial material down to water level, at a depth of several feet. Bordering the boulder field are wooded slopes of moderate declivity, with scattered blocky patches and numerous blocks projecting through the forest floor.

The morphology and lithology of the boulder field, together with its present aspect of stagnation and decay, are best explained as resulting from periglacial climatic conditions during the near approach of the Wisconsin ice sheet, inferred to have effected a marked interruption of the stream erosion cycle, with frost action in a major role. The bouldery

material is believed to have been supplied by intensified mechanical weathering, to have been carried downslope onto the valley flat by accelerated mass movement, and then to have been left immobile when deglaciation brought climatic amelioration. Subsequent resumption of the normal processes of weathering and erosion now observable has worked toward gradual breakdown of the boulders in place and gradual flushing of interstitial soil material.

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Description of the Boulder Field and its Environs. The main section of the Hickory Run boulder field is a fish-shaped bouldery tract measuring roughly 400 by 1800 feet. Branching eastward from it is a subsidiary bouldery tract, the bare portion of which is separated from the main boulder field by a zone of boulders that are partly covered by vegetation.

The general surface of the boulder field is a barren expanse of jumbled cobbles and boulders of widely varied size and shape, so loosely packed that some of them shift in position when walked on. Irregular hollows and projecting boulders make for a very uneven surface, with a microrelief of about 4 feet. Despite the roughness in detail, however, the overall appearance of the boulder field is one of remarkable flatness, and the axial gradient, in fact, is close to 1^{o}. The bareness of the boulder field is striking. Except for a few trees near the margins, vegetation is virtually absent, and no soil is to be seen on or between the boulders.

Numerous individual boulders show rough surfaces, and many are pitted by weathering, particularly on the upper surface. Spalling and splitting along joint planes are common also. The color of the rock in the greater part of the boulder field is dull reddish, but mottling by dark-colored lichens is widespread. Some boulders when broken open are seen to be darker inside than on the surface, indicating discoloration by chemical weathering.

The boulder field is continuous from one side of the valley flat to the other. It has no surface drainage, at least in times of ordinary runoff. Locally the sound of running water under the boulders is audible, and in three widely separated pits water level was seen to be from 4 to 6 feet below the average surface of the field. Along the southern margin of the boulder field the ground is swampy in places. The possibility that the surface of the boulder field might be flooded at times of heavy rainfall was suggested by the presence of debris draped around tree trunks in the area immediately downvalley from the boulder field.

In traversing the boulder field, it is found that the surface characteristics and ease of walking are distinctly different in different sections. Toward the northeast, walking is particularly difficult. The surface is extremely uneven, footing is insecure, and many blocks sway when stepped on. Large, upended blocks and slabs are particularly common. The average size of the blocks or boulders is somewhat larger than in the western section, angularity of outline is more pronounced, and tabular form is more common. The tumultuous appearance of the surface suggests arrested motion after forcible movement, somewhat in the fashion of an ice jam in a river.

In the semidetached eastern section of the boulder field, blocks are much larger than in any other section. Many are 15 to 20 feet long, and some reach a maximum of about 25 feet. Bedding planes in the various blocks show dips that are erratic both in amount and in direction. Surface irregularity is extreme, with deep hollows and crevices between blocks, giving a microrelief of 6 to 8 feet. The observer must climb or jump rather than walk.

Lithologically also, the northeastern and eastern sections of the boulder field are different. In the eastern section quartzitic conglomerate is the common rock. In the northeastern section quartzitic sandstone is predominant, and the prevailing color is darker; conglomerate is rare, and where found it is generally much finer grained than in the eastern section.

Toward the west, on the main section of the boulder field, surface roughness decreases and the proportion of smaller boulders increases. Near the western end, the average size of the boulders is reduced to a few feet, and rounding is more noticeable. Walking is much easier here.

Subsurface characteristics of the boulder accumulation were observed at three well-separated places in pits excavated to water level, at depths of 4 to 6 feet. In two pits bottoms were seen to be sandy, and in the third bouldery. Above water level there is no interstitial material. The boulders are loosely packed and the proportion of open space is large. Boulders beneath the surface all show a conspicuous rusty-brown to black stain, and a few were incrusted completely with black mineral matter. In general, the boulders appeared to be of smaller average size below the surface than on the surface. Boulders below the surface also show less roughness than those on top.

The margins of the boulder field are irregular, with considerable interfingering of the bare area with the soil-covered area. At many places the transition is gradual. Locally near the east end of the boulder field, however, the break is sharp between the bare surface of the boulder field and the adjacent vegetation-covered flat. The flat, if projected outward, would cover all but the higher points of the larger boulders beyond. The bouldery area appears to be expanding by marginal sapping of the soil-covered zone, as suggested by several small bouldery patches from which stripping of the soil is working outward, probably through the action of subsurface waters.

Valley slopes bordering the boulder field are gradual at most places, although locally on the north side near the northeastern end the boulders pass up over slopes as steep as 23°. On the wooded slopes rising from the boulder field, numerous weather-beaten boulders project through the soil mantle, and small, open bouldery patches, surficially similar to the main boulder field, are widely though irregularly distributed. The general appearance is such as to suggest that, if the forest and the soil mantle were stripped off from the slopes, a bouldery surface similar to and continuous with that of the boulder field itself would be produced.

Upvalley from the boulder field, narrow, irregular, and discontinuous bouldery bands persist for several hundred feet. About half a mile east of the boulder field, at the head of the valley, there is a large, swampy flat bordered on the north side by rock ledges rising some 40 feet above the flat. These ledges are undergoing disintegration in place, and are mantled by loose blocks. There is no indication of active creep toward the valley, and no appreciable talus at the base of the steeper ledges. That the rate of separation and removal of the blocks is slow compared with the present rate of weathering is suggested by a joint block that has been much rounded by weathering while the gap between it and the once contiguous facing block has not opened more than about a foot under gravitational movement. Further breakdown of the rounded, detached block, in place, is evidenced by a comparatively recent fracture separating a sizable segment of the block from its parent by about an inch.

Downvalley from the boulder field is a tree-covered bouldery area with moss on the ground surface. Flowing water can be seen in scattered openings between the boulders. A definite stream emerges about half a mile below the boulder field.

Comparison with Other Areas. Talus and other types of bouldery accumulations are well known in mountainous areas of strong relief and steep slopes. Accumulations of similar material on low gradients in areas of moderate relief, however, are much less common. Of those that exist, probably only a small proportion have been described in geologic literature, as they easily escape notice in wooded terrane, and furthermore have been of little interest to many geologists. Comparisons are therefore limited to a relatively small number of described localities.

Ashley has noted four bouldery areas in eastern Pennsylvania, popularly known as Devil's Race Courses, and Peltier has given additional data on block fields in the same region. None of the occurrences described by these workers have the areal extent and low gradient of the Hickory Run boulder field.

Chadwick has reported a rock stream in New York, but he does not give sufficient detail to permit comparison.

In Maryland and adjoining parts of West Virginia, "rock streams" up to about 1800 feet in length and 100 feet in width are found. Although having the same surface appearance as the Hickory Run boulder field, they differ in being narrower and in having a steeper gradient and a smaller range in the size of the boulders.

In Wisconsin, in the Baraboo section of the Driftless Area, there are several boulder fields and rock streams, but all are smaller and steeper than at Hickory Run.

In northern Sweden, boulder fields more or less similar to the Hickory Run occurrence have been described by Hogbom. Various boulder accumulations in upland areas of central Europe have been described by many writers, but few if any of those occurrences are comparable to the Hickory Run occurrence in size and low gradient.

Undoubtedly the closest parallel to the Hickory Run boulder field is found in the "stone rivers" of the Falkland Islands, in the South Atlantic. These features, made known by the classic descriptions of Charles Darwin, Sir Wyville Thomson, and J. G. Andersson, indeed may be regarded as the type example for this type of landform. The streamlike accumulations of blocks and boulders ramify through entire valley systems, and are bordered by bouldery, soil-mantled slopes rising to the hill crests, interrupted in places by bouldery tracts barren of soil. Differences between the Falkland Island and Hickory Run occurrences are mainly those of size and extent.

In short, the Hickory Run boulder field is unusual, if not unique, among comparable accumulations of blocks and boulders on record in the United States by reason of its large extent and low gradient. It probably is matched by few of the described boulder fields of Europe, but it is dwarfed by comparison with the stone rivers of the Falkland Islands.

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Conclusions. The Hickory Run boulder field is an anomalous feature in terms of present-day processes in its locale. It is best explained as a relict or "fossil" phenomenon, dating back to a time when glaciation of adjoining territory was attended by more frigid climatic conditions. It is believed to represent a special, local facies of a more extensive rubble deposit, formed by accelerated mechanical weathering and mass movement related to intensified frost action, probably with perennially frozen subsoil. These processes were actuated with the advent of Wisconsin glaciation, and for a time were so vigorous as to interrupt the normal progress of stream erosion, mantling the slopes and choking the stream valley with debris too coarse for running water to move. When deglaciation brought climatic amelioration, frost action lost its effectiveness, and "normal" processes of weathering and erosion by running water returned, working now toward the very gradual reduction and removal of the rubble inherited from the preceding episode. As a first step, interstitial soil material was flushed from the bouldery accumulation along the valley bottom, producing the barren aspect now so striking.

The large size and low gradient of the boulder field, which make it an unusual example of its kind, are interpreted as due to proximity to the glacial border, making for maximum intensity of the periglacial processes.

PERIGLACIAL FROST WEDGING IN THE "ROCK CITIES". . . . .

Smith, H. T. U.; *Geological Society of America, Bulletin,* 64:1474, 1953.

Abstract. The "rock cities" near Olean and Salamanca, New York, consist of large blocks of massive conglomerate, ranging up to about 75 feet in length, separated by interconnecting passages along widened joint planes. The passages range up to several feet in width, and upwards of 10 feet in depth. Their walls are comparatively straight and approximately parallel, and follow a rectangular to angulate pattern. Adjoining the parent ledges, the blocks show no departure from bedrock either in dip or in level, but farther outward they display varying degrees of tilting and downward movement, grading into landslide masses. At present, the blocks appear to be immobile and undergoing gradual disintegration in place.

The enlargement of openings along joint planes without tilting or deleveling indicates a force acting only in a horizontal direction. Frost wedging is the one agency available to exert such a force to such a degree, and is believed to have pushed the blocks outward to the point at which gravitational forces introduced downward movement with accompanying disturbance. Conditions are no longer favorable for such processes, but must have been optimum during Wisconsin time, when the ice front at successive times lay near by to the north. The "rock cities" are thus interpreted as a hitherto unrecognized species of periglacial phenomena.

• Strange Inclusions and Involutions in the Drift

A PHENOMENON OF THE KANSAS DRIFT IN NEBRASKA

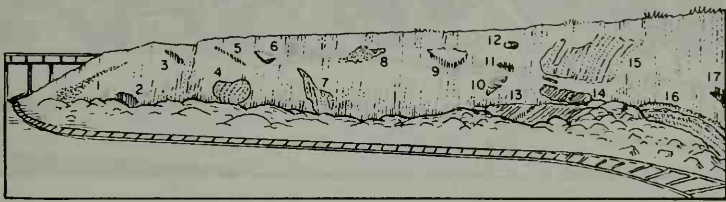
Barbour, Erwin H.; *Journal of Geology,* 22:807-810, 1914.

Among the minor phenomena of the glacial drift in Nebraska there is one which, though rarely observed by the public, is of interest and should be commended to the attention of naturalists. The reference here is to certain large, well-defined masses or blocks of such materials as sand, gravel, and coarse pebbles, which occur imbedded in the drift clays along with glacial bowlders, and which presumably have been similarly transported and deposited. These masses or blocks vary widely in color, texture, and kind. They also vary from the glacial matrix in which they are found and are the more striking by virtue of contrast. They are not of frequent occurrence, but may occasionally be seen in fresh exposures especially in deep railroad cuts. Unfortunately they are quickly effaced by weathering and by growing vegetation. The most notable examples are found in the Milford cut-off of the Burlington Railroad, particularly at Pleasantdale. For a mile or so west of the station at Pleasantdale, especially on the right bank, fine examples occur in almost continuous succession.

The drift at this place is a jointed sandy clay of a rusty gray color, of a fairly compact texture, and about twenty-five feet in thickness. It is somewhat startling to find in it great stray blocks of various materials. These blocks are generally large and angular or rounded masses of incoherent soil, sand, and gravel, more or less stratified, cross-bedded, and tipped at all angles. It is still more surprising to find sections of small stream beds and channel deposits tilted and overturned. The dense quartzitic and occasional granitic bowlders characteristic of the Nebraska drift, and these incoherent sand and gravel blocks occur together. Perhaps the arenaceous and argillaceous blocks were likewise dense and coherent at the time of transportation and deposition, the assumption being that they were rigid because frigid. Accordingly we have coined for them, and for a long time have used as a convenient generic field name, the word "frigites," and have used as specific terms the additional names "soilfrigites," "clayfrigites," "sandfrigites," "gravelfrigites," "couleefrigites," etc., according to the component materials. Perhaps, as has been suggested, these are Aftonian.

Incident to the protracted frigidity of a glacial period is the freezing of soils, sands, and gravel to the rigidity of rock (frigite). Any natural force which could rend and transport rock could rend and transport the rocklike soils and sands. Continental glaciers are powerful graders and levelers. They act resistlessly upon rock and frozen soils and sands, breaking them into blocks and transporting them long distances southward. The load of rocks and frozen blocks is finally dropped by the melting ice, and buried in glacial mud. The blocks are thus preserved in their integrity. A stream bed, or coulee, could in a like manner be frozen, subsequently broken into sections, transported, and deposited.

The term "glacial drift" as used in an unfortunately restricted and local sense in Nebraska refers to that particular portion of the Kansan drift, which is rendered conspicuous by coarse pebbles and bowlders of reddish Sioux quartzite. This layer is pretty generally recognized, and though it may be but a foot or two in thickness it is often expedient to speak of it popularly as "the drift." In a broader sense, however, our



Bank of Kansan drift at Pleasantdale, Nebraska. (1, 3, 4, 8, 10, 11, 13, 14, 17) sandfrigites; (12) large, cross-bedded sandfrigite about 30 feet long; (15) sandfrigite about 30 feet long; (2, 5, 9, 16) couleefrigites. Section about 1,000 feet long.

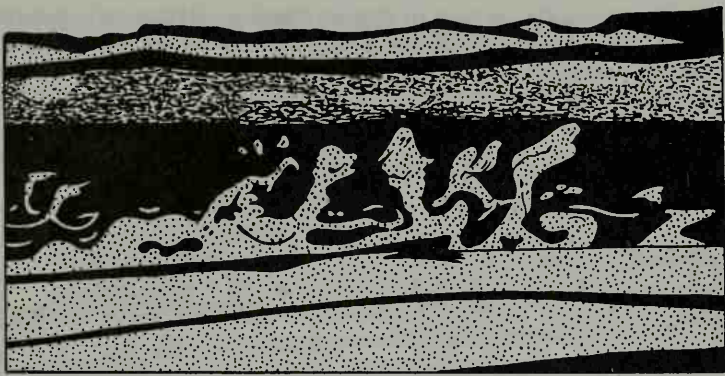
drift also includes, though less obviously, extensive beds of glacial clay, generally spoken of as joint clay, which may reach fifty feet in thickness. It has long been said facetiously by eastern geologists that the glacial deposits of Nebraska are "buttered on so thin that one cannot tell the buttered side." It is probable, however, that this bit of good humor would never have become classic had our drift not been confounded with our loess. There may be recognized an older, bottom layer of a dark, or even black color (sub-Aftonian, Jerseyan, or Nebraskan), and a younger, top layer of a lighter color, generally of a yellowish or reddish cast (Kansan), neglecting any Aftonian sands and gravels. The frigites herein described are confined to the Kansan drift.

It so happens that the drift often resembles the loess so closely that they run together, and seem to be terms in the same series. At times it puzzles even those who are experienced to distinguish between them. The southeastern half of Nebraska has for convenience been generally figured as one continuous loess sheet.

PHYSICAL EFFECTS OF PLEISTOCENE CLIMATIC CHANGES IN NON-GLACIATED AREAS

Smith, H. T. U.; *Geological Society of America, Bulletin,* 60:1485-1515, 1949.

Involutions in unconsolidated sediments. Highly irregular, aimlessly contorted, interpenetrating structures (Fig. 4) in Pleistocene sediments have been variously referred to as "involutions," "cryoturbations," "wurgeboden," "taschenboden," and "brodelboden." Structures of this type have been described from Germany (Keilhack, 1927; Bahr, 1932;



Involutions in Pleistocene sediments.

Steeger, 1944), Denmark (Norvang, 1946), Holland (Edelman et al, 1936), and from this country (Denny, 1936; Sharp, 1942a). These structures are found in flat-lying sediments and are characterized by random orientation and lack of lateral continuity, in ground plan; no progressive movement is involved in their formation. They are thus distinguished from the drag structures produced by solifluction and from drag and flowage structures produced by other processes not related to frost action (Shrock, 1948, 156-160, 258-280).

Sharp gave detailed descriptions of involutions and discussed the question of origin at some length. He concluded that the involutions were formed by intense differential freezing and thawing, together with the growth and melting of bodies of ground ice. Norvang, in discussing more or less similar features, postulated buried soil polygons (described below). Since these features have no definite surface expression insofar as known, no direct evidence as to their origin has been observed in arctic regions. It is generally agreed, however, that they could have been formed only in association with perennially frozen ground, and thus provide good evidence of former frigid periglacial conditions. Poser (1947a) used these features as one criterion in reconstructing periglacial climate in Europe during the last glacial stage. (p. 1501)

• Unglaciated Areas

UNGLACIATED ENCLAVES IN GLACIATED REGIONS

B., L. C. W.; *Geographical Journal,* 114:232-233, 1949.

To Irish Geography (Vol. II, no. 1, 1949) Professor D. L. Linton contributes an illuminating article on nunatak and other unglaciated surfaces in the glaciated parts of this country and Scandinavia. The study exemplifies the great care which must be taken in the light of modern knowledge before drawing inferences concerning the past history of rocks with respect to ice-action, and the importance of considering British glaciological problems in relation to those in a neighbouring land of higher relief like Scandinavia. The article is really a sequel to a paper by Dr. Farrington on "Unglaciated areas in Southern Ireland" (Irish Geography, 1947) in which he points out the absence of drifts and transported boulders in a number of upland tracts stretching across the country from Dingle Bay to Dungarvan Bay. Dr. Farrington's conclusions are based only on negative evidence, whereas Professor Linton reviews the positive evidence for unglaciated surfaces in different parts of Northern Europe. In the first edition of James Geikie's 'Great Ice Age' (1874), reference is made to unglaciated enclaves in the Southern Pennines, but the most important work on this subject has been done in Norway. There the unglaciated features comprise, in addition to the higher mountain nunataks of the peninsula, a number of plateau remnants of various sizes in the Lofoten Islands and in Finnmark ranging from about 500 feet to 3000 feet in altitude. Some of these plateau surfaces which, however, harbour corries due to local glaciers, are demonstrated to be of pre-glacial origin. Ahlmann is quoted as referring to them as "parts of a mountain topography advanced to old age" and Undaas as insisting that an eroding ice-sheet is selective in action, leaving behind a broken terrain, and could never have shaped the smooth flowing outlines of these peneplane-like forms. The latter moreover have not only the outlines resulting from normal erosion, but are actually covered by the products thereof. It is concluded that "long flowing outlines," whether in Norway, Scotland or Ireland, are essentially of pre-glacial origin and that care must be exercised not to confuse this kind of landscape with such rounded or smooth contours as may actually be due to ice-sculpture.

Professor Linton adds an original contribution of his own, based on many years' work in the Scottish Highlands, relating especially to the significance of the tors in North-East Scotland which could hardly have survived the passage across them of a sheet of moving ice. The classic ground of tors in the British Isles is of course Dartmoor, which is known to have lain outside the British ice-sheet, though there is some evidence that this Devonshire highland underwent local glaciation, as would indeed be inferred on purely climatic grounds. The tors which crown some of the high Cairngorm summits resemble those of Dartmoor in showing the effects of deep weathering, but differ in being masked by the forms produced by local glaciation. Unlike the Western Highlands which were submerged beneath an ice-sheet, the eastern Grampians exhibit only localized ice-action---in the corries, troughs and certain valleys. If ice did pass over the eastern mountains its effects must have been depositional rather than erosive. The significance of the Cairngorm tors is strengthened by the occurrence of similar "tower-form erosion remnants" (to quote Nordhagen) in Norway, and of "pillars" in those parts of the Ural mountains which according to the 'Great Soviet Atlas' escaped glaciation. Professor Linton observes that though the best-known examples of tors are built of granite they are by no means confined to that rock or even to the acid intrusives. The writer of this note was certainly struck by the fact that the dark micaschists which form the impressively jagged coast between Bolt Head and Bolt Tail in South Devon have weathered into shapes on the cliff plateau very much resembling in general appearance, if not in structural detail, the granite tors of Dartmoor itself.

THE DRIFTLESS AREA OF THE UPPER MISSISSIPPI

Anonymous; *Science,* 10:306-307, 1887.

Book Review. The Driftless Area of the Upper Mississippi. By T. C. Chamberlin and R. D. Salisbury. (A monograph accompanying the Sixth Annual Report of the Director of the United States Geological Survey.) Washington, Government.

In no direction is the Geological Survey advancing the science more rapidly than in the department of glaciology. The monograph on the great terminal moraine has done more than any other single research to make the continental ice-cap a reality, and to silence the iceberg theory of the drift; and the present contribution is scarcely less valuable or wide-reaching in its conclusions.

In the midst of the great mantle of drift that overspreads the Upper Mississippi basin, there lies a drift-barren tract of about ten thousand square miles,---the driftless area of Wisconsin and adjoining States. This island in the sea of drift is unique; and, strongely enough, the margin of the drift on almost every hand lies on a slope descending toward the driftless area. Probably no other district on the globe is so favorably situated to serve as a standard of comparison and contrast between glaciated and unglaciated areas, and a means of estimating the results of the drift agencies. All of the formations of that region, with their attendant topographies, sweep curvingly across the driftless area from an ice-ridden region on the one hand, to a like ice-ridden region on the other, displaying in a most striking manner the contrasts that arose from the single factor of glaciation. The driftless region is especially instructive concerning glacial extension and restriction, and it throws important light upon the movements of the ice-sheet over a very large adjacent territory. The great drift-burdened ice-stream, as it moved south-westward from the Canadian heights, was divided and diverted; and the separated currents swept around the area, and mingled their burdens below it.

The facts bearing upon these and many minor aspects of the driftless area are marshalled and discussed in a masterly manner, the more important features being also clearly exhibited in a series of well-executed maps and cuts. Among the subordinate contrasts which this region presents, none are more noticeable than the absence of falls in the driftless area, and their comparative abundance beyond its limits,---falls indicating a youthful, and usually a post-glacial, topography. And certainly there could be no more convincing evidence that the region has never been invaded by glaciers than is to be found in the fragile pinnacles of rock which abound over a large part of its surface.

The residuary earths of the driftless area are compared physically, microscopically, and chemically with the glacial clay or till. Nearly one million measurements of the ultimate particles show that the residuary earths are much finer grained and more homogeneous than the drift clay; and they are also remarkably free from calcareous matter, which forms a large proportion of all the true drift of that region.

In its remarkably sinuous course across the continent, the great terminal moraine impinges upon the eastern side of the driftless area, and affords specially fine contrasts between the characteristics of driftless and drift-bearing regions; while upon the west it is bordered by the loess; and the much-disputed question as to the origin of this interesting formation is settled provisionally in favor of its being essentially an aqueous or lacustrine deposit of glacial clays.

In the concluding chapter, on the history and genesis of the driftless area, it is shown more clearly that the marginal phenomena confirm Professor Chamberlin's previously published classification of the quaternary epochs. He recognizes (1) an earlier glacial epoch, in which two successive ice-sheets were separated by an interglacial period sufficiently marked to permit the growth of vegetation over the surface; (2) a prolonged interglacial epoch, during which the land was elevated to the extent of eight hundred to one thousand feet, and again forest-clad; (3) a later glacial epoch, during which the great terminal moraine was formed, while subordinate moraines and vegetable deposits testify to repeated recessions and advances of the ice; (4) the Champlain epoch, during which marine and lacustrine deposits were formed; (5) the terrace epoch, when the streams carved the flood-plains of the Champlain epoch into terraces.

The origin of the driftless area is found in the fact that the elevated land lying north-east of it must have acted as a wedge to divide the ice, while the diverging troughs of Lake Superior and Lake Michigan tended to prevent the streams from re-uniting immediately south of the obstruction. Climatic influences also probably played an important part in staying the progress of the ice which was advancing directly toward the driftless area. In the language of the authors, diverted by highlands, led away by valleys, consumed by wastage where weak, self-perpetuated where where strong, the fingers of the mer de glace closed around the ancient Jardin of the Upper Mississippi valley, but failed to close upon it.

"DRIFTLESS AREA" OF WISCONSIN WAS GLACIATED

Black, Robert F.; *Geological Society of America, Bulletin,* 71:1827, 1960.

Abstract. Isolated deposits explainable only by glaciation are on crests of the highest ridges in all but La Crosse County in the classical "Driftless

area" of southwest Wisconsin.

Fresh gravel of foreign rocks, such as granite, gabbro, and basalt, is beneath thick loess in southeast Grant County. The gravel was probably deposited by meltwaters from a late Altonian ice advance (Wisconsinan stage) of about 30,000 years ago. A Carbon-14 date of 24,600 ± 11000 years B. P. (GRO-2114, courtesy of M. T. Beatty, Francis D. Hole, and Gerhard Lee) on buried soil at the base of the loess nearby implies that loess did not start accumulating until the Farmdalian substage. Coarse sand and gravel of well-rounded to angular quartz, chert, jasper, and siliceous metamorphic rocks are in kamelike deposits in many places. Well-rounded pebbles of those materials are in present soils and are intimately mixed with large angular blocks of sandstone and dolomite, with irregular masses of chert, and with clay, silt, and sand in till-like deposits many feet thick. Angular blocks of St. Peter sandstone weighing several tons are on top of Platteville limestone, which is stratigraphically above the St. Peter.

Locally contorted bedrock, absence of thick residual soils and of weathering in the deposits, and absence of old loess further confirm glaciation of much, if not all, the Driftless area during the early Wisconsinan stage or all of it during a pre-Wisconsinan stage.

NO DRIFT IN SIBERIA

Donnelly, Ignatius; *Ragnarok: The Age of Fire and Gravel,* University Books, New York, 1970. (Originally published 1883)

But let us look at another point:

If the vast deposits of sand, gravel, clay, and bowlders, which are found in Europe and America, were placed there by a great continental ice-sheet, reaching down from the north pole to latitude 35° or 40°; if it was the ice that tore and scraped up the face of the rocks and rolled the stones and striated them, and left them in great sheets and heaps all over the land---then it follows, as a matter of course, that in all the regions equally near the pole, and equally cold in climate, the ice must have formed a similar sheet, and in like manner have torn up the rocks and ground them into gravel and clay. This conclusion is irresistible. If the cold of the north caused the ice, and the ice caused the Drift, then in all the cold north-lands there must have been ice, and consequently there ought to have been Drift. If we can find, therefore, any extensive cold region of the earth where the Drift is not, then we can not escape the conclusion that the cold and the ice did not make the Drift.

Let us see: One of the coldest regions of the earth is Siberia. It is a vast tract reaching to the Arctic Circle; it is the north part of the Continent of Asia; it is intersected by great mountain-ranges. Here, if anywhere, we should find the Drift; here, if anywhere, was the ice-field, "the sea of ice." It is more elevated and more mountainous than the interior of North America where the drift-deposits are extensive; it is nearer the pole than New York and Illinois, covered as these are with hundreds of feet of <u>debris</u>, and yet <u>there is no Drift in Siberia</u>!

I quote from a high authority, and a firm believer in the theory that glaciers or ice-sheets caused the drift; James Geikie says:

"It is remarkable that nowhere <u>in the great plains of Siberia do any</u>

traces of glacial action appear to have been observed. If cones and mounds of gravel and great erratics like those that sprinkle so wide an area in Northern America and Northern Europe had occurred, they would hardly have failed to arrest the attention of explorers. Middendorff does, indeed, mention the occurrence of trains of large erratics which he observed along the banks of some of the rivers, but these, he has no doubt, were carried down by river-ice. The general character of the 'tundras' is that of wide, flat plains, covered for the most part with a grassy and mossy vegetation, but here and there bare and sandy. Frequently nothing intervenes to break the monotony of the landscape....It would appear, then, that in Northern Asia representatives of the glacial deposits which are met with in similar latitudes in Europe and America do not occur. The northern drift of Russia and Germany; the asar of Sweden; the kames, eskers, and erratics of Britain; and the iceberg-drift of Northern America have, apparently, no equivalent in Siberia. Consequently we find the great river-deposits, with their mammalian remains, which tell of a milder climate than now obtains in those high latitudes, still lying undisturbed at the surface." (Ibid)

Think of the significance of all this. There is no Drift in Siberia; no "till," no "bowlder-clay," no stratified masses of gravel, sand, and stones. There was, then, no Drift age in all Northern Asia, up to the Arctic Circle! (pp. 28-29)

THE LOESS

The loess consists of widespread deposits of unconsolidated silt. Apparently of Pleistocene origin, the loess usually occurs in areas that were peripheral to the hypothetical great ice sheets of the Glacial Epoch. The papers below demonstrate that the loess possesses unusual and distinctive properties. Wherever it covers older sediments, it has helped shape human activities, particularly in China.

Always controversial as to origin, wind deposition of the loess is widely subscribed to. Alluvial deposition also has its adherents. Even extraterrestrial sources have been invoked.

ON THE MODE OF ORIGIN OF THE LOESS

Richthofen, F.; *Geological Magazine,* 19:293-305, 1882.

Any theory which undertakes to deal with the problem of the origin of the Loess must give a valid explanation of the following characteristic peculiarities of it, viz.:

1st. The petrographical, stratigraphical, and faunistic difference of the Loess from all accumulations of inorganic matter which have been deposited previously and subsequently to its formation, and are preserved to this day.

2nd. The nearly perfect homogeneousness of composition and structure, which the Loess preserves throughout all the regions in which it is found on the continents of Europe and Asia; it offers in this respect a remarkable contrast to all sediments proved to be deposited from water within the last geological epochs, excepting those of the deep sea, which are here out of the question.

3rd. The independence of the distribution of the Loess from the amount of altitude above sea-level. In China it ranges from a few feet to about 8000 feet above the sea, and farther west it rises probably to much greater altitudes. In Europe it is known at all elevations up to about 5000 feet, at which it occurs in the Carpathians.

4th. The peculiar shape of every large body of Loess, as it is recognized where erosion has cut gorges through it down to the underlying ground without obliterating the original features of the deposit. These are different according to the hilly or level character of the subjacent ground. In hilly regions the Loess, if little developed, fills up depressions between every pair of lower ridges, and in each of them presents a concave surface; but where it attains greater thickness, it spreads over the lower hills, and conceals the inequalities of the ground. Its concave surface extends then over the entire area separating two higher ranges, in such a manner as to make the line of profile resemble the curve that would be produced by a rope stretched loosely between the two ranges. This shape of surface is precisely similar to that which is characteristic of the salt steppes of Central Asia. It must, however, be remarked that, just as in these, the development is frequently unequal on either side of a valley, and that the preponderance of the deposit on the same (f. i. the westerly) side can sometimes be observed in each basin throughout a larger region. The lowest portion of the surface of larger basins is frequently taken up by stratified soil consisting of the finest particles of Loess, and exhibiting a strong impregnation with alkaline salts. Over table lands and plains Loess is spread in the shape of most uniform sheets.

5th. The composition of pure Loess, which is the same from whatever region specimens may be taken, extremely fine particles of hydrated silicate of alumina being the largely prevailing ingredient, while there is always present an admixture of small grains of quartz and fine laminae of mica. It contains, besides, carbonate of lime, the segregation of which gives origin to the well-known concretions common to all deposits of Loess, and is always impregnated with alkaline salts. A yellow colouring matter caused by a ferruginous substance is never wanting.

6th. The almost exclusive occurrence of angular grains of quartz in the pure kinds of Loess.

7th. The complete absence of stratification. To this must be added the singular position of the laminae of mica. When these are deposited by water, they are arranged horizontally and accumulated in separate layers, while in Loess they are distributed without any order, and occur in every possible position.

8th. The capillary structure caused by the occurrence of innumerable tubes, mostly incrustated with carbonate of lime, which have generally a vertical position, and ramify downwards like the roots of grass. Where Loess is covered by vegetation, the tubes may be seen taken up by rootlets to the depth of a foot or a few feet from the surface. In this internal structure, besides the mode of occurrence, is founded the chief difference of Loess from ordinary loam. The former may be designated as a kind of calcareous loam provided with internal structure.

9th. The tendency to vertical cleavage, which is the immediate consequence of the two last-named properties.

10th. The fact that land shells are imbedded in immense numbers throughout the Loess, and that the most delicate shells are perfectly preserved. Fresh-water shells are of extremely rare occurrence, as has been correctly pointed out by Mr. Howorth.

11th. The great quantity of bones of mammals found in the Loess, the genera and mostly the species, or the next relatives, of which are known to abound at present in steppes and on grassy plains. Herbivorous animals are represented as well as carnivorous preying on the former.

12th. The fact that wherever Loess fills a basin between hills, the inclined slopes of these are covered by angular fragments of the adjoining rock, on which the yellow soil rests. Layers of these fragments, beginning with a slight inclination and then passing into a horizontal position, extend from the hill-sides for some distance into the accumulation of the Loess itself, separating it in the neighbourhood of the encasing slopes into layers of varying thickness, while towards the central portion of each large basin this separation ceases almost completely, and the soil is very homogeneous from top to bottom, even in those instances where the vertical thickness is 1500 feet and more.

It is perfectly evident that no theory starting from the hypothesis of the deposition of Loess by water can explain all or any single one of these properties. Neither the sea nor lakes nor rivers could deposit it in altitudes of 8000 feet on hill-sides. Origin from water is perfectly unable to explain the lack of stratification, the profuse existence of capillary tubes, the vertical cleavage, the promiscuous occurrence of grains of quartz, the angular shape of these, the confused position of the laminae of mica, the imbedding of land shells, and of bones of terrestrial mammals.

There is but one great class of agencies which can be called in aid for explaining the covering of hundreds of thousands of square miles, in little interrupted continuity, and almost irrespective of altitude, with a perfectly homogeneous soil. It is those which are founded in the energy of the motions of the atmospheric ocean which bathes alike plains and hill-tops. Too little weight has been granted hitherto by geologists to these agencies, and yet there is no other which has contributed in a greater measure to determine and to modify the character of the surface of any portion of the ground after its emergence from the sea, and to predestinate wide regions for the existence of certain kinds of plants and animals, and for the modes of nomadic or agricultural life of mankind. (pp. 295-297)

THE LOESS-DEPOSITS OF NORTHERN CHINA

Williams, Frederick; *Popular Science Monthly,* 22:243-248, 1882.

Scientists as well as economists and statesmen are turning with a scrutiny, renewed as each year advances, toward the great region of middle Asia---a territory which, if it supplies society with immigrants much too thrifty for the tastes of our broader-minded Celtic brethren, bids fair in many ways to furnish materials for scientific research that can be compared in interest to no other portion of the world's surface. Without delaying to mention here the recent travelers who are rapidly lessening the bounds of that tract, still confessed to be the least known area of the globe, it is our purpose to direct attention to a geological phenomenon among the most important as well as peculiar of any hitherto brought to light in this field of investigation: we mean the loess-beds covering a great portion of Northern China.

The term loess, now generally accepted, has been used to designate a tertiary deposit appearing in the Rhine Valley, along the Danube, and in several isolated sections of Europe. Its formation has heretofore been ascribed to glaciers, but its enormous extent and thickness in China demand some other origin. The substance is a brownish-colored earth, extremely porous, and, when dry, easily powdered between the fingers, when it becomes an impalpable dust that may be rubbed into the pores of the skin. Its particles are somewhat angular in shape, the lumps varying from the size of a peanut to a foot in length, whose appearance warrants the peculiarly appropriate Chinese name meaning "ginger-stones." After washing, the stuff is readily disintegrated, and spread far and wide by rivers during their times of flood. Mr. Kingsmill, in the "Journal of the Geological Society" (London), states that a number of specimens, which crumbled in the moist air of a Shanghai summer, rearranged themselves afterward in the bottom of a drawer in which they had been placed. Every atom of loess is perforated by small tubes, usually very minute, circulating after the manner of root-fibers, and lined with a thin coating of carbonate of lime. The direction of these canals being always from above downward, cleavage in the loess mass, irrespective of size, is invariably vertical, while, from the same cause, water is falling upon a deposit of this material never collects in the form of puddles or lakes on its surface, but sinks at once to the local water-level.

The loess territory of China begins, at its eastern limit, with the foothills of the great alluvial plain---roughly speaking, upon the line drawn from Peking to Kaifung in Honan. From this rises a terrace of from ninety to two hundred and fifty feet in height, consisting entirely of loess; and westward of it, in a nearly north and south line, stretches the Taihang Shan, or dividing range between the alluvial land and the hill-districts of Shansi. An almost uninterrupted loess-covered country extends west of this line to Lake Koko-nor and headwaters of the Yellow River. On the north the formation can be traced from the vicinity of Kalgan, along the water-shed of the Mongolian steppes, and into the desert beyond the Ala Shan range. Toward the south its limits are less sharply defined; though covering all the country of the Wei basin (in Shensi), none is found in Sz'chuen, due south of this valley, but it appears in parts of Honan and Eastern Shantung. Excepting occasional spurs and isolated spots. loess may be considered as ending everywhere on the north side of the Yangtse Valley, and, to convey a general notion, as covering the parallelogram between longitudes 99° and 115° east, and latitudes 33° and 41° north. The district within China Proper represents a territory half as large again as that of the German Empire, while outside of the provinces there is reason to believe that loess spreads far to the east and north, possibly in varying thicknesses quite across the desert. Baron von Richthofen observed this deposit in Shansi to a height of 7,200 feet above the sea, and supposes that it may occur at higher levels.

One of the most striking as well as important phenomena of this formation is the perpendicular splitting of its mass---already referred to---into sudden and multitudinous clefts that cut up the country in every direction, and render observation as well as travel often exceedingly difficult. The cliffs, caused by erosion, vary from cracks measured by inches to canons half a mile wide and hundreds of feet deep; they branch out in every direction, ramifying through the country after the manner of tree-roots in the soil---from each root a rootlet, and from these other small fibers---until the system of passages develops into a labyrinth of far-reaching and intermingling lanes. Were the loess throughout of the uniform structure seen in single clefts, such a region would indeed be absolutely impassable, the vertical banks becoming precipices of often more than a thousand feet. The fact, however, that loess exhibits in every locality a terrace formation, renders its surface not only habitable, but highly convenient for agricultural purposes; it has given rise, moreover, to the theory advanced by Kingsmill and some others, of its stratification, and from this a proof of its origin as a marine deposit.

But, since attention was first directed to this formation by Mr. Pumpelly, in 1864, its structure has been more carefully examined by other geologists, whose hypotheses are pretty generally discarded for that of Baron von Richthofen. This gentleman, who may be considered _facile princeps_ among foreign geologists who have visited China, argues that these apparent layers of loess are due to external conditions, as of rocks and _debris_ sliding from surrounding hill-sides upon the loess-dust as it sifted into the basin or valley, thus interrupting the homogeneity of the gradually rising deposit. In the sides of gorges near the mountains are seen layers of coarse _debris_ which, in going toward the valley-bottom, become finer, while the layers themselves are thinner and separated by an increasing vertical distance; along these rubble-beds are numerous calcareous concretions which stand upright. These are, then, the terrace-forming layers which, by their resistance to the action of water, cause the broken chasms and step-like contour of the loess regions. Each bank does, indeed, cleave vertically, sometimes---since the erosion works from below---leaving an overhanging bank; but, meeting with this horizontal layer of marlstones, the abrasion is interrupted, and a ledge is made. Falling clods upon such spaces are gradually spread over their surfaces by natural action, converting them into rich fields. When seen from a height in good seasons, these systems of terraces present an endless succession of green fields and growing crops; viewed from the deep cut of some stream or road-bed, the traveler sees nothing but yellow walls of loam and dusty tiers of loess-ridges. As may be readily imagined, a country of this nature exhibits many landscapes of unrivaled picturesqueness, especially when lofty crags, which some variation in the water-course has left as giant guardsmen of fertile river-valleys, stand out in bold relief against the green background of neighboring hills and a fruitful alluvial bottom, or when an opening of some ascending pass allows the eye to range over leagues of sharp-cut ridges and teeming crops, the work of the careful cultivator.

The extreme ease with which loess is cut away tends at times to seriously embarrass traffic. Dust made by the cart-wheels on a highway is taken up by strong winds during the dry season and blown over the surrounding lands, much after the manner in which it was originally deposited here. This action, continued over centuries, and assisted by occasional deluges of rain, which find a ready channel in the road-bed, has hollowed the country routes into depressions of often fifty or a hundred feet, where the passenger may ride for miles without obtaining a glimpse of field or landscape. Lieutenant Kreitner, of the Szechenyi exploring expedition (whose pleasant article on Thibet appeared in "The Popular Science Monthly" for August, 1882) illustrates, by a personal experience when in Shansi, the difficulty and danger of departing from the highway when in one of these deep cuts; after scrambling for miles along the broken loess above the road, he only regained it when a further passage was cut off by a precipice on the one side, while a jump of some thirty feet into the beaten track was his only alternative upon the other.

Difficult as may be such a territory for roads and the purposes of trade, its advantages to a farmer are manifold. Wherever this deposit extends, there the husbandman has an assured harvest two and even three times in a year. It is easily worked, exceedingly fertile, and submits to constant tillage, with no other manure than a sprinkling of its own loam dug from the nearest bank. But loess performs still another service to its inhabitants. Caves made at the bases of its straight clefts afford homes to millions of people in the northern provinces. Choosing an escarpment where the consistency of the earth is greatest, the natives cut for themselves rooms and houses, whose partition-walls, cement, beds, and furniture are made in toto from the same loess. Whole villages cluster together in a series of adjoining or superimposed chambers, some of which pierce the soil to a depth of often more than two hundred feet. In costlier dwellings the terrace or succession of terraces thus perforated are faced with brick, as well as the arching of rooms within. The advantages of such habitations consist as well in imperviousness to changes of temperature without as in their durability when constructed in properly selected places---many loess dwellings outlasting six or seven generations. The capabilities of defense in a country such as this, where an invading army must inevitably become lost in the tangle of interlacing ways, and where the defenders may always remain concealed, are very suggestive.

There remains, lastly, a peculiar property of loess which is perhaps more important than all other features when measured by its man-serving efficiency. This is the manner in which it brings forth crops without the aid of manure. From a period more than two thousand years before Christ, to the present day, the province of Shansi has borne the name of "Granary of the Empire," while its fertile soil, hwang-tu, or "yellow earth," is the origin of the imperial color. Spite of this productiveness, which, in the fourteenth century, caused Friar Odoric to admiringly call it "the second country in the world," its present capacity for raising crops seems to be as great as ever. In the nature of this substance lies the reason for this apparently inexhaustible fecundity. Its remarkably porous structure must, indeed, cause it to absorb the gases necessary to plant-life to a much greater degree than other soils, but the stable production of those mineral substances needful to the yearly succession of crops is in the ground itself. The salts contained more or less in solution at the water-level of the region are freed by the capillary action of the loess when rainwater sinks through the spongy mass from above. Surface moisture, following the downward direction of the tiny loess-tubes, establishes a connection with the waters compressed below, when, owing to the law of diffusion, the ingredients, being released, mix with the moisture of the little canals, and are there taken from the lowest to the topmost levels, permeating the ground and furnishing nourishment to the plant-roots at the surface. It is on account of this curious action of loess that a copious rainfall is more necessary in Northern China than elsewhere, for with a dearth of rain the capillary communication from above, below, and *vice versa*, is interrupted, and vegetation loses both its moisture and manure. Drought and famine are consequently synonymous terms here.

As to the origin of loess, Baron von Richthofen's theory is substantially as follows: The uniform composition of this material over extended areas, coupled with the absence of stratification and of marine or fresh-water organic remains, renders impossible the hypothesis that it is a water-deposit. On the other hand, it contains vast quantities of land-shells and the vestiges of animals (mammalia) at every level---both in remarkably perfect condition. Concluding, also, that from the conformation of the neighboring mountain-chains and their peculiar weathering, the glacial theory is inadmissible, he advances the supposition that loess is a sub-aerial deposit, and that its fields are the drained analogues of the steppe-basins of Central Asia. They date from a geological era of great dryness, before the existence of the Yellow and other rivers of the northern provinces. As the rocks and hills of the highlands disintegrated, the sand was removed, not by water-courses seaward, but by the high winds ranging over a treeless desert landward, until the dust settled in the grass-covered districts of what is at present China Proper. New vegetation was at once nourished, while its roots were raised by the constantly arriving deposit; the decay of old roots produced the lime-lined canals which impart to this material its peculiar characteristics. Any one who has observed the terrible dust-storms of Northern China, when the air is filled with an impalpable yellow powder, which leaves its coating upon everything, and often extends in a fog-like cloud hundreds of miles to sea, will understand the power of this action during many thousand centuries. This deposition received the shells and bones of innumerable animals, while the dissolved solutions contained in its bulk staid therein, or saturated the water of small lakes. By the sinking of mountain chains in the south, rain-clouds emptied themselves over this region with much greater frequency, and gradually the system became drained, the erosion working backward from the coast, slowly cutting into one basin after another. With the sinking of its salts to lower levels, unexampled richness was added to the wonderful topography of this singular formation.

Mr. Pumpelly, while accepting this ingenious theory in place of his own (that of a fresh-water lake deposit), adds that the supply of loess might have been materially increased by the vast *mers-de-glace* of High Asia and the Tien Shan, whose streams have for ages transported the products of glacial attrition into Central Asia and Northwestern China. Again, he insists that Richthofen has not given importance enough to the parting planes, wrongly considered by his predecessors in the study of Chinese geology as planes of stratification. "These" he says, "account for the marginal layers of *debris* brought down from the mountains. And the continuous and more abundant growth of grasses *at one plane* would produce a modification of the soil structurally and chemically, which superincumbent accumulations could never efface. It should seem probable that we have herein, also, the explanation of the calcareous concretions which abound along these planes; for the greater amount of carbonic acid generated by the slow decay of this vegetation would, by forming a bicarbonate, give to the lime the mobility necessary to produce the concretions."

It is hardly within the scope of this article to do more than present in brief outline an exposition of the loess-theory that has made its originator already celebrated throughout Germany. Nor can we follow Baron von Richthofen further into the extension of his postulate, wherein one is scarcely surprised at finding a plausible and attractive application of this idea of loess-formation to the entire Europe-Asiatic Continent, to the pampas of the South and prairies of the North American world. While the three or four northwestern provinces of China exhibit undoubtedly the strangest and most picturesque features of this formation, its influence upon the climate of Central Asia, the reactionary effect of this upon the surface configuration of the steppe-lands, and thus on the historical and ethnographical development of the cradle of the human race, are but some of the legitimate generalizations---if not necessary results---coming from this interesting phase of nature.

NOTE ON THE ORIGIN OF LOESS

Penniston, J. B.; *Popular Astronomy,* 39:429-430, 1931.

Three explanations have been offered as to the origin of loess, namely that it is a wind deposit, a water deposit, and a volcanic deposit. There is yet one other possible explanation and that is that loess may be of meteoric origin. The reasons for this latter hypothesis are as follows: (1) The disregard of contour lines in the deposit of loess, particularly in Chinese loess (a study of which forms the basis of this note), favors a meteoric origin even better than that of an aeolian deposit. (2) The chemical composition of loess is about that of stony meteorites, though the same may be said for volcanic material. (3) The absence of horizontal lamination is a serious objection to the wind and water hypothesis while it favors one of meteoric origin. (4) The vertical stratification of loess has never been satisfactorily accounted for. Water, as from a fine drizzle of rain, would descend unevenly on coming in contact with newly fallen meteoric matter and would soon develop favored lines of flow while the finest material would be segregated along these lines of flow and ultimately crystallized as is found in the hollow tubes in loess. It is, of course, these lines of flow that cause the vertical stratification. (5) Loess was laid down during the last glacial epoch and one of the causes that has been urged for explaining the Ice Age is that the solar system passed through a region rich in meteoric matter. (6) The angularity of loess grains with little or no evidence of rounded edges is inconsistent with the wind and water hypotheses but if the meteors of that period exploded to even smaller bits than they do at present we should obtain a material not unlike loess.

The objections against the meteoric hypothesis of the origin of loess are as follows: (1) Most astronomers seem to favor an equal distribution of meteorites over the surface of the earth while loess is, of course, unequally distributed. The actual data, however, on meteorite finds and falls favor an unequal distribution of meteoric matter on the earth. (2) Loess contains frequent grains of quartz and mica scales while present meteorites very rarely do, but we need not assume that meteoric material in the past has always been exactly the same as that now. (3) At present meteoric matter reaches the earth either in the form of microscopic dust from burnt-out meteors or else as bodies of considerable size varying from a few grains in weight to several hundred pounds. Meteors do explode and the disintegration in the past may have been more complete than that now, thus producing the fine material of loess.

Although the origin of loess has never been satisfactorily explained, the possibility of a meteoric origin seems to have been overlooked in the literature on the subject. Further investigation is necessary before this new explanation can be accepted but it does seem worth noting because of its bearing on the Lockyer meteoric hypothesis and on the Chamberlin-Moulton planetesimal hypothesis.

ADDITIONAL NOTE ON THE ORIGIN OF LOESS

Penniston, John B.; *Popular Astronomy,* 51:170-172, 1943.

1. Previous Notes---My "Note on the Origin of Loess," published in Popular Astronomy in August-September, 1931, introduced a meteoritic hypothesis as to the origin of loess. My other note, "The Break-up of Meteors," in the June-July, 1932, issue of Popular Astronomy had in mind primarily the accounting for the sharply angular splinters of loess. In addition a short article on "The Distribution of Meteorites" (to be published later) has been prepared by me because of its bearing on the distribution of loess.

2. The Sun, a Nova---Some years ago I reached the conclusion that the Sun may have been a nova at the time of the last Ice Age. Both Shapley and Belot, I later found, had anticipated my theory at least in part as to the nova stage of the Sun. Reasoning further, I concluded that the Sun may have thrown off so much material at the nova stage as to give rise to an important formation on the Earth; consequently I asked myself what geological formation is there that has never been satisfactorily explained; loess immediately suggested itself.

At the present time stony meteorites contain much silica in various compounds but, with a few exceptions, no quartz. If the material thrown off by the Sun experienced sudden congelation, this is to be expected; but on the other hand, if the material was enormously greater in amount, the silica might be metamorphosed into quartz if the temperature was maintained high enough for a sufficient period of time. If the temperature was maintained still higher, the silica might have become tridymite of which there has been one known sample among meteorites. At a still higher temperature cristobalite might have resulted, of which there is no known meteoritic example.

3. Calcium Carbonate Tubes---In a personal communication Dr. Rollin T. Chamberlin of the University of Chicago seemed to be in agreement with me that the vertical tubes of calcium carbonate in loess are probably due to the action of descending rain water. Let us remember, however, that chemical reactions in general are narrowly limited as to conditions permitting their occurrence. In the first place if the original material of loess contained carbonate of lime (calcium carbonate), rain water would not segregate it from the other material as carbonate of lime

is relatively insoluble in water except when the water contains carbonic acid and in this case the end product would have been a bicarbonate instead of a carbonate. Instead of segregating the carbonate of lime the rain water would act to cement the whole mass together like the eolianites or eolian rocks of Bermuda.

Let us suppose that the original material of loess contained calcium oxide; in that case descending rain water would take the calcium oxide up in solution forming calcium hydroxide; this latter product readily absorbs carbon dioxide, which normally occurs in the air, whereupon the solution precipitates carbonate of lime. If the original material contained calcium oxide, then it could have been either volcanic material or meteoritic matter, since calcium oxide (unslacked lime) does not normally occur in earthy combinations except those that have been recently through a burning process. Lack of characteristic volcanic products seem to limit the material to a meteoritic origin. Meteorites, as is known, do contain calcium oxide in appreciable amounts.

4. American Loess---Dr. Chamberlin also called my attention to the fact that loess occurs about fifty feet thick near some of the large American rivers, as for instance the Missouri River near Council Bluffs, Iowa, but the formation thins out so that it almost vanishes thirty miles to the eastward. This condition is not consistent with an eolian hypothesis as to the origin of the formation. Wind action produces the thick part of its deposit on the lee side away from the source of the material, which in this case most geologists assume to be the glacial flood plain of the Missouri, just the opposite of what the conditions actually are.

On the other hand if the material was meteoritic in origin, it would still be subject to air currents in its descent to the Earth. At the higher altitudes the meteoritic material would drift from west to east under the influence of the Earth's rotation. In addition let us accept Hobb's theory of glacial anticyclones with special reference to the glacial flood plain of the Missouri in the present problem. The anticyclone currents, where they operate in opposition to the direction of the west to east drift to the meteoritic material, would cause the material to be deposited in far greater amounts in a narrow zone on the eastern banks of the large American rivers, as is actually the case. It is also worth noting that the particles of loess are remarkably uniform in size and are coarser than the fine material of boulder clay or glacial till and fine rock flour such as would be present in glacial material collected by the wind from the flood plains of the large rivers.

5. Test of Logic---A rigorous application of logic leads to a breakdown of the eolian hypothesis of the origin of loess, mainly due to the absence of trituration or rounded edges in the particles of loess although the lack of cross-bedding in loess also points in the same direction. Special emphasis should be placed upon accounting for the presence of calcium carbonate tubes in loess because of the limiting conditions it establishes upon a satisfactory explanation. Finally, there seems to be nothing really prohibitive to a meteoritic origin of loess, and if we stick to the inductive method the new explanation seems to be the more probable one.

ORIGIN OF NORTH CHINA LOESS

Smalley, I. J.; *Nature,* 267:484, 1977.

Chinese civilisation developed on the great North China loess deposits, Ho (Cradle of the East, Chicago University Press, 1975) has argued convincingly that this development took place in isolation, uninfluenced by the parallel progress in the Middle East. A major factor which did influence the growth of the early Chinese civilisation was the presence of the loess which was an ideal soil for the early farmers. The origin of this North China loess is still in dispute. Most of the other loess deposits in the world have glacial connections and their formation can be seen as part of a sequence of Pleistocene events, but the Chinese loess does not have an obvious glacial link.

The results of the first electron microscope observations of Chinese loess have now been published (Lu et al, Geochimica 47, 1976). These allow the Chinese workers to reject totally the Berg theory of in situ formation, but they still find themselves unable to accept totally a direct glacial connection. The grains observed are broken and have sharp edges, and silica precipitation and chemical etching are commonly observed on the quartz silt particles, which might have been subjected to relatively long weathering processes before being transported to the loess accumulation areas. In the relevant areas the authors suggest that glaciation only occurred on mountain tops, and that this may have produced some loess, but they favour a distant western source for the majority of the material. No specific particle-producing mechanism is described.

It may be that in this case a larger than usual transportation stage was involved and that material was formed in distant glaciated regions and that the continuing aridity and the presence of mixed particle deposits in the post-Pleistocene times prevented the formation of stable loess deposits. In Europe and North America loess deposits form very close to the ice limits. The Lu et al. paper is an encouraging sign of the renewal of interest in loess sedimentology in China. It is a pity that those otherwise admirable data handlers, Science Citation Index and Mineralogical Abstracts, have not realised that in Chinese the family name (as used in references) comes first; so this important paper has been listed under Yanchou et al. which could cause some confusion.

PATTERNED GROUND

This section extends the scope of the inquiry into geometric and patterned geology from the small scale (rocks) to dimensions of feet to hundreds of feet. (See Chapter 2 for global patterns.) At these intermediate dimensions, natural forces persist in generating lines, polygons, circles, and other nonrandom forms. From the polar stone polygons to the similarly shaped cracks on the sun-baked mud flats of southern climes, the human eye preferentially picks out orderly features of the landscape.

The hand of the geometer is obscure in many instances. Where the polygonal urge is strong, natural forces are usually instrumental in breaking up continuous surfaces. Perfect circles are impossible, and polygons would seem the most economical answer, just as they are in the beehive. The creation of rock rings due to progressive weathering is also easy to conceive. But sine waves in ice and beach pyramids require more thought.

• Polar Patterned Ground

CLASSIFICATION OF PATTERNED GROUND....

Washburn, A. L.; *Geological Society of America, Bulletin,* 67:823-866, 1956.

Abstract. Patterned ground, which occurs principally in polar, subpolar, and alpine regions, is broadly classified into sorted and nonsorted varieties of circles, nets, polygons, steps, and stripes. This descriptive classification and the associated terminology eliminate confusion resulting from the many overlapping and synonymous terms in the literature.

The origin of patterned ground is far from satisfactorily explained. Hypotheses are reviewed and summarized according to dominant processes as follows: (1) ejection of stones from fines by multigelation (often-repeated freezing and thawing), (2) mass heaving, (3) local differential heaving, (4) cryostatic movement (movement by frost-generated hydrostatic pressure), (5) circulation due to ice thrusting, (6) frost wedging, (7) absorption of water by colloids, (8) weathering, (9) contraction due to drying, (10) contraction due to low temperature, (11) contraction due to thawing, (12) convection due to temperature-controlled density differences, (13) convection due to moisture-controlled density differences, (14) movement due to moisture-controlled changes in intergranular pressure, (15) differential thawing and eluviation, (16) vibration, (17) artesian flow, (18) rillwork (for stripes), (19) solifluction in combination with one or more of the above processes (for stripes).

Conclusions regarding origin are that: (1) the origin of most forms of patterned ground is uncertain; (2) patterned ground is polygenetic; (3) some forms may be combination products in a continuous system having different processes as end members; (4) climatic and terrain interpretation of patterned ground, both active and "fossil", is limited by lack of reliable data about formative processes.

With respect to future research, it is apparent that: (1) laboratory experiments, including cold-room studies specifically dealing with patterned ground, are urgently required; (2) excavations rather than surface observations should be stressed in the field; (3) physicists, pedologists, plant ecologists, and engineers versed in soil mechanics have much to contribute to patterned-ground research, and joint work between them and geo-

logists should produce particularly valuable results.

Definition of Patterned Ground. Patterned ground is a group term for the more or less symmetrical forms, such as circles, polygons, nets, steps, and stripes, that are characteristic of, but not necessarily confined to, mantle subject to intensive frost action.

Patterned ground that is demonstrated to have a distinctive climatic or geographic distribution exclusive of other environments can be designated by appropriate adjectives. Thus, cold-climate patterned ground describes most, but not all, patterned ground.

The term patterned ground was suggested by Washburn because of the following considerations:

The terms Rutmark, Strukturboden, Polygonboden, Polygonenboden, Zellenboden, stone circles, stone rings, stone nets, stone polygons, mud circles, soil circles, mud polygons, soil polygons, fissure polygons, tundra polygons, stone stripes, soil stripes, solifluction stripes and others have all been used to describe features here collectively named patterned ground for want of a satisfactory collective term in English. The term structure ground is awkward, and soil structures is objectionable because it may imply the presence of humus and, as recognized by Sharp, a soil profile, both of which may be absent. Regularity is inherent in the term pattern, and the writer would restrict the use of patterned ground to more or less symmetrical features rather than include phenomena such as stone-banked terraces, rock glaciers, etc. The term patterned ground thus corresponds most closely to the German term Strukturboden as employed by Sorensen although Strukturboden was originally introduced by Meinardus.

The term patterned ground has been widely adopted. The Highway Research Board Committee on Frost Heave and Frost Action in Soil defined the term in connection with patterns resulting from frost action, but the original discussion quoted above did not specify such a limitation, and the occurrence of desiccation patterns very similar to certain patterns attributed to frost action make a narrow definition undesirable. The objection suggested by Black that some types of patterned ground are bedrock forms and not ground in the strict sense of the word does not seem serious in view of the broad use of the term ground (for instance, ground water is not restricted to unconsolidated deposits) and the fact that forms in bedrock are exceptional.

The unit component of patterned ground (excepting steps and stripes) ---a circle, polygon, or intermediate form---is here termed the mesh.

Classification of Patterned Ground. Many closely related classifications of patterned ground have been developed, such as those of Meinardus, Hogbom, Beskow, Huxley and Odell, Steche, Sorensen, and Troll. The writer's classification retains the essential elements of the classifications cited above---pattern, and presence or absence of sorting---and reflects a revised terminology that is orderly and consistent.

A revised terminology is needed. Different terms have been used for similar forms and the same term for dissimilar ones. Stone-polygons, stone rings, and stone nets are a few of the many terms used for stone-bordered polygonal features. The term stone-polygons has also been used to describe almost perfectly circular forms of possibly different origin, called stone circles by Huxley and Odell. Elton used the terms stone-polygons and stone-circles interchangeably in discussing the latter. The use of the name "circular....polygon" to distinguish circular from polygonal forms illustrates the problem.

Terminology difficulties also exist regarding forms of patterned ground without a marked stone border. Although the term fissure-polygons is appropriate in places, it is misleading for forms lacking obvious fissures. Moreover, fissures do not necessarily indicate absence of stone borders, for some polygons with fissures have stone borders as well, coincident with the fissures. Elton objected to the term fissure-polygons and suggested mud-polygons, but this term is ambiguous because forms without a stone border do not invariably consist of "mud" but may consist of sand, gravel, or a nonsorted mixture of fines and stones, including boulders. Ice-wedge polygons, tundra polygons, and Taimyr polygons are three synonymous terms where one would suffice.

Elton combined forms with and without a stone border under the group term soil-polygons, but it is misleading to use the term soil, as previously noted, or to refer to obviously circular forms as polygons. A variety of overlapping terms is also used for steplike and striped forms of patterned ground.

Genetic terms such as Brodelboden, based on an unproved mode of origin, are undesirable, as emphasized by Bryan. Clearly it is not yet time for a sound genetic classification of patterned ground, as pointed out by Troll and illustrated by the numerous hypotheses of origin.

Two commonly obvious characteristics of patterned ground that can be ascertained in the field without digging and are also usable in photo-interpretation are: (1) the pattern---whether dominantly circular, polygonal, intermediate (nets), steplike, or striped, (2) the presence or absence of obvious sorting between stones and fines. The following classification, based on Washburn, combines the two characteristics. The arrangement of the classification is in the direction of increasing gradient; thus most circles, nets, and polygons occur on essentially horizontal ground, and steps and stripes are limited to slopes. Where steps and stripes occur together the latter are on the steeper gradient.

- Circles
  - Sorted (including debris islands)
  - Nonsorted (including peat rings, tussock rings)
- Nets
  - Sorted
  - Nonsorted (including earth hummocks)
- Polygons
  - Sorted
  - Nonsorted (including frost-crack polygons, ice-wedge polygons, tussock-birch-heath polygons, desiccation polygons)
- Steps
  - Sorted
  - Nonsorted
- Stripes
  - Sorted
  - Nonsorted

As pointed out by Black some patterned ground forms are gradational in pattern and sorting. With respect to patterns, some sorted circles grade into sorted polygons, and some sorted polygons merge into steps and stripes. There seems to be a similar gradational series with nonsorted forms of patterned ground. With respect to sorting, transitional types have been reported between sorted and nonsorted circles and between sorted and nonsorted polygons. Thus, in places it is difficult to classify a given form, but most classifications involve the same problem. A single broad heading may include similar forms of differing origin, but the only solution to this difficulty is a sound genetic classification, which requires more knowledge of formative processes than is now possessed.

The writer believes that the use of the simple descriptive terms of the present classification, supplemented by qualifying adjectives, such as miniature, large, sandy, silty, or clayey, and by detailed quantitative descriptions where necessary, will help develop a sound genetic classification. The terminology of the present classification is not intended to supplant existing terms, such as ice-wedge polygons, peat rings, tussock rings, tussock-birch-heath polygons, and any other appropriate descriptive or genetic terms that can be used in a unique sense.

The following definitions are reworded and formalized from Washburn except where otherwise noted. References given for synonyms clarify the sense in which a term has been used and generally, but not necessarily, include the first use.

Sorted Circles. Definition: Sorted circles are patterned ground whose mesh is dominantly circular and has a sorted appearance commonly due to a border of stones surrounding finer material. Depending on usage, more or less synonymous terms may include those listed below for sorted polygons and, in addition, stone circles, Steinringe, Meinardus, Brodelboden, and others.

Debris islands are sorted circles occurring amid blocks or boulders. This term is here used for the first time, although it is essentially a translation of the German synonyms, Erdinseln and Schuttinseln (earth islands and debris islands).

Form and size: Sorted circles form singly or in groups and where crowded closely together may be difficult to distinguish from sorted polygons. (Cf. sorted nets.) Vegetation if present does not usually emphasize the pattern as strongly as in nonsorted forms. In Svalbard where sorted circles are classically developed they vary in diameter from 0.8 to over 3 m. Miniature sorted circles within larger sorted forms have been described.

Debris islands are generally isolated forms but according to Hamberg they may also be grouped. Hamberg reported diameters of about 1 m.

Constitution: The stones in the border around the central area of finer material may range from pebbles in miniature sorted circles to boulders in large ones. The finer material may grade into or abut sharply against the border. The central areas of most sorted circles contain abundant fines, but some consist of gravels largely free of fines, at least at the surface. In any one area the size of bordering stones commonly increases as depth and breadth of the stone borders increase; Meinardus and Poser indicated that in general the size of bordering stones increases with the over-all size of a form. The diameter of a form may reflect depth of sorting in some places, but not in others: Paterson described a large sorted circle with stones up to a foot across resting almost directly on underlying rock. On the whole, sorting and distribution of rock particles in sorted circles is similar to that in sorted polygons, although less information on circles is available in the literature. Involuted structure in small sorted circles has been reported.

Debris islands consist of more or less isolated patches of fines surrounded by boulders or blocks. Small stones were present among the fines in the descriptions noted.

Occurrence: Sorted circles are characteristic of polar environments, but some forms occur also in subpolar and alpine regions. Circles may develop on mantle derived from subjacent bedrock or on transported mantle. Permafrost is present where sorted circles are best developed but apparently is not necessary for their formation; in Iceland, where permafrost is sporadic, some sorted circles are reported where it is absent.

Debris islands have been reported from polar, subpolar, and alpine environments. They characteristically occur in block or boulder rubble, and some of the descriptions associate them with slopes. Meinardus recognized this association although he pointed out that the surface of a debris island is approximately horizontal. Debris islands may occur also on essentially horizontal surfaces. Paterson reported a "circular shingle polygon", which appears to be a debris island whose "convex mud centre" was not over 15 cm (6 inches) thick with bordering stones resting almost directly on rock. Some debris islands, as on Victoria Island, occur in areas of permafrost.

Nonsorted Circles. Definition: Nonsorted circles are patterned ground whose mesh is dominantly circular and has a nonsorted appearance due to the absence of a border of stones such as that characterizing sorted circles.

More or less synonymous terms are spot-medallions and cemetery hummocks, mud circles, frost scars, peat rings, and tussock rings.

Form and Size: Nonsorted circles, like sorted circles, develop singly or in groups. Vegetation is a characteristic element in outlining the pattern. Many isolated nonsorted circles form relatively bare spots amid vegetation; grouped circles commonly have borders of vegetation separating the individual circles. In places the bordering vegetation forms a ridge, ranging 20-90 cm (8-36 inches) high in peat rings described by Hopkins and Sigafoos. Other non-sorted circles lack a distinct ridge. Dimensions are similar to those of sorted circles. Rousseau reported diameters of 0.5-2 m, and Poire gave comparable dimensions. The "frost scars" of Hopkins and Sigafoos varied "from a few inches to several tens of feet in maximum diameter" and their peat rings and tussock rings, from 1.2 to 3.7 m (4-12 feet) across. Well-developed nonsorted circles tend to have central areas that are distinctly domed, the local relief varying in tussock rings from 7.5 to 15 cm (3-6 inches) to about 1 m. Miniature nonsorted polygons occur on some of the domed areas.

Constitution: Nonsorted circles (peat rings) studied by Hopkins and Sigafoos"....consisted of silt with a little sand and a few pebbles but contained no rock fragments more than 3 inches in largest dimension". The forms described by Washburn consisted also of fines, but with numerous stones. According to Hopkins and Sigafoos, bare spots such as nonsorted circles should have a high ice-lens content compared to surrounding vegetation-covered ground---a relationship confirmed by D. G. MacVicar, Jr. for nonsorted circles in the Chandler Lake area of northern Alaska. Cross sections developed by Hopkins and Sigafoos demonstrate that involutions are common subsurface features.

Occurrence: Nonsorted circles occur mainly in polar, subpolar, and alpine environments, but circles similar in pattern occur elsewhere as in subhumid and semiarid areas in Australia where they are known as "normal gilgai". Most nonsorted circles are confined to essentially horizontal surfaces. Permafrost is believed by Hopkins and Sigafoos to be associated necessarily with the peat rings and tussock rings they studied. "Fossil" forms of nonsorted (and perhaps sorted) circles may be represented by involutions in some stratigraphic sections.

Sorted Nets. Definition: A sorted net is patterned ground whose mesh is intermediate between that of a sorted circle and a sorted polygon and has a sorted appearance commonly due to a border of stones surrounding finer material. The term was defined by Washburn. "Net" as in stone nets is common in patterned-ground literature.

Discussion: Except for pattern, sorted nets resemble sorted polygons. The term provides a convenient pigeonhole for forms with a mesh that is neither dominantly circular nor polygonal; obviously it would be difficult and misleading to classify such forms as either circles or polygons. Thus, Antevs described mesh patterns that ranged from a well-defined polygonal to "nearly round" or "circular" shape. Troll, also, illustrated forms that could be described as sorted nets because of their intermediate pattern. Since accurate recognition of patterns is probably an essential element in determining the origins of patterned ground, the term sorted net should not be used indiscriminately but should be restricted according to the above definition.

Nonsorted Nets. Definition: A nonsorted net is patterned ground whose mesh is intermediate between that of a nonsorted circle and a nonsorted polygon and has a nonsorted appearance due to the absence of a border of stones such as that characterizing a sorted net. This term is here used for the first time.

Discussion: Except for pattern nonsorted nets resemble nonsorted polygons although some nonsorted polygons (including many ice-wedge polygons) have a mesh larger than that of any nonsorted net. Again, the term is a convenient pigeonhole for forms that are difficult to classify and should be restricted to such forms. An example is cited from arctic Canada. Hopkins and Sigafoos described closely spaced nonsorted circles ("frost scars") as evolving into tussock-birch-heath polygons; presumedly such an evolution should produce intermediate patterns that would also be difficult to classify as either circles or polygons.

Earth hummocks are a particular type of nonsorted net with a mesh characterized by a three-dimensional knoblike shape and cover of vegetation. The term earth hummocks is derived from Sharp. More or less synonymous terms are thufur, Bulten, Hugelboden, Rasenhugel. Palsen are large earth-hummock-like features typical of parts of Scandinavia and Siberia.

Earth hummocks form in groups rather than singly. Earth hummocks in Iceland are 25-50 cm high and 1-2 m in diameter. Sharp observed similar dimensions in Canada although he noted that forms on hillsides tended to be elongate across the slope. The Icelandic earth hummocks consist of a clay (Ton) or loam (Lehm) interior covered by peat and by vegetation composed of grasses and mosses, acid in reaction. In the Canadian forms described by Sharp. "The hummocks consist of an earthen core with a 3- to 6-inch hull of humus, moss, and plant roots. The plants on top of the mounds are chiefly grass and small bushes with grass and moss predominant in the low damp areas between." Earth hummocks are probably most common in subarctic and alpine environments, but Troll cited some arctic occurrences, including Nieland's observations in Greenland. Earth hummocks are apparently best developed on more or less horizontal surfaces. Thoroddsen reported they do not occur on mountain sides in Iceland. However, according to Sharp, "Well-developed hummocks are common on slopes up to 20 degrees. They do not form on much steeper slopes..." where he observed them in Canada. Although earth hummocks are almost certainly related to frost action, their prevalence in Iceland, where permafrost is sporadic, and particularly in the southern coastal region, where permafrost is absent, indicates that earth hummocks are not necessarily associated with permafrost.

Sorted Polygons. Definition: Sorted polygons are patterned ground whose mesh is dominantly polygonal and has a sorted appearance commonly due to a border of stones surrounding finer material.

Depending on usage, more or less synonymous terms may include stone-polygons, stone rings, stone nets, Polygonenboden-Typus I, Steinnetze or Steinnetzwerk, and others.

Form and Size: In contrast to circles, sorted polygons apparently never develop singly. As with sorted circles, vegetation if present does not in most places emphasize the pattern as strongly as it does in nonsorted forms of patterned ground. According to Steche sorted polygons range in size from a few centimeters in diameter to large forms 10 meters across, with the size tending to increase with increasing severity of climate and availability of water; however, miniature forms may occur in vegetation-free central areas of large forms as well as independently.

Constitution: Size range and sorting of stones and fines in sorted polygons are similar to sorted circles, although Ahlmann indicated that the largest stones are not necessarily associated with the largest polygons. The central area of a sorted polygon may appear to consist almost entirely of fines but closer inspection may reveal a number of stones. Like sorted circles, some sorted polygons develop in gravel. Especially in large polygons, tabular stones of the borders tend to be on edge and oriented parallel to the border. The stony borders of many sorted forms, including nets, narrow downward. Other borders widen with depth, suggesting that distinct types may be involved as indicated by Poser. Lundqvist reported that stones within the central areas of sorted polygons tend to show a preferred orientation with the long axes transverse to the nearest border, the exact angle possibly influenced by other nearby borders.

Occurrence: Sorted polygons are characteristic of polar, subpolar, and alpine environments. They are much more widespread than sorted circles. According to Huxley and Odell they occur"....apparently rarely (at least when well developed) on perfectly level ground;" further observations are desirable with respect to this question. "Fossil" forms have been recognized from regions that were subjected to a more severe climate during the Pleistocene. As with circles, polygons occur on mantle derived from the subjacent bedrock or on transported mantle. Permafrost is not necessarily associated with miniature sorted polygons but is present where large sorted ones are best developed. A peculiar sorted polygonal form from Christmas Island in the Pacific Ocean and sorted polygonal patterns from the Libyan Desert illustrate the fact that sorted polygonal patterns are not confined to polar, subpolar, or alpine environments.

Nonsorted Polygons. Definition: Nonsorted polygons are patterned ground whose mesh is dominantly polygonal and has a nonsorted appearance due to the absence of a border of stones such as that characterizing sorted polygons.

Depending on usage, more or less synonymous terms may include fissure-polygons, mud-polygons, contractional polygons, Polygonboden, Polygonenboden-Typus II, Zellenboden, and others.

Tussock-birch-heath polygons, vegetation polygons and frost-crack polygons, ice-wedge polygons, and desiccation polygons are special varieties of nonsorted polygons.

Ice-wedge polygons are nonsorted polygons characterized by bordering ice wedges. Tundra polygons and Taimyr polygons are synonyms for ice-wedge polygons, but Steche and Troll have objected to the term tundra polygons, and the name Taimyr polygons implies a too limited geographic restriction. Polygons without ice wedges that have a surface appearance practically identical to ice-wedge polygons but may be of different origin have been described. Obviously such forms, and other nonsorted polygons in which the presence or absence of ice wedges is not established, should not be termed ice-wedge polygons, as recognized by Hopkins, Karlstrom, et al. in their use of the term frost-crack polygons for somewhat similar forms not necessarily associated with permafrost.

Form and Size: Like the sorted variety, nonsorted polygons apparently never develop singly. The borders are commonly but not invariably marked by obvious fissures in the ground. Vegetation if present is generally concentrated along the borders and emphasizes the polygonal pattern, especially in large forms. Nonsorted polygons range in diameter from a few centimeters to many meters. Commonly the small ones have a pentagonal or hexagonal mesh and lack ice wedges. Small nonsorted polygons occur in the central areas of some larger sorted and nonsorted polygons. Tussock-birch-heath polygons are characterized by the vegetation assemblage indicated and have a diameter range of 2.1-4.6 m (7-15 feet) except where drawn out on a slope.

Ice-wedge polygons are typically large. Although diameters as small as 1-3 m have been reported, and 4.6 m (15 feet) is not uncommon, the average size is larger. Steche cited a diameter range of 10-40 m and Troll a range of 15-20 m. Black has given maximum diameters of 100 m or more. The pattern tends to be tetragonal, but pentagonal and hexagonal forms occur also; Schenk suggested that the tetragonal forms are characteristically associated with inclined surfaces, but detailed data are lacking on this point. The borders may be either ridges or depressions, giving rise respectively to low-centered or high-centered ice-wedge polygons.

Constitution: Nonsorted polygons may consist of silt, sand, or gravel, or of a nonsorted mixture of fines and stones. Vegetation is an essential element of some types, such as the tussock-birch-heath polygons described by Hopkins and Sigafoos and the vegetation polygons of Hopkins, Karlstrom, et al. Because nonsorted patterned ground is common in uniform mantle, and sorted forms can develop only in mantle consisting of rock particles of various sizes, it has been suggested that each of these types of patterned ground is restricted to the mantle type indicated. This conclusion is erroneous, for as indicated above nonsorted polygons may consist of a nonsorted mixture of fines and stones. The borders of nonsorted polygons are commonly characterized by wedge-shaped fissures narrowing downward. In places tabular stones lie parallel to the fissure sides, reflecting the wedge shape of the fissure. In ice-wedge polygons the bordering fissures, whether in ridges or depressions, are underlain by an irregularly wedgeshaped mass of more or less clear ice. Cross sections show that beds adjacent to ice wedges may be contorted and upturned. Involutions are common in the tussock-birch-heath polygons studied by Hopkins and Sigafoos.

Occurrence: The occurrence of most nonsorted polygons is similar to that of sorted ones. Under special conditions nonsorted polygons occur on appreciable slopes; Longwell described polygonal "slope mudcracks," Roscoe reported large nonsorted polygons on steep slopes in the Antarctic, and the present writer has seen small forms 15 cm across on a sandy slope of 27^{o} in Greenland. Evidence has been cited frequently for "fossil" forms, especially ice-wedge structures, from temperate regions formerly subjected to a more severe climate. As with sorted polygons, permafrost is not necessary for the formation of most small forms, although it appears essential for the tussock-birch-heath variety described by Hopkins and Sigafoos. Permafrost is always present with ice-wedge polygons. The fallacy of assuming that the formation of all forms of patterned ground, especially nonsorted polygons, is confined to polar, sub-polar, or alpine regions is demonstrated by desiccation polygons in temperate and arid regions, by Lang's and Knechtel's description of nonsorted polygons 24.5-27.5 m (80-90 feet) in diameter in Animas Valley, New Mexico, and by the recent formation in Poland of nonsorted polygons 1.5-3 m in diameter, attributed to desiccation, which are very similar to arctic forms. As with other types of patterned ground, almost all nonsorted polygons are associated with mantle material. Yet an unusual type has been described in which intensive frost wedging along the joints of polygonally jointed, flat-lying bedrock developed a pronounced polygonal pattern at the surface.

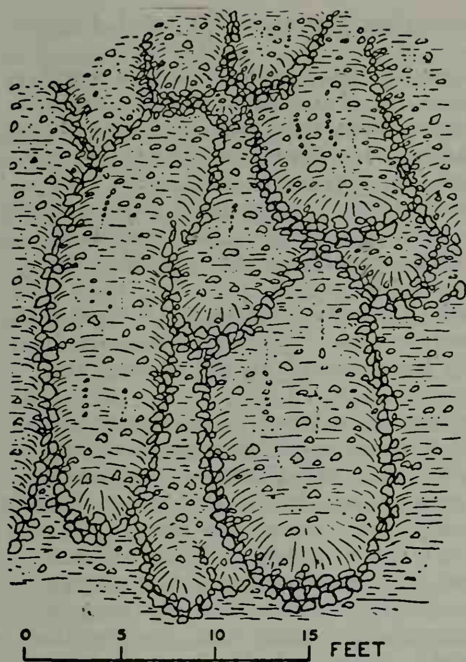
Sorted Steps. Definition: Sorted steps are patterned ground with a steplike form and a sorted appearance due to a downslope border of stones embanking an area of finer material upslope. This term is here used for the first time.

Depending on usage, more or less synonymous terms may include stone semicircles, stone-banked terraces, stone garlands, Steinguirlanden, and others.

Antevs considered stone garlands and stone-banked terraces synonymous but Sharp regarded them as two closely related types. The forms described by Antevs are generally larger, more terracelike, and more irregular than sorted steps. But because the forms described by Sharp as stone garlands are more or less regular, clearly transitional between sorted polygons and sorted stripes and therefore a type of patterned ground, they are here regarded as sorted steps. The term terracette, which was considered in place of step, is pre-empted, and the term garland has been used for a wide variety of features. Thus, terms such as stonebanked terraces and stone garlands should be reserved for terrace-like features that lack a more or less regular pattern and are not well-defined forms of patterned ground.

Form and Size: Sorted steps form in groups, rarely if ever singly. Vegetation if present does not generally emphasize the pattern as strongly as in the nonsorted forms. The steps described by Sharp are 1/2-2.4 m (4-8 feet) wide, parallel to the contour, and up to 7.6 m (25 feet) long in a downslope direction: the stone borders are most pronounced at the downslope end where they form distinct embankments. These embankments or risers are convex downslope, and the steps appear to overlap and intersect. The steps grade upslope into sorted polygons and downslope into sorted stripes.

Constitution: The treads of the sorted steps described above consisted of gravelly sand, silt, and clay within stone borders that contained boulders



Sorted steps in till.

up to 0.3 m (1 foot) in diameter. Tabular stones in the borders were commonly on edge; they were oriented vertically along the lateral margins and dipped upslope at angles of 60^o–70^o in the risers.

Occurrence: Sorted steps seem to have the same general occurrence as sorted polygons and sorted stripes, except that they are characteristic of moderate slopes, transitional between the essentially horizontal surfaces commonly associated with circles or polygons and the steeper slopes associated with stripes. Sharp recorded sorted steps on slopes of 5^o–15^o, but the treads had only a 2- to 3-degree inclination downslope.

Nonsorted Steps. Definition: Nonsorted steps are patterned ground with a steplike form and a nonsorted appearance due to a downslope border of vegetation embanking an area of relatively bare ground upslope. This term is here used for the first time.

Depending on usage, more or less synonymous terms may include turf-banked terraces, Terrassenboden, and others. Many of the comments made on the terminology of sorted steps apply in a general way to nonsorted steps. Thus, terms such as turf-banked terraces and turf garlands should be reserved for irregular, terracelike features that are not clearly defined forms of patterned ground; such features are probably far more common than nonsorted steps.

Form and Size: Nonsorted steps, like sorted steps, form in groups and have lower borders (risers) that tend to be convex downslope. Vegetation is a characteristic element in outlining the pattern. The nonsorted steps described by Sharp differed from adjacent earth hummocks, grading back into the hill slope instead of having an intervening depression. These steps were approximately the same size as the earth hummocks, i.e., 0.3-0.6 m (1-2 feet) high with ground-plan dimensions of 0.3-1.5 m (1-5 feet).

Constitution: The absence of stone borders, such as those characterizing sorted steps, is an essential feature of nonsorted steps. The nonsorted steps of Sharp consisted of an earthen core with a 7.5-15 cm (3-6 inch) hull of humus, moss, and plant roots. Where this vegetation was lacking on the upper surface of steps there was stony soil.

Occurrence: Apparently nonsorted steps have the same general occurrence as earth hummocks but are confined to slopes. Because earth hummocks need not be associated with permafrost, it is probable that nonsorted steps, too, may occur without it.

Sorted Stripes. Definition: Sorted stripes are patterned ground with a striped pattern and a sorted appearance due to parallel lines of stones and intervening strips of dominantly finer material oriented down the steepest available slope.

More or less synonymous terms are soil stripes, stone-bordered stripes, striped ground and striped soil, stone-stripes, earth stripes, rock stripes, Steinstreifen and Steinbander, Streifenboden, and others.

Form and Size: Sorted stripes never form singly; they are essentially parallel and may be sinuous. Vegetation if present does not usually emphasize the pattern as strongly as in nonsorted stripes. The width of individual stony stripes ranges from a few centimeters to 1.5 meters (5 feet) or more, and the intervening stripes of finer material may be two or four times wider, according to Sharp. Sharp also reported that he was able to trace individual stripes continuously for several hundred feet.

Constitution: In sorted stripes the stones range from pebbles in miniature stony stripes to boulders in large ones. The intervening stripes of finer material, in many places poorly sorted, may also contain stones. Tabular fragments in the stony stripes may be on edge and oriented parallel to the stripes. The depth of sorting tends to vary with the size of the forms, as in sorted polygons and sorted circles, extending to a depth of 0.6-0.9 m (2-3 feet) in the forms observed by Sharp. The stony stripes commonly narrow downward in vertical section, and in places the stones become smaller in the same direction. A cross section by Sharp suggests that, as with sorted polygons, this downward narrowing is not universal.

Occurrence: Except for being confined to slopes, sorted stripes commonly have the same occurrence as sorted polygons. Sorted polygons may merge into sorted stripes through a transition gradient of approximately 3^{o}-7^{o}, and sorted steps may occur as transition forms. Some sorted stripes, however, occur without associated sorted polygons. Maximum slopes on which sorted stripes have been reported vary from 15^{o} to 30^{o}. As with sorted polygons, large sorted stripes commonly occur with permafrost, although small ones may occur without it. The small sorted stripes described by Poser from the vicinity of Reykjavik, Iceland, are located in permafrost-free ground. Because sorted stripes are slope phenomena they are probably rarely preserved in "fossil" form in stratigraphic sections, although such forms have been reported by Ducker and Norvang.

Nonsorted Stripes. Definition: Nonsorted stripes are patterned ground with a striped pattern and a nonsorted appearance due to parallel lines of vegetation-covered ground and intervening strips of relatively bare ground oriented down the steepest available slope.

A synonymous term is solifluction stripes, but since solifluction is also associated with sorted stripes, the term nonsorted stripes is preferable. The designation vegetation stripes has been used both as a synonym and as a term for sorted stripes emphasized by vegetation.

Form and Size: Nonsorted stripes resemble sorted stripes, but vegetation is a characteristic element in outlining the pattern. Nonsorted stripes have not been extensively discussed in the literature. One report from arctic Canada states that vegetation occupied slight depressions similar to the bordering depressions of nonsorted polygons that occurred on nearly level ground immediately upslope. These stripes of vegetation were discontinuous and were 0.3-0.6 m (1-2 feet) wide and spaced 3-4.6 m (10-15 feet) apart. Elsewhere, the alternating stripes of vegetation and bare ground were about equally wide. Nonsorted stripes have also been described by Poser.

Constitution: The absence of lines of stones, such as those characterizing sorted stripes, is an essential feature of nonsorted stripes. The nonsorted stripes discussed above and others in the same area consisted of a nonsorted mixture of fines and stones, as did Poser's, except for a concentration of stones in places at the surface. The stripes of vegetation are commonly wedge-shaped in vertical section and narrow downward. This relationship was also noted by the writer in the vicinity of Holman Island Post, Victoria Island.

Occurrence: Allowing for the difference in slope, the occurrence of nonsorted stripes is presumably about the same as for nonsorted polygons. That patterns resembling typical nonsorted stripes are not confined to polar, subpolar, or alpine regions is demonstrated by "wavy gilgai" in various parts of Australia. As with sorted stripes, preservation of "fossil" nonsorted stripes in stratigraphic sections is probably exceptional.

The Problem of Patterned-Ground Origin. Despite the voluminous literature on patterned ground, very little is established about its genesis, and it is hoped this review will help investigators to focus on the critical elements of the many problems involved. A polygenetic origin is stressed by several investigators, including Poser who decided that no one hypothesis could explain the variety of forms that exist. The present review of the many hypotheses that have been suggested supports the polygenetic concept, which, in order to explain all forms of patterned ground, implies multiple processes or multiple facets of a complex process such as frost action. As suggested in more detail in the conclusion, the writer favors the view that a complete explanation involves processes and forms that are end members of a continuous system having combination processes and forms as intermediate products.

[At this point Washburn devotes 20 pages to the survey and documentation of the various hypotheses of origin. These are summarized very nicely in his conclusions.]

Conclusions. The descriptive classification of patterned ground adopted in this paper eliminates ambiguities and confusion resulting from the many overlapping and synonymous terms that have appeared in the literature. The classification is based on geometric pattern and presence or absence of sorting, and its main classes comprise sorted and nonsorted varieties of circles, nets, polygons, steps, and stripes. In the absence of more data on the genesis of the forms involved, any comprehensive classification but a purely descriptive one is believed to be impractical and premature.

The preceding discussion of hypotheses and processes supports the conclusion of Poser and others concerning the polygenetic origin of patterned ground. Although this conclusion is not new, it is here fully documented. Thus, the writer believes that any over-all explanation must involve separate processes, with frost action being regarded as a complex of processes that are highly important but not the only ones represented. Not only are many different types of patterned ground involved, but it seems probable that somewhat similar forms may originate by quite different processes. Another and obvious conclusion is that the genesis of the various kinds of patterned ground is far from established.

In polygonal patterns, it is certain that some meshes are products of drying, and very probable that others result from contraction due to low temperature. The writer believes that both types occur in cold climates and that some meshes may be combination forms reflecting the operation of both processes. In the case of circular patterns, the evidence indicates that probably local differential heaving and perhaps cryostatic movement are genetic processes of widespread significance. Possibly these processes, too, complement each other in complex fashion. For instance, cryostatic movement could bring saturated fines adjacent to coarser material with the result that the fines might be subjected to intense local heaving.

With respect to sorting, ejection of stones toward freezing surfaces by multigelation, their movement by gravity, and eluviation of fines may be key processes. They do not explain polygonal, circular, or striped patterns as the above-mentioned processes may but they are associated with these processes and may determine whether sorted or nonsorted forms are produced if other conditions remain equal.

Solifluction is probably of major significance in the origin of patterned ground on a slope. Presumably it combines with one or more of the other processes to produce the various types of patterned ground that are confined to slopes.

It is tempting to speculate that desiccation, contraction due to low temperature, local differential heaving, and cryostatic movement may combine to form a single continuous system responsible for both polygonal and circular patterns. Geometrically the end members could be represented by the corners of a tetrahedron, and the combination patterns by intermediate positions. Such intermediate positions might account for some nets, which according to the usage in this paper are neither dominantly circular or polygonal. If to these pattern-forming processes are added ejection of stones, their movement by gravity, and eluviation as sorting processes, and solifluction as the key modifier of patterns on a slope, elements of a comprehensive explanation of patterned ground are at hand. Whether or not these processes turn out to be the key ones, the writer predicts that a complete explanation of patterned ground will involve several specific processes arranged in a similar model.

Of the remaining processes reviewed, the writer believes that in the absence of additional evidence, circulation due to ice thrusting and convection due to temperature-controlled density differences can be eliminated from further consideration in the origin of patterned ground. Frost wedging, weathering, artesian pressure, and rillwork are probably valid genetic processes in special situations but not of widespread significance. The writer regards all the other reviewed processes as speculative but nevertheless stimulating in the light of present inadequate knowledge.

Before the origin of patterned ground is fully understood and the climatic significance and interpretation of present-day and "fossil" forms correctly established, it will be necessary to have much more detailed and accurate information than is now available. Cold-room studies, field observations of subsurface phenomena at different times of the year, and cooperative work between geologists, physicists, soil engineers, pedologists, and plant ecologists are urgent desiderata in further research.

• Rock Rings

"ROCK DOUGHNUTS," A PRODUCT OF GRANITE WEATHERING

Blank, Horace, R.; *American Journal of Science,* 249:822-829, 1951.

Introduction. Shallow depressions on the flat or gently sloping summits of large exposures of granite and similar igneous rocks have been described by several observers, and were named "weather pits" by Matthes. Similar depressions in limestone were called "tinajitas" by Udden, and were later described also by Smith and Albritton. King pictures them on sandstone in South Africa, where he states they are known as "rock tanks."

The pits have been attributed by most of these authors to the solvent action of impounded rain water, perhaps aided by organic matter. Their development may be initiated by exfoliation spalling and assisted by the removal of disintegration and evaporation products by the wind. Their origin need not be further discussed here.

The present writer has observed numerous weather pits of various sizes on granite at several localities in central and in trans-Pecos Texas. A very few of them are surrounded by raised annular rims, and these are the subject of the present discussion. They may conveniently be called "rock doughnuts."

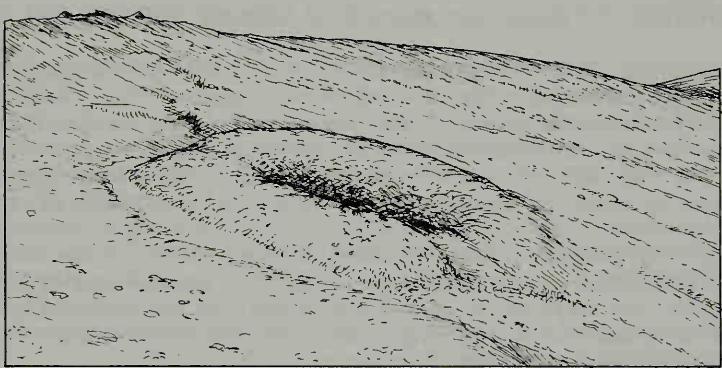
The writer is indebted to W. Armstrong Price, of the Department of Oceanography, A. & M. College of Texas, for one possible explanation of the origin of the doughnuts, and is happy to acknowledge various helpful suggestions from members of the Departments of Geology and Civil Engineering.

Occurrence and Description. During 1948 and 1949 rock doughnuts were found and studied at Enchanted Rock, which is in southwestern Llano County about 19 miles south-southwest from Llano, Texas, and in the vicinity of Katemcy, northern Mason County. A poorly developed example was also observed in granite-porphyry at the Rockpile Park, in the Davis Mountains about 25 miles west-northwest from Fort Davis, Texas.

The largest doughnut found is located on the west side of the main granite dome at Enchanted Rock, just above the nearly vertical portion of the west face of this dome. A smaller one occurs on the east side of the first large dome to the southwest. Four doughnuts, one of which has been partly destroyed by disintegration, occur on the northwest side of the Flatrock dome, close to the Katemcy-Fredonia road about 6 miles east of Katemcy and 3 miles west of Fredonia. Two more good ones were found on the summit of a granite knob about 1.5 miles south-southeast from Katemcy. A few other less perfect examples were found in this general vicinity.

Most of the doughnuts occur on granite surfaces having a decided slope, although not on the steepest slopes. Two or three, however, were found on sensibly horizontal surfaces, such as the bottom of a large weather pit. Most, but again not all of them, occur along joints, which in such cases pass right through the doughnut. At Flatrock dome three excellent doughnuts occur in line along a joint, but nearby a still more perfect example shows no jointing at all.

East rock doughnut consists of a nearly circular weather pit, from about 6 inches to about 6 feet in diameter, encircled by a rounded annular ridge up to about 6 inches high and 18 inches wide. In shape each resembles half of a doughnut or an automobile inner tube split in the plane of the wheel. In some examples the annular ridge in turn is surrounded by a shallow annular depression, which shows evidence of scour by running water and connects with shallow channels in the rock above and below.



A rock doughnut from Enchanted Rock, Texas.

After rains some of the inner pits hold water for some time. In most of the doughnuts this water apparently overflows through a low place on the downhill side of the annular ridge. Like other weather pits in their vicinity, the inner pits of many doughnuts contain a little sand or gravel composed of disintegrated granite, and the largest found, at Enchanted Rock, contained sufficient soil to support grass.

A few weather pits are encircled by broad, low, and rather indefinite ridges which merge into the surrounding rock mass. Also, at the Flatrock dome there are pits, each with a well-defined, narrow ridge on the downhill side only. These ill-defined and partly formed doughnuts strongly suggest intermediate stages in the development of the more perfect examples.

Nature of the Rock. At all the localities at which doughnuts were found in Llano and Mason counties the rock is substantially the same. It is a coarse pink granite consisting essentially of pink microcline, white plagioclase, quartz, and biotite. The largest grains are those of the microcline, which at places reach several centimeters in length and give the rock a porphyritic texture. The quartz and biotite, though in grains much smaller than the feldspars, are still plainly visible. Detailed descriptions, both megascopic and microscopic, and chemical analyses of the granite at Enchanted Rock and at the Flatrock dome have been given by Barnes. A Rosiwal analysis of a specimen from the Flatrock dome is given by Keppel.

Weathering and erosion of the granite domes take place by granular disintegration, commonly assisted by exfoliation spalling (on a large scale at Enchanted Rock), and by the washing away of the resulting sand or gruss, which consists chiefly of microcline and quartz. On many of the unbroken dome surfaces weathering seems to be extremely superficial, but all loose pieces and spalls show it to some extent. Consequently it is very difficult to obtain an entirely unweathered specimen by means of hand tools. Weathering begins as a slight chalking of the plagioclase, together with an oxidation of the biotite that produces rusty stains which commonly penetrate the quartz also. A weakening of the structures between the grains accompanies these changes, and the rock eventually becomes friable.

At none of the doughnuts found was there any observable difference in composition, texture, or appearance of the granite as exposed in the central pit, on the annular ridge, and in the surrounding rock mass, although some such difference was expected and was looked for. Microscopic examination of the rock from the different parts of the doughnut might be desirable but has not yet been made. Collecting fresh samples from these solid rock surfaces is a problem in itself.

Possible Origin. The origin of the rock doughnuts is extremely puzzling, and the writer has as yet no satisfactory explanation for them. They are unquestionably connected with the weather pits, but they are rare in comparison with the total number of weather pits, which suggests that they result from some unusual modification or extension of the processes responsible for the pits.

Although detailed petrographic or chemical analyses are lacking, the apparent identity of the granite in all parts of the doughnuts with that in the surrounding dome surface makes it very unlikely that the doughnuts result from original differences within the rock. Matthes attributed the beginnings of the Yosemite weather pits to "local aggregates of readily soluble minerals," but L. L. Smith found no difference in the texture or composition of the rock within and without the pits on the granite domes of South Carolina.

Water running down the slopes of the granite domes eventually forms shallow channels in the rock. At a few places these bifurcate and come together again, leaving an "island" of granite. As the channels deepen this process could produce a knob of granite surrounded by an annular channel; in fact such a knob was found about 1.5 miles south-southeast from Katemcy. If then a pit should start in the top of the knob, perhaps from an exfoliation spall, a doughnut could conceivably be produced. But this explanation would seem to require that the annular channel be deeper and better developed than the central pit, whereas the reverse was everywhere found to be the case. All evidence seems to indicate that the pits are older than the annular channels, which are not present at all doughnuts.

Where joints in the granite run directly down the slope of the domes there is commonly a series of small weather pits along them. At two localities in the area south of Katemcy such joints are bordered by ridges which rise from a few inches to nearly a foot above the surrounding surface. These ridges are themselves bordered by shallow channels, which receive runoff not only from the top of the dome but to a smaller extent from the ridges. The ridges broaden and bend around the weather pits along the joints. There is some suggestion that a trellis drainage pattern is in process of formation, and that eventually the ridges may become dissected into a series of knobs, of which those containing the weather pits will become doughnuts. However, this hypothesis merely transfers the problem of the origin of the doughnuts to the equally difficult one of the origin of the ridges along the joints, and of course does not account for those doughnuts occurring in the unjointed granite.

A hypothesis of "case hardening" was proposed by Anderson to account for large pits and other weathering phenomena on granodiorite in Idaho, and the same process was later invoked by White to explain his "indurated veneer" on granites in the southeastern Piedmont. A similar induration hypothesis for the origin of the rock doughnuts was first suggested to the writer by W. Armstrong Price. The water standing in an ordinary weather pit, containing dissolved solids from the rock, conceivably might penetrate the granite for a short distance around the pit in spite of the very limited porosity of this rock. A halo of saturated granite would thus be formed around the pit. As the water evaporated, its solutes and their oxidation products would remain in this halo, possibly indurating the rock and rendering a hollow cylinder of granite more resistant to erosion than the remainder of the mass.

If this indurated cylinder did not extend much above the highest water level in the weather pit, the partial doughnuts at Flatrock dome, with their ridges only on the downhill side, could readily be accounted for. But the existence of perfect doughnuts on moderately steep slopes would require that the water in the rock on the uphill side be drawn by capillarity at least a foot higher than the water level in the pit, or else that at least a foot of solid granite has been eroded from the downhill side since the doughnut first began to form. Tilting of the entire dome is too unlikely to be considered.

A process of induration would plausibly account for the origin of the doughnuts, but its application to the ridges along joints, is more difficult. Here water occupies the trough between the ridges only during the brief periods of actual runoff, which would seem too short a time for it to penetrate the rock.

But the chief objection to the induration hypothesis is that megascopically, at least, there is not the slightest evidence of induration in any of the rock doughnuts found in central Texas. In almost every case the same degree of weathering is present on the doughnut ridge and on the adjacent dome surface, and in the one exception found it was the doughnut ridge which had begun to disintegrate. Most of the doughnuts occur on hard, sound granite on which the skin of weathered rock is very thin, as already stated. There is no evidence of any indurated veneer. At the Rockpile Park in trans-Pecos Texas some indication of an indurated veneer was found on the granite-porphyry, but there only one doughnut, poorly developed, was observed.

White pictures ring-shaped weather pits in the granite of Wilkes County, North Carolina, which he attributes to breaching of a widespread indurated veneer by the growth of ring-shaped patches of moss. It is interesting that the resulting micro-relief in the surface of the granite is exactly the reverse of the Texas rock doughnuts. It is hardly possible, however, to reverse White's explanation, even though in central Texas much of the granite surface, including the doughnut ridges, supports a growth of minute lichens.

The presence or absence of induration in the rock doughnuts can be definitely established only by petrographic examination of samples carefully cut from the central pit, the annular ridge, the annular channel, and the adjacent dome surface, preferably by some means, such as a diamond saw or core drill, which would not disrupt the rock. It may be possible, however, to explain the doughnuts and ridges by differential weathering without recourse to induration.

If, during a heavy rain, water should run off the bare surface of the dome as a sheet flood of sensible depth, any pre-existing weather pits, if not too large, would soon fill to the brim. Thereafter the water flowing through and over a weather pit would have its velocity retarded as compared with the rest of the sheet. Eddies could therefore develop around the border of the pit, thus reducing the total quantity of water which would pass over this annular area in a given time. Assuming that the weathering of the granite takes place by granular disintegration induced by the solvent or chemical action of water, that is, by corrosion rather than by corrasion, then many repetitions of the above flow pattern over an immensely long period of time would result in less corrosion on the annular area than on the rest of the dome surface, and a residual annular ridge could be formed.

The ridges along joints could be explained in the same way. Once the water, by concentrating along the outcrop of the joint, had worn a trough along it, during all subsequent sheet floods the water in this trough would flow at a higher velocity than that covering the adjacent dome surface. Eddies could therefore develop along the edges of the trough, and in time the total solvent action of the water would be less along these strips than on the rest of the dome surface.

This explanation meets with grave difficulties in accounting for doughnuts on sensibly horizontal surfaces. Even here during heavy rains the water might have some movement, but any difference in velocity within and without a pit on such a surface would certainly be very slight.

Once the ridges, whether annular or straight, were initiated they would divert water and cause still greater differences in solvent action between their own areas and the general rock surface; thus they would continue to grow. They would be destroyed, however, by exvoliation of the rock. Thus rock doughnuts should be found only where destruction of the dome surfaces by exfoliation proceeds more slowly than by granular disintegration. This may explain their rarity. It may be significant that in the Enchanted Rock region, where exfoliation is active, only two doughnuts and no ridges along joints were found, whereas in the Katemcy region, where little exfoliation was observed, doughnuts are more numerous and joint ridges exist. Matthes suggests that the Yosemite weather pits are very old and develop at an extremely slow rate, as they are not found on freshly glaciated rock surfaces. If the rock doughnuts have been formed by the process of differential corrosion above suggested they must be among the oldest of weather pits.

CIRCULAR PATTERNS AND EXFOLIATION IN CRYSTALLINE TERRANE.....

Hack, John T.; *Geological Society of America, Bulletin,* 77:975-986, 1966.

Abstract: Aerial photographs of areas of crystalline rock in the Piedmont and Blue Ridge of western North Carolina reveal numerous large-scale arcuate, circular, and elliptical patterns with diameters from 1000 to more than 4000 feet. They are commonly defined by curving streams, curving ridges, and curving belts of contrasting vegetation. Geological mapping shows that the circular patterns are not related to primary geologic structures; circumstantial evidence indicates that they are related to exfoliation or sheeting. Rock spalls up to half a mile in diameter may be formed by dilation of the rock as the erosion surface is lowered. The spalls enable tectonic joints to open, forming thin layers of rock of differing permeability and susceptibility to erosion. Exfoliation is probably involved in the erosive process and is probably more important than has been realized, especially in crystalline terrane.

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Introduction. Distinctive circular patterns in the Grandfather Mountain area of North Carolina were observed on aerial photographs during a study of geomorphic features along the Blue Ridge escarpment. These patterns are discussed here in the belief that they are widespread erosional forms that have not previously been described and that they are worthy of study. They are believed to be the result of sheeting or exfoliation. If sheeting is the correct explanation, a better understanding of sheeting phenomena may aid in understanding the distribution of shallow ground water and weathered materials in crystalline terrane.

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Description of the Circular Patterns. The circular patterns in the Grandfather Mountain area are defined by arcuate drainage and vegetation lines, domical features, and basin-shaped hollows. Diameters vary widely, but many are 2000-3000 feet across and some, more than 1 mile. Figure 2 shows the outlines of the most obvious patterns in the central part of the area. The arcuate patterns, however, are actually more densely distributed than shown. As some are much more obvious than others, delineating them on a map is a subjective procedure. Moreover the photographs used in the identification of the features are of uneven quality, and in a few places, particularly in the area east of Wilson Creek in the northern part of the map area, some small areas are not covered by the photographs examined. The map, therefore, is intended only to give an idea of their size range and general distribution in this area of complex geology.

In the Grandfather Mountain window the Wilson Creek Gneiss is mostly granitice, ranging in texture from coarse-grained cataclastic gneiss to very fine-grained phyllonite. The Blowing Rock Gneiss is coarse-grained augen gneiss with microcline porphyroclasts averaging 2-4 cm in length. It also contains finer grained rocks resembling the Wilson Creek Gneiss. The Brown Mountain Granite is massive, coarse-grained, and poorly foliated and lineated. The Grandfather Mountain Formation in this area is primarily sericitic arkose and arkosic quartzite but also contains felsic volcanic rocks.

Rocks of the Blue Ridge thrust sheet consist of fine-grained to medium-grained biotite gneiss interlayered with biotite-muscovite schist. The Brevard zone includes blastomylonite, phyllonitic schist and gneiss, and fine-grained biotite-quartz-plagioclase gneiss. Rocks of the Inner Piedmont include layered quartz-biotite-plagioclase gneiss and mica schist, and biotite-quartz monzonite. A biabase dike of Triassic age crosses the southern part of the area from northwest to southeast.

Although the arcuate and circular patterns average about 2500 feet in diameter (Fig. 2), in some places they are consistently smaller, especially in the outcrop area of the Blowing Rock Gneiss, where the average diameter is between 500 and 1000 feet. The patterns are generally unaffected by geologic contacts, and many cross rock boundaries. They are formed in massive rocks, like the Brown Mountain Granite, as well as in highly foliated rocks like the Wilson Creek Gneiss and the mica schist of the Blue Ridge thrust sheet. The patterns are less abundant in some rock types than in others. Although they occur with varying density throughout the area of Figure 2, they appear to be totally absent from such rocks as the Beech Granite of the Blue Ridge thrust sheet, which occupies a large area between the Elk and Watauga rivers; in addition, they are uncommon in the Brevard fault zone.

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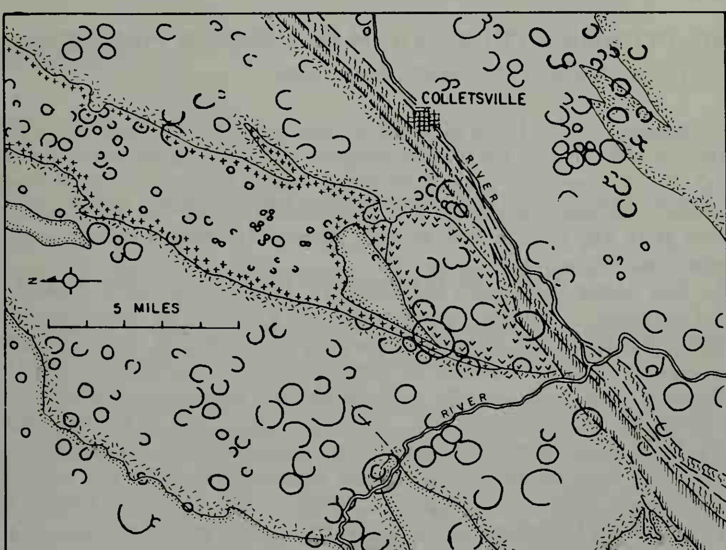


Geological map of the Grandfather Mountain area, showing the most obvious circular structures seen on aerial photographs. (Fig. 2)

Conclusions. Ringlike patterns, bowl-shaped basins, and domical hills in the Grandfather Mountain area are more abundant and more nearly circular than would be expected if not formed by some special process. Study of the areal distribution of circular patterns, in places almost perfect in form, shows that they are for the most part peculiar to crystalline rocks of fairly homogeneous texture. That these features are formed by some general nonlocal process is proved by the fact that aerial photographs show similar features in homogeneous rocks of other areas, such as the Blue Ridge of northern Virginia and the Yosemite Valley of California. The features are believed to result from the formation of thick spalls of large diameter. Fractures seen in roadcuts in an area of Brown Mountain Granite show that sheeting joints of the required kind are present and also that the opening of tectonic joints which facilitate the formation of circular basins is probably dependent on exfoliation.

Much of the crystalline terrane of western North Carolina is characterized by bare rock surfaces, abrupt changes in stream gradient, and waterfalls. This topography is probably partly the result of exfoliation, which causes a complex arrangement near the surface of rocks of varying permeability and resistance to erosion.

• Beach Pyramids

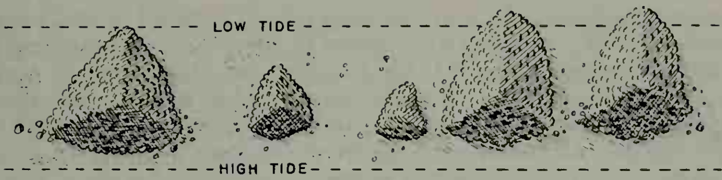
NATURAL PYRAMIDS ON A BEACH IN THE NEW HEBRIDES

Baker, John R.; *Nature,* 122:843-844, 1928.

While engaged recently in biological research in the New Hebrides (in the Pacific Ocean) under the Percy Sladen Trust, I came across a curious geological phenomenon on the black sandy beach to the east of the mouth of the R. Yoro in Big Bay, Espiritu Santo. I have never heard of anything resembling it in any part of the world. Possibly there are readers of Nature who can explain it.

All the way along the beach for three or four miles there extends a row of piles of pebbles. Most of these piles are a couple of feet high in the middle and a dozen paces across. They are covered at high tide and wholly or nearly wholly exposed at low tide. The constituent pebbles, of black volcanic rock, are mostly oval in shape, somewhat flattened, and perhaps three or four inches long. Between each pile of pebbles and the next there is in most cases an expanse of sand several paces across, which is almost bare of pebbles. There is a tendency for the piles to assume a definite shape (see Fig. 1), namely, the shape of a very low pyramid has been plastered on, as it were, to the seaward side of a larger one (see right-hand side of Fig. 1). Each pile of pebbles rests on a similarly shaped accumulation of sand; and where there are no pebbles, the sand alone continues the succession of pyramids.

I erected sticks to mark the position of two adjacent well-formed pyra-



Naturally formed beach pyramids.

mids, to see whether they would shift their position at all. Next day one of them was as before, while the other had shifted slightly, and a small one had arisen between them. Two days later again the two marked pyramids had disappeared, one completely, the other so nearly completely that I should not have guessed of its previous existence had I not marked it before.

It is perhaps significant I noticed a strong current running in a westerly direction parallel to the shore.

This curious row of low pyramids extends along the beach to the west of the mouth of the river also; but here the phenomenon is less clearly defined, for the stones are much more numerous and the pyramids are not separated by bare areas. At Tasiriki, near the southwest corner of the same island, there is a somewhat similar row of piles of pebbles.

• River Striations

STRIATIONS IN GRAVEL BARS OF THE YUKON AND PORCUPINE RIVERS.....

Barnett, V. H.; *Journal of Geology,* 16:76–78, 1908.

The presence of furrows in gravel bars of spreading and meandering streams in Alaska seems not to have been mentioned in the literature on Alaskan geology.

These channels may be seen on the extensive bars of the Yukon and of the Porcupine rivers throughout the Yukon Flats. The bars are remarkably well developed along the Porcupine for about a hundred miles above its union with the Yukon and in low water they are exposed as broad, gravelly, and sandy beaches from one to five miles in extent. These extensive bars give excellent opportunity to observe the striations. An uprooted tree is often seen lodged on a bar with a channel marking its trail.

Three hypotheses may be offered in explanation of these furrows: first, that they are caused by tree trunks held firmly to the river bottom, either by accumulated debris or ice, and moved forward by the force of the stream; second, that they are caused by blocks of ice beneath a load or ice jam and moved forward in the breakup; or, third, that they are due to trees passing over bars only partly supported by water, the current banking up behind the stump, though having sufficient force to push slowly along, yet not able to remove the marks of the tree.

The third method would seem a simple explanation for the origin of the furrow shown in Fig. 1. [Figures omitted] Here an uprooted pine tree may be seen at the down-stream side with a straight furrow passing up stream.

It does not seem to the writer that any accumulation of debris that might collect in the roots of a tree would be competent to hold it to the bottom with sufficient force to make the furrows shown in Fig. 2. The force of the water would tend to relieve the roots of any material competent to sink the tree, such as rocks or frozen earth. The only other material at hand to which one might ascribe such a force, is ice.

There is evidence that during the ice breakup of spring, great pressure is exerted on the banks and shallow portions of the stream.

At a number of places last summer the writer observed talus where rock fragments were pressed into a pavement. These were seen both along the Yukon and along the Porcupine rivers. Russell in his paper on the surface geology of Alaska speaks of the river ice as producing pavements of pebbles along the banks and of the pebbles being faced and striated on their upper side. These pavements occur between the high-water and low-water lines, and as the water was low at the time of the writer's visit, an excellent opportunity was presented to observe them. The pavements are composed of variously sized rock fragments, from a few inches in diameter up to two or three feet, sometimes water-worn, but more often angular, with their upper side smooth and striated parallel to the stream.

There seems no doubt, therefore, that moving ice if equipped with proper means could produce the furrows observed in the gravels.

....

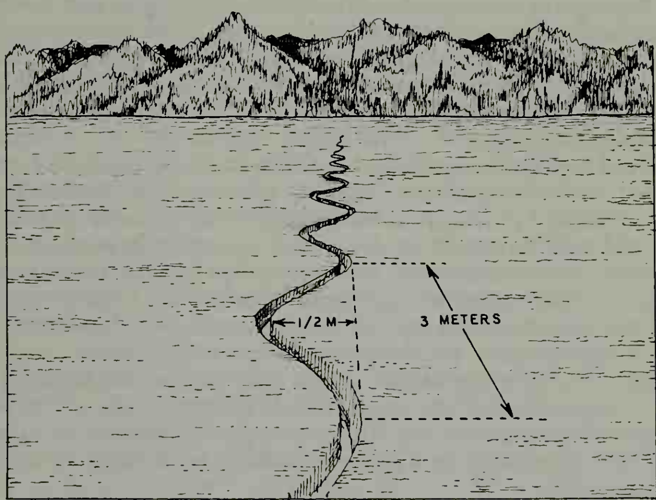
• Ice Cracks

A SINE CURVE CRACK IN NATURAL ICE

Groselj, Pavel; *Nature,* 135:877, 1935.

In January of this year, an interesting phenomenon was observed on Lake Bohinj in the Julian Alps. This lake, in the extreme north-west of Yugoslavia, is a typical alpine lake, its basin having been hollowed out by a diluvial glacier. Its altitude is 523 m., it is about 4 km. long and 1 km. wide. In winter the lake is thickly frozen over and last winter was no exception. Acute tangential tensions always set up in the ice crust and find adjustment in various cracks which extend over the entire width of the lake in straight or broken lines, as the case may be. As a rule, the cracking of the ice is accompanied by a powerful detonation which can be heard distinctly for a distance of several kilometres.

On January 4, Mr. F. Avein noticed a peculiar crack in the ice. It extended across the entire lake and was about one kilometre in length. Near the southern shore its course was curved and then followed a straight line to the opposite shore. The crack itself, however, was in the form of an almost perfect sine curve (Fig. 1). The wave-length of this curve was about three metres, its amplitude about 0.5 m. The ice was about 15 cm. thick. The crack was about 10 cm. wide and, on January 4, a thin crust of new ice had already formed upon it. There were several other cracks in the ice, but all of them normal, that is, straight. They too were newly frozen over and, therefore, appeared to be of the same age as the sine curve crack.



Sine-curve crack in the ice of Lake Bohinj.

It is suggested that the detonation caused by the occurrence of one of the normal cracks liberated the tensions in the sine curve crack. The percussion started by the cracking of the ice travelled through the ice in the form of longitudinal vibrations. Periodically alternating condensations and attenuations passed across the crack as it was being formed in a straight line. Might not the combination of these two phenomena furnish the explanation of the sine curve track of the crack? I am indebted to Mr. F. Avein for the photograph and description of this strange phenomenon.

• Unusual Mud Cracks

GIANT DESICCATION POLYGONS OF GREAT BASIN PLAYAS

Neal, James T., et al; *Geological Society of America, Bulletin,* 79:69-90, 1968.

Abstract. Several previous investigators have recognized giant polygonal fissure patterns in 6 playas of the Basin and Range Physiographic Province (Great Basin). This paper extends the study to 39 playas in Oregon, Nevada, California, Arizona, and New Mexico, with observations on the physical and mineralogical features of fissured and nonfissured areas.

Fissures are often 5 m deep and the polygons may attain a width of 300 m. These giant mud cracks develop in clay playas and are attributed to desiccation phenomena. As dehydration proceeds from the surface downward and penetrates the capillary fringe above the water table, shrinkage occurs, which ultimately results in rupture at depth that extends upward to the surface.

The mineral constituents of sediments in both the fissured and nonfissured areas are predominantly clay minerals, carbonates, salines, and analcite, with fine grains of quartz, feldspar, and ferro-magnesian silicates. Fissured playas possess significantly greater quantities of clay and carbonate minerals as compared to nonfissured playas. The clay minerals, carbonates, and analcite are primarily present in $< 2\mu$ size fraction. This colloidal aggregate is believed to exert a major influence on the physical behavior of the sediments which contain the giant polygons. In particular, the dehydration to an almost dry condition of a clay mass, in which the water content may exceed the mineral content, results in a major loss of volume. The shrinkage leads to rupture with the formation of fissures. The fissures form orthogonal polygons characteristic of volume change in a largely uniform horizontal mass with one surface exposed.

POLYGONAL FRACTURE AND FOLD SYSTEMS IN THE SALT CRUST.....

Christiansen, F. W.; *Science*, 139:607-609, 1963.

Abstract. "Small folds and fractures (thrusts) up to 50 feet apart that have produced polygonal patterns in the Bonneville salt crust, western Utah, are believed to be caused by the annual expansion of the salt crust due to the growth of salt crystals within the salt layer plus the effect of increased summer temperature. It is suggested that these strain systems are caused by positive (compressional) isotropic planar stresses developed within the salt layers of the salt crust.

• Ten O'Clock Marks

TEN O'CLOCK MARKS

Lang, Walter B.; *Science,* 100:288, 1944.

Some fifteen years ago while engaged in the reconnaissance survey of western Texas and southeastern New Mexico leading to a search for suitable potash core-drill sites, the writer while examining the terrain became conscious of a faint linear arrangement of patches of light sandy-loam soil which appeared on clear winter mornings following a frosty night. The peculiar lumpy condition of the soil was plainly due to frost action, but the origin of the faint-grained pattern superimposed upon this matte of raised soil was less certain.

The pattern once noticed is easily recognized elsewhere. It appears as a series of parallel straight lines as if the surface had been raked into small ridges and furrows about an inch or more from crest to crest and three-eighths to three-quarter inch deep. Wherever these striated surfaces were seen, the lines always pointed in a southeasterly direction which accords with the position of the sun at about ten o'clock on a winter morning in the vicinity of latitude North 30°. This suggested that some action of the sun was the cause of the pattern and as it had been seen always on ground sparsely covered by small bunch and buffalo grass, it was assumed the long, low-angle shadows cast by the grass had caused the differential melting of the frost in the soil. Consequently the subject was dismissed as of little importance until one day a year or two later I chanced to see a wide spread of frost-lifted loam with well-developed striae out in the middle of a broad playa, far removed from anything that could possibly cast a shadow. All the striae were oriented in line with the position of the sun in mid-morning. It was plain that two events had occurred between nightfall and late morning to change a previously smooth sandy-loam surface into this roughened and striated condition. Patches of ground containing a proper amount of moisture had frozen during the night raising lumps of soil above the level of the flat and in the morning the warmth of the sun in drawing the frost had caused a differential collapse of the raised material. The thawing and collapse on an exposed surface occurs at a critical moment and all within a few minutes of time. To one's imagination it appears as if streams of quanta had bombarded the supports from beneath rows of pedestalled soil but left other rows untouched.

Where moisture is supplied from beneath the surface and not from the atmosphere during a night of freezing temperature, frost-lift of soil is a common occurrence. It is most conspicuous in the south-eastern states where saturated sandy soils oozing water during a night of freezing temperature grow carpets of slim, columnar, ice crystals which carry up with them the overlying surface material. When the ice on a level surface melts, the soil and debris fall back into place without giving suggestion of a regular or linear pattern. On a sloping surface the material drops down grade, thus serving the process of soil creep.

One winter, some years later, I came upon a smooth northwesterly facing embankment with a four-foot radius of curvature. It was covered with frost-striae, but the lines did not have a constant direction. It was evident that this surface became progressively exposed to the sun from the upper to the lower part of the slope and that during this period of advancing exposure, the sun had moved through a wide arc to the west. Thus tangents to the curved striae were found to point in the direction of the sun at the time of initial exposure. This example gives further emphasis to the strange relation that the sun's rays have to these striae.

In all previous cases the effect was produced by the morning sun that by about ten o'clock on a winter day had warmed the air and the ground sufficiently to melt the frost. Those seen on the curved surface were formed in the afternoon. To produce and preserve these striae required an evenly balanced temperature throughout the day, one in which the air near the ground remained slightly below freezing in the shade but was raised slightly above freezing in the direct rays of the sun. The pattern progressively developed as the frozen surface emerged from the shadow.

This spring I happened to see straight striae on snow in Washington. The surface was dirty, but no relation existed between the arrangement of the dirt and the course of the striae. Their trend was also toward the position of the late morning sun. Foreign material, especially dark rock fragments, often make conical holes in ice and snow which point to the sun but there seem to be few parallel examples of ablation effects to serve as an explanation as to how these ten o'clock marks are formed. That these striae are repetitional realities is certain, for they have served the writer as a compass on overcast days, when the marks will persist a day or two under favorable conditions. The solution of the problem of their origin requires more detailed observation than it was possible for the writer to give to them in the fulfillment of his other duties.

• Gilgai

DESERT GILGAI

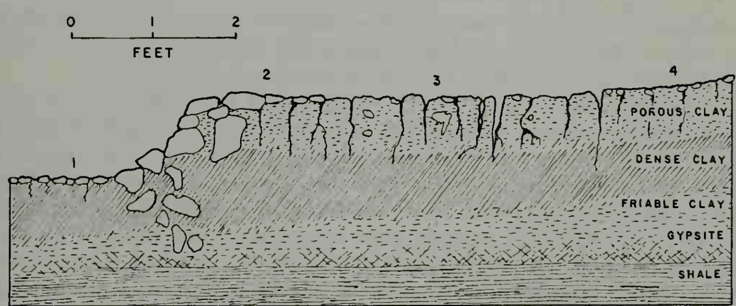
Ollier, C. D.; *Nature,* 212:581-583, 1966.

Patterned ground is a well known geomorphic and soil phenomenon that has been described from many parts of the world, particularly from periglacial or formerly periglacial regions. Patterned ground, however, is often found beyond the range of any possible periglacial action, and the Australian name "gilgai" has been applied to many of these examples. The gilgai of the northern part of South Australia were first described by Jessup, who gave a regional account of soil types and indicated the distribution of the gilgai. Ollier and Tuddenham described slope development at Coober Pedy, in the same area, and mentioned desert gilgai as one of the features affecting physiographic development. The present article is a more detailed account of these desert gilgai.

Coober Pedy is situated on the Stuart Range, an erosion scarp some 20-90 ft. high which forms the divide between two flat plains. The area is underlain by flat Cretaceous sediments, mainly sandstones and claystones, and there is a siliceous duricrust on the upper surface. The area is part of the Central Australian stony desert: sand deposits are lacking and the area is carpeted by a layer of stones (gibbers)---usually only one stone thick---which form a typical lag gravel. The climate is typically arid with maximum temperature up to about 120°F and a large diurnal range, extending to rare frosts. Rainfall may amount to about 6 in. a year, but completely dry years are known. Further details of the physiography, climate and vegetation are given by Jessup and by Ollier and Tuddenham.

Desert gilgai are found on upper and lower plains where they are circular, and on the gentle lower slopes of the scarp (up to about 5°) where they are stepped. Both types are characterized by bare patches, where gibbers are few or absent, and a rim where gibbers are concentrated. The bare patch is normally slightly lower than the rim in circular gilgai, and in the steps it is at about the same level. Both sorts of gilgai are scattered; the circles are widely spaced and never close enough to form a net, and the steps are usually single, but sometimes they occur in small groups. Washburn reports that isolated steps are very unusual. The circular gilgai have bare patches 5-25 ft. in diameter and the surfaces are a few inches below the rim. The steps are often about 10 ft. wide and of indeterminate length for they simply merge into the slope behind. Jessup records larger gilgai with deeper depressions. On the classification of Washburn the gilgai of the flat sites are "sorted circles" and those of the slopes are "sorted steps". On the classification of Verger, the round ones are "anarchic depressions" and the steps are "mounds with one orientation".

All parts of desert gilgai present roughly the same soil profile---that of Jessup's "stony tableland" soils. Apart from the gibbers this consists of a heavy clay topsoil, 1-2 ft. thick with a few concretions rich in gypsum in the lower part, overlying a horizon rich in finely divided gypsum ("gypsite" layer) which in turn overlies bedrock. On sites without gilgai there is a surface layer of gibbers but very few stones in the rest of the profile.



Cross section of sorted-step desert gilgai.

In the circular desert gilgai gibbers are almost absent in the centre and are concentrated in the rim, but remain only a surface deposit. In the steps the gibbers, including some very large ones, extend right through the profile of the rim. No preferred orientation was detected in the attitude of the buried gibbers.

Soil structure is variable. The topsoil of the bare patches is deeply cracked and breaks into large irregular blocks that divide further into subangular clods. This upper layer has a great deal of pore space and a very low density. Below the topsoil is a layer of denser clay which breaks into angular peds, and under this there is more a friable soil with concretions and a more nutty structure. Structure is indeterminable among the mass of gibbers of the rim, and on the downhill side the soil generally has a sub-angular blocky structure. There may be considerable variation in structure. There may be considerable variation in structure, for this description differs from that of Jessup. [Soil analysis omitted.]

Washburn has reviewed the numerous theories which were developed up to 1955 to explain the formation of patterned ground. Almost all the theories which he includes are concerned with cold climate phenomena, and the coldness usually features in the proposed explanations. Coober Pedy is an area that has never been subjected to periglacial conditions and such theories cannot apply directly, they can only suggest mechanisms.

The only desert gilgai reported in the literature are sorted steps formed on gravel fans in Death Valley, California. The fine material of the steps contain up to 5 per cent of water soluble salt, so these steps probably have a different origin from the Australian ones, and are probably fossil features that date from a previous climatic period.

Verger has also considered some of the theories of formation of gilgai in non-glaciated areas, but none of them can be applied easily to the desert gilgai. Various suggestions have been made for the formation of gilgai in Australia, but they all involve repeated swelling and contraction caused by alternate wetting and drying. This was also the basis of the mechanism for desert gilgai formation suggested by Ollier and Teddenham.

The soil contains much clay, and the very low density of the topsoil when dry suggests an ability to expand on wetting, followed by contraction (but not immediately collapse) on drying. If a small patch of soil swells into a dome, gibbers could fall from the raised part and settle lower down. On flat sites the stones would accumulate around the edge of the clay dome from which they fall.

On slopes most stones move to the downhill side, giving rise to stepped gilgai, and as the step may also creep downhill by mass movement some gibbers may be incorporated into the subsoil by overriding.

If, as is claimed, the carpet of gibbers is a lag gravel, then when gilgai formation exposes bare patches to wind erosion they should be deflated until a new carpet of stones provides protection. There seem to be two possible relationships between the gilgai and deflation. First, the gilgai may have been formed later than a uniform gibber plain, in which case deflation is no longer important. Second, there may be repeated formation and destruction of gilgai in equilibrium with the environment. It would be necessary to watch changes in gilgai over a period of years, perhaps many years, to determine their evolution, and this has not been done, but because strong winds and dust storms are still prevalent in the areas the second hypothesis is preferred. This suggested alternation between lag gravel and gilgai formation is complicated by the insufficiency of stones in the subsoil to make a complete carpet of lag gravel, so that some sort of lateral movement of gibbers must be considered. Perhaps when bare patches are deflated into distinct depressions the gibbers of the rim fall back towards the centre. In the stepped gilgai there is no problem because hillside creep could provide new gibbers.

Jessup does not believe that the surface gravel layer is a lag deposit, but has suggested that the rise of gibbers through a slowly accumulating aeolian deposit is involved in the development of the soil profile. I do not accept this hypothesis, but Jessup's experiments indicate that there may be some turbulence in the stony tableland soils, and a more complicated mechanism than the simple one outlined above may be involved.

Leeper and Hallsworth et al. have shown that in some gilgai the subsoil of the depressions comes to the surface in the rims (puffs), and thus suggests some sort of turbulent flow within the soil. Jessup thought that sodium content might indicate the same sort of turbulence in desert gilgai, but the analyses reported here do not suggest any circulation within the soil. The conclusion is that the desert gilgai, unlike many varieties, are formed by simple vertical swelling and shrinking rather than by churning or circulating within the soil.

• Linear Sink-Hole Formations

LINEAR AND DENDRITIC SINK-HOLE PATTERNS.....

Melton, Frank A.; *Science,* 80:123–124, 1934.

Sink-holes arranged in straight lines have lately been discovered in the High Plains in the southeastern part of New Mexico. These manifestations of the dissolving action of ground-water range in size from features which are very small to others more than 1,800 feet in diameter. They are connected in places by straight "trenches" of varying depth, which are possibly also the result of solution. The basins possess different degrees of roundness, the larger ones being the more elongate. These straight alinements, extending for 10 or 15 miles, are usually arranged in a parallel series which may be seen at various places throughout a considerable region. In Lea County, in an area as large as a 15-minute quadrangle, the mode of these linear trends is north 64° west. The mean deviation from this value is only a few degrees.

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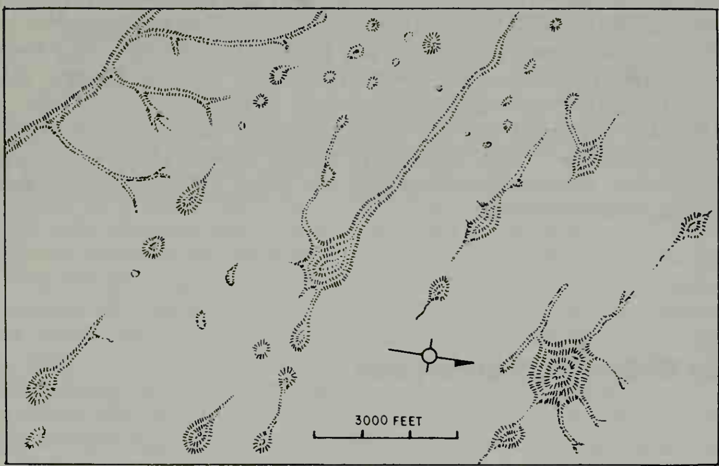
The large basins doubtless owe their alinement directly to a system of parallel fractures in the underlying bed-rock. Faults and joints with somewhat similar trend are prominent features in the Yates oil district and at other localities to the southeastward. Some of the smaller sink-holes likewise may be due to the presence of joints in the bed-rock, though in this case there is probably only an indirect connection. For example, straight ravines may have been eroded along these fractures in the Triassic strata before their burial by the Tertiary caliche deposits. Removal of limestone by underground drainage through the hypothetical valleys may thus have formed many small depressions as well as the elongate "trenches" in the present surface. Since the caliche is seldom found to be jointed with an intensity similar to that of the underlying terrane it does not seem probable that planes of fracture in this superficial formation could have been responsible for such an alinement.



Alignment of sink-holes in southeastern New Mexico. Shaded areas represent dark soil.

In addition to this linear arrangement, a branching pattern is manifested in some places by groups of connected basins having an average diameter of less than 200 feet. This pattern has doubtless developed through the work of ground-water within the caliche, either as it integrated separate drainage channels into a connected system, or as it flowed along branching valleys buried beneath the porous Tertiary beds. The available facts are inadequate to test these two alternatives. The writer has seen similar branching patterns in Florida; linear patterns formed by a series of parallel lines, however, are rare in that state as well as in the Mammoth Cave district of Kentucky.

CURIOSITIES OF COAL

Geologists are generally agreed that coal is simply altered plant materials. The real coal controversy has always revolved around whether: (1) the coal beds were formed in situ from steadily accumulating vegetable matter (as in a peat bog); or (2) plant debris was first accumulated by water action (rivers and floods) and then transformed.

The purported plant origin of coal is difficult to controvert, for this ubiquitous black rock contains an abundance of fossil leaves, spores, seeds, and sundry woody structures. It is possible, however, to direct attention to several odd and poorly understood types of coal, such as mother-of-coal (fusain), jelly-coal, bird's-eye coal, and the like. In addition, miners frequently discover coal balls (a type of concretion full of plant fossils) and must contend with curious jointing (cleat) that prevails over wide areas. But these phenomena are merely curious, hardly world-shaking.

The deeper mysteries of coal formation are to be discovered in the macroscopic structure of the coal beds and accompanying strata.

1. Coal beds are remarkably uniform in thickness over thousands of square miles; a fact hard-to-explain with in-situ or flood theories. Coal seams and adjacent shale and clay strata, whether fractions of an inch or several feet in thickness, often persist for hundreds of miles.
2. Coal seams are frequently members of cyclothems, in which the same sequences of strata repeat dozens of times. (See pp. 179-184.)
3. Miners sometimes encounter erratic boulders in coal. It has always been a mystery how these rocks were transported to the embryonic coal measures. Ice-rafting, always a favorite carrier of erratics, hardly seems applicable in dinosaur-haunted tropical swamps.
4. Numerous fossil trees, still upright, penetrate some coal beds suggesting that plant material accumulated so rapidly that some trees did not have time to decay.
5. Coal underclays, though often containing root-like structures, hardly qualify as capable of sustaining a long succession of forests that were eventually converted into coal layers ranging from a fraction of an inch in thickness to hundreds of feet.

All in all, the riddle of coal formation is not as cut-and-dried as school textbooks would have it.

• Erratic Rocks in Coal Seams

THE FORMATION OF COAL BEDS

Stevenson, John J.; *American Philosophical Society, Proceedings,* 50:1-116, 50:519-643, 51:423-553, 52:31-162, 1911-1913.

Fragments of rock are the foreign bodies which are the most perplexing. The earliest recorded observation seems to be that by Phillips in 1865, followed by that of Noeggerath in 1862, both of which have been cited by Stur. Roemer soon afterward described 3 small fragments from a coal bed in Upper Silesia; they were of crystalline rock, unlike anything known in Silesia. E. B. Andrews in 1870 announced the discovery of a waterworn quartzite fragment in the coal at Zaleski, Ohio, half embedded in the coal. Newberry in 1874 saw a fragment of talcose slate in the parting of Coal No. 1 at Mineral Ridge, Ohio, which he thought might have come from the Canadian Highlands; somewhat later he found a rounded quartzite fragment in the Block coal, resembling a Huronian rock in Canada. Stevenson in 1877 reported the discovery of a waterworn limestone bowlder embedded in the Sewickley coal of Fayette county, Pennsylvania. It was about 2 feet in diameter and extended above as well as below the coal. He believed that it had not been deposited prior to the coal, for that was splashed as though the fragment had fallen into soft material. Similar notices appeared from time to time but in all cases they were merely casual.

Stur in 1885 gave a summary statement of knowledge respecting such occurrences. He notes the discovery by Roemer in 1883 of a mass weighing 55 kilogrammes, granite such as is unknown in the region. He adds instances coming under his own observation in several Austrian coal fields, but the notes refer to somewhat widely separated localities and the fragments are of small size Radcliffe described 6 bowlders from Dukenfield, England, embedded partly in the coal and partly in the overlying shale. The portion within the coal had a coaly crust but no such crust appears on the part within the shale. All are of quartzite and the weight was 5 to 166 pounds. One specimen was on edge. W. B. Dawkins remarked in the discussion that such fragments occur frequently in Lancashire and that all are of quartzite; Bonney made the broader statement that they are of common occurrence in coal. In the same volume, J. Spencer referred to a granite fragment, weighing 6 pounds, which had been found in the Ganister coal bed and he adds that the surrounding coal was undisturbed. He remarked that bowlders had been found at many localities, that they were always isolated and that they had come from a distance. Gresley in 1890 reported that a well-rounded quartzite bowlder, 11 by 8 inches, had been taken from underclay at 1 foot below the Mammoth coal bed near Mt. Carmel, Pennsylvania.

Orton says that prior to 1892 the Ohio bowlders had come from the Middle Kittanning coal bed at Zaleski. The first was discovered by Andrews in 1870, but many were discovered afterwards, there being at times scores in a single room. The largest weighs 400 pounds and is in the State museum at Columbus. A new horizon was made by finding a quartz bowlder, weighing 10 pounds and 10 ounces, at Mineral Ridge. It was in undisturbed coal at 2 feet below the roof and it was covered with a closely adhering, slickensided crust of coal. Stainier gathered observations made by himself and others in the Belgian fields. Some of the fragments are rounded and smooth, evidently rolled pebbles, while others are irregular in form like concretions, but composed of sedimentary material and so are to be regarded as foreign bodies. Pebbles of the former type were obtained at 8 localities. They are not rare in La Rochelle colliery of Charleroi at the 500-meter level but they are wanting at the 250-meter level. The bed yields an impure coal and earthy partings are numerous where the pebbles occur. The largest is oval, 14 by 8 by 8 centimeters. Schmitz obtained rounded fragments from localities in the Charleroi and Centre basins, and Lohest found them in the Liege basin. The largest specimens weigh 20 and 25 kilogrammes. It is noteworthy that the Belgian fragments are of sedimentary origin; some resemble Carboniferous rocks and all are in coaly material. These records seem to suggest that pebbles are not abundant in coal and that they are even of comparatively rare occurrence---the instances noted by Orton and Stainier are not exceptions, as they are examples of extreme localization.

Barrois undertook systematic study of the matter in a definite area and presented the results in an elaborate memoir, of which only the merest synopsis can be given here. Most of the fragments were obtained during a four months' exploration of the Vein-du-Nord, a double bed, showing great constancy in the explored area, which is 7 kilometers long. The upper bench, 0.25 meter thick, has 14 per cent. of volatile and only 2 per cent. of ash, while the lower bench, 0.35 meter thick, has 17.2 per cent. of volatile and 10 per cent. of ash. The rock fragments are coated with soft sooty coal, often pyritous, and the lamination is more or less distorted about them. In all, 295 specimens were secured, of which 86 per cent. were derived from Coal Measures rocks, a few from Cambro-Silurian deposits and nearly 11 per cent. from the distant Archaean. The largest fragment weighs about 120 kilogrammes or approximately 280 pounds. The great preponderance of fragments from the Coal Measures shows that outcrops of those rocks were not far away, so that at the time of the Assise d'Andenne---the Lower Coal Measures---the beds of that epoch were no longer mere muds and sands, but consolidated shales and sandstones; some fragments show even the jointing of contraction. Many are thoroughly waterworn, others are angular, and both types are mingled indiscriminately. In some other coal beds of this region, fragments have been found in the mur, coated with clay which is marked with lacework of Stigmaria rootlets.

Fragments were found in all portions of the bed, from bottom to top, but the upper bench yielded 50 times as many as the lower. The number averages only one to each 100 square meters of area, but the distribution is irregular and they occur, as it were, in nests. The more abundant occurrences are associated with contractions of the bed, where the roof or the underclay replaces more or less of the coal. Rolls in the roof usually consist of material differing in character and arrangement from the overlying shale, as though deposited in channels of streamlets made after formation of the coal. The underclay swellings may have been laid down in drowned channels made anterior to formation of the coal and occupied after that formation had been begun. Variation in direction of channels during accumulation of the beds might account for distribution of the fragments but the existence of such waterways within this area is problematical and it is well to seek another explanation.

Phillips's hypothesis that the fragments were transported by trees, uprooted from banks of streams, has found favor with allochthonists and autochthonists alike; but there are serious objections to it. The weight of some fragments, upwards of 100 kilogrammes, is too great to admit of transportation by Stigmaria, while the presence of blocks of mud would suggest that hollow trees had shared in the work. In any event, there would always remain the remarkable purity of the coal, so difficult to explain in view of the great amount of inorganic material known to be transported by floating trees. There seem to be insuperable difficulties in the way of a conception that the presence of fragments is due to the agency of trees growing outside of the area in which coal was forming. Objection to the hypothesis of transport by floating ice is equally serious. Beyond doubt there were widespread changes in climatic conditions toward the close of the Palaeozoic, but attempts to reconcile the tropical character of the Nord-basin flora with a cold climate have not been successful. The markings on the fragments do not resemble those made by glacial action.

The presence of fragments in the mur is proof that they were brought in prior to formation of the coal, when streams were distributing the detritus which became the mur. Stigmaria became rooted in that and enlaced the fragments, which some day they were to transfer to the coal. The fall of trees, overturned in the marsh by age or wind, tore portions of the mur from below; fragments, there encased, came gradually to the surface of the coal; at times a stump fell into a stream and its load would be deposited in the channel. This hypothesis explains local abundance of fragments by two factors; their previous existence in the mur and the fragility of the mur itself; so that they would form in succession part of the mur and part of the coal. The purity of the coal eliminates, during formation of the bed, the agency of convoys of allochthonous trees loaded with extraneous debris.

The condition is not peculiar to the Coal Measures. It is found in coal formations of other ages. Hutton found in the Upper Cretaceous of southern New Zealand a sandstone mass, 8 feet by 3, resting on the coal, which convinced him "that there can be no doubt that this boulder has been floated to its present position among the roots of a tree and that therefore the coal beds are formed partly from driftwood." He states the Tertiary brown coals in several fields contain pebbles of white quartz; these beds, according to Hector, rest on fireclay. Jack found pebbles in coals of Upper Cretaceous age in Queensland.

The presence of rock fragments in coal has always been perplexing to allochthonists and autochthonists alike, though each seems to be certain that in some way or another they afford an important argument in favor of his doctrine. They are certainly transported materials; some were brought from rocks far away and most of them are distinctly waterworn. If all were small, any geologist could conceive of an explanation, which would be satisfactory to himself, as refutation might be difficult; but when one has to deal with masses of several hundred pounds, such as the Ohio blocks, transported several hundreds of miles, the problem becomes serious.

Some writers have been inclined to regard ice as the transporting agent; but the character of the Coal Measures vegetation appears to be conclusive against the supposition that intense cold prevailed during any part of the year at any locality whence the fragments have been reported. It is very true that sharply contrasted climates may exist only a few miles apart, as in southern California, but that condition requires topographical features which did not exist. The whole Coal Measures area of Ohio was a low plain; the nearest highlands were in Canada, hundreds of miles toward the north, and the Appalachians, hundreds of miles away toward the east. The agency of ice must be set aside as in the highest degree improbable.

The majority of authors have supposed that uprooted trees floated away carrying the masses entangled in their roots; but the difficulties involved in this conception appear to be insuperable. There can be no doubt that trees do seize such blocks and that under proper conditions they could transport them. Any one, who has seen the manner in which the white birch of the White Mountains enwraps its roots about blocks of stone weighing half a tone or more, recognizes that trees do seize large fragments. But that is not the question. The observer is confronted at once with the problem of conveying that tree and its load to deep water, sea or lake, where the great tree, 75 or more feet high, may float in vertical position, almost wholly submerged. Trees grow on the land, where alone the fragments can be obtained. The transfer cannot be made by torrents, as tree and load would be deposited at the first rapids. A debacle, like that of Martigny or Johnstown, cannot be conceived of as the agent, since a topography would be required such as did not exist near any of the extensive coal fields whence large fragments have been reported. Even had it existed, the terrific collisions, as the flood dashed through narrow gorges and spread out in wider portions of the valley, would have dislodged the fragments long before reaching the open water. The bowlders cannot be relics of floating islands, such as those of the Orinoco, Amazon or Congo, since the origin of those islands forbids the suggestion. Nor is there any reason to suppose that trees growing on the seashore could become the transporting agents, for, even though river-worn or wave-worn fragments were abundant on the shore, the difficulty of transferring the tree to deep water would still remain. If the trees grew on the river banks along the lower reaches of a great stream, and were undercut, they would be stranded at the first bar to become snags or towheads, which even the greatest flood possible on such a river could not dislodge, as conditions along the Mississippi abundantly show. It is impossible to conceive of any means whereby a tree capable of carrying such a load could be floated away to deep water, unless it grew on the wall of a fiord---where it could not secure the water-worn fragments.

The assumption that shales, sandstones and conglomerates were deposited necessarily in deep water or in a permanent body of water must be regarded as unsupported by any positive evidence. The writer, during a tedious search through the literature, has not found that authors think that the proposition needs evidence; it seems to be accepted as axiomatic. But evidence to refute the doctrine abounds in the Tertiary and Quaternary and, in so far as the Appalachian Coal Measures are concerned, the facts seem to indicate that they are flood-plain deposits and reworked alluvial fans. This condition may afford a clue to explanation for some of the occurrences. Rivers, torrential in their upper reaches, flowed across the plain. Rolled fragments of varying size were pushed along the beds. Pebbles of quartz, 5 inches in diameter, have been found in the Sharon of southern Ohio at not less than 300 miles from their source. During a great flood, if the stream were dammed temporarily, the water would sweep over the "bottoms" or break across the necks of curves; a new channel would be cut, the old channel above for a short distance would be scoured and its sand and pebbles would be strewn on the river-plain. This happens only too often along the Mississippi, as has been shown on preceding pages. In such a rush of water, a block of 400 pounds would be gathered up in the mass as readily as though it were a pebble; but gravity would act promptly and the coarse fragments in the load would be left scattered on the surface while the finer materials would go far beyond. Succeeding floods would cover the sands and gravels as well as the larger fragments with finer materials in which the larger river-worn masses would be widely separated, for the most part, though here and there they would be grouped in smaller areas. One finds this condition in the "bottoms" of large and small streams alike. The fragments in the underclay, mentioned by Barrois, Ashley and Gresley, were not deposited with the clay but before it; their distribution is wholly similar to what is seen now. The mode of transference to the coal, as described by Barrois, is in accord with what one may see in actual bogs; once transferred by plants rooted in the underclay, they would be removed successively into higher portions by plants rooted in the bog---for there is every reason to believe that the Coal Measures plants had as much liking for peat soil as is shown by many towering plants of the present day.

At the same time, the writer recognizes that the suggested explanation is not altogether satisfactory at some localities, where the required conditions cannot be proved. (pp. 82-89)

ON THE OCCURRENCE OF A QUARTZ BOWLDER IN THE SHARON COAL.....

Orton, Edward; *American Journal of Science,* 3:44:62-63, 1892.

It is well known that bowlders, ranging in size from a few cubic inches to several cubic feet, are occasionally met with in coal seams, buried partially or entirely in the substance of the coal. Facts of this sort have been reported both in this country and in England. The State of Ohio has furnished the largest number, if not all, of the cases reported in this country. In England, Mark Stirrup, Esq., Hon. Secretary of the Manchester Geological Society, has reported in the Transactions of this Society a number of such occurrences, all derived from mines in the neighborhood of Manchester.

The Ohio examples that have been hitherto put on record are without exception, so far as my observation goes, composed of gray quartzite, presenting the appearance of pretty thoroughly metamorphosed sandstones. By correspondence and comparison of specimens with Mr. Stirrup, I learn that the English bowlders of the coal agree very closely with ours in composition and general character.

All of these bowlders are well rounded and some that I have seen show remarkably smooth surfaces which suggest the polish due to glacier action rather than the abrading agency of water in motion. They are always partially covered with closely adhering coal, which shows more or less of the striated structure known as slickensides.

The Ohio bowlders have all been derived from a single coal seam, viz:

the Middle Kittanning seam of our scale, and thus far, only from the western boundary of this seam, in Perry and Vinton counties. Furthermore, a single mine in the last named county, viz: the main mine at Zaleski, has furnished thus far all the specimens. According to the testimony of the superintendent and miners, scores of these bowlders have sometimes been found in working out a single room. The first example in Ohio was recorded by the late Prof. E. B. Andrews (Geol. Survey of Ohio Rept. of Progress, 1870, p. 78.) This bowlder came from the mine named above.

By far the largest of this class of bowlders thus far known was found buried in the coal of the same seams at Shawnee, Perry Co., in 1876. The seam was normal above it and also below. The weight of this bowlder is not less than 400 lbs. It is preserved in the geological museum of the State University at Columbus.

A new example of these bowlders of the coal has lately been brought to light that differs so much from the examples previously reported that it deserves brief mention. It was found in the Marshall Mine of Mineral Ridge, Mahoning county, by Mr. F. C. Goff, of Cleveland, who is extensively engaged in mining and shipping coal, and it was removed from its bed by his own hands. The thickness of the coal seam is three feet and the bowlder lay two feet below the top. The seam was in no wise disturbed in its structure by the presence of the bowlder. The weight of the block in its present condition, after the removal of a few small fragments, is 10 lbs. 10 oz. It measures about eight inches in its longest dimension. The coal is very closely welded to it over part of its surface and it shows the usual slickensided appearance.

The noteworthy points in regard to this bowlder are the following, viz: (1) It is the first so far as I know that has been reported from this coal seam, viz: the Sharon Seam or the lowest coal of the Conglomerate Coal Measures of Pennsylvania and Ohio. (2) It is not a metamorphic sandstone or quartzite, like those previously named, but is an excellent example of vein quartz. (3) It has not been worn or shaped in any way by either water or glacial action, but is angular as if freshly broken from the parent mass.

No full and satisfactory explanation of this line of facts has yet been advanced. The quartzite above named could perhaps be accounted for without referring them in origin to the metamorphic rocks of the older regions of the continent. May not an ordinary sandstone pebble or bowlder of the Coal Measures have been converted into a quartzite by the solution of a portion of its silica through the agency of the organic acids that accompanied the formation of coal. But like the white quartz pebbles of the great Sharon Conglomerate that underlies this coal seam, the bowlder here described must be referred to the ledges of the eastern or northern mountain borders of the continent as it then existed. The pebbles of the conglomerate never exceed a few ounces in weight and their rounded forms and smooth surfaces bear witness to an immense amount of abrasion before they reached their present resting places; but the bowlder in question, with its weight of 11 lbs. and its sharp and unworn edges and with its anomalous location, certainly shows a very different history.

• Cleat and Jointing in Coal Beds

JOINTING IN THE COAL BEDS OF OHIO

Ver Steeg, Karl; *Science,* 96:83, 1942.

The results obtained from a study of jointing in the coal beds of Ohio are interesting. From data secured by field work and from engineers and operators, some important facts have come to light. The jointing or cleat, as it is commonly known, shows remarkable regularity or uniformity in trend. The joints appear to follow the trend of the Appalachians to the east. The direction of the joints appear to be the same, even though more than one coal bed is involved. In Mahoning, Columbiana, Stark, Tuscarawas, Wayne, Holmes, Belmont, Jefferson, Harrison, Carroll, Guernsey and Noble counties, the joints occur in two sets commonly known as the face and the butt joints. The two systems occur at right angles to each other, one set running in a northeast-southwest direction and the other having a northwest-southeast trend. Farther south in Muskingum, Perry, Hocking, Athens and Morgan counties, one system trends in a direction a few degrees west of north and the other at right angles, has a course running a few degrees north of east or nearly east and west.

There is a variety of opinion as to the origin of the cleat in coal. One group of geologists believe that the cause is inherent in the coal itself, and that jointing is the result of contraction from the loss of gases such as methane and carbon dioxide, moisture, and the rearrangement of the carbon compounds, which has caused loss of substance. The other group are convinced that the cleat is the result of tectonic forces. The writer is inclined to follow the latter group. It is difficult to explain the remarkable uniformity in direction of the joints and the parallelism with the Appalachian folds unless we assume diastrophic movements. Moreover, shrinkage of coal, one would assume, would produce jointing in all directions.

ON THE CONDITIONS UNDER WHICH THE VEGETABLE MATTER OF THE ILLINOIS COAL BEDS ACCUMULATED

Savage, T. E.; *Journal of Geology,* 22:754-765, 1914.

<u>Structural Features of the Coal Beds</u>. One of the more conspicuous structural features of the coal beds of Illinois, which are representative of the larger beds everywhere, is their stratification, the more prominent bedding planes being 3-5 or more inches apart. These bedding planes form partings along which the coal separates rather easily, and they usually show well-developed bands of "mother coal" or mineral charcoal. These stratification planes often become more conspicuous when the bed is weathered, but some of them are prominent on unweathered faces. Such a conspicuous clean parting of mineral charcoal occurs 20-24 inches below the roof of the Herrin coal over several hundred square miles in

western and southern Illinois, and appears to be almost coextensive with that bed. Along this charcoal zone the coal separates so perfectly that where the overlying shale does not stand well in the mines the bench above this parting is left for a roof. Five or six inches higher is another mineral charcoal parting almost equally well developed and persistent.

Between the more prominent partings and bedding planes the coal from roof to floor is made up of alternating bright and dull laminae, which are usually 1/2 to 1/32 of an inch thick, though in places they are considerably thicker. The aggregate dull bands generally make up nearly or quite one-half of the coal beds, and they appear to be of the same general nature as the bedding planes mentioned above. They are often rather uniform in thickness over considerable areas, but in places they thicken for some distance and in others they thin down to knife-edge partings. The bright laminae appear to be rather homogeneous in structure; but where the coal is split along well-developed dull laminae the cleavage planes almost always show distinct mineral charcoal surfaces. A typical dull lamina appears to be composed of a film of dull, structureless coal at the top, which passes downward into coarse-textured, fibrous, mineral charcoal in the middle part, and this, in turn, grades downward into a film of dull, structureless coal below.

The features above described are not peculiar to Illinois coals. H. S. Rogers and others have noted the alternations of laminae of bright and dull coal, and the predominance of mineral charcoal in the dull laminae, in the coals of the Appalachian region, and the writer has observed the same characteristics in the coals of Iowa. They have been described from coal beds generally in different parts of the world. The mineral charcoal is so constantly present, and so intimately mingled in, and constitutes such an important part of, the dull laminae of the coals of Illinois that they must have been developed together, and a satisfactory explanation of the one must also explain the other. (pp. 756-757)

• Underclays, Partings, Binders

THE "SLATE BINDERS" OF THE "PITTSBURG" COAL-BED

Gresley, W. S.; *American Geologist*, 14:356-365, 1894.

Given, a "bench" or layer of good bituminous coal, of very uniform quality, varying in thickness from say 22 to 27 inches, with one or two more or less irregular slaty partings or binders here and there in it; and imagine such a deposit spread out over at least 15,000 square miles. The edges or outcroppings of this layer of coal reveal no signs of a beginning or of an end; in other words, there is nothing to indicate that this coal did not originally extend hundreds of miles beyond any of its existing limits. We will not now discuss the question. How did this layer of coal get where it is? but proceed at once to observe that it has a practically dead-level and even surface or top. Suppose this vast expanse of dead-level coal vegetation to be completely covered or sealed over by a thin layer or band of shale, or "slate," as miners call it. We will suppose the thickness of this film of shale to be from 1/4 to 1/2 of an inch only. Imagine a practically unbroken 15,000+ square mile sheet of shale only 3/8 of an inch thick! On top of this shale-band let a second and equally uniform layer of the same coal as the thicker one below, be deposited, whose thickness is about 4 inches---a layer of coal practically free from impurities, and, in every respect, similar to the rest of the seam, regarded as a whole. Again, on top of this 4-inch band of coal conceive a second layer of shale to exist, in thickness and kind just about the same as the shale-layer 4 inches below it. Then above this suppose we have a uniform bench of coal 3 feet to 5 feet high. Here, then, we have three separate and distinct benches or divisions of a coal-seam separated horizontally by a couple of thin, parallel-bedded layers of shale; or, looked at in another way, we have a, say, 15,000 square mile 4-inch band of excellent coal sandwiches between two very thin, but remarkably persistent layers of what is presumably hardened mud, these again being enclosed by thicker layers of the same kind of coal. Now, the foregoing is in reality a description of what actually occurs in nature; it is the lower or workable division of the "great Pittsburg bed." These two "slate-binders" seem to be so remarkable as regards their geographical extent, uniformity in thickness, composition, distance apart vertically, etc., that some special effort ought to be made to explain: 1---What they are or signify; 2---How they got there; and, 3---Whence they came,---three questions, so far as I know, not yet at all satisfactorily answered, and much less easy of solution than at first sight appears. My wish in this connection is that this paper may stir up sufficient interest in this matter to lead to further, extended, and closer observation; and such a detailed study of the Pittsburgh bed as it (a typical one) surely deserves and ought to receive at the hands of all local geologists and men capable of doing useful work on it. Of course, the question of the origin and formation of the shale-bands in the coal opens up that of the whole question of the formation of coal-seams, for the bands are part and parcel of the seam; the two substances (coal and shale) cannot be considered separately. (pp. 356-357)

THE ORIGIN OF THE COAL MEASURES FIRE CLAYS

Hopkins, T. C.; *American Geologist,* 28:47-51, 1901.

While the present paper deals principally with the blue clays of the Coal Measures, the term fire clay, of course, cannot properly be limited to these clays, as valuable refractory clays occur in strata both older and newer than the Coal Measures without any connection with coal seams of any kind. Thus, in Missouri, fire clays occur in Lower Carboniferous, Silurian, and Ordovician strata and in New Jersey in Cretaceous or more recent. Many of the residual kaolins of the Piedmont belt are highly refractory.

The explanation commonly offered for the origin of the blue fire clays of the Coal Measures is that they are the soils on which grew the vegetation that forms the coal seams lying on top of them, and the reducing and leaching action of the vegetable acids from the living and the decaying vegetation has changed the common clay to the refractory fire clay. This appears to be a satisfactory explanation for many of the clays, but there are some of the deposits that are not satisfactorily explained in this way.

The deoxidizing and leaching action of both living and decaying vegetation is illustrated in many of the bogs and swamps of the present, and in a less degree in the meadow and the forest soil. The organic acids of the vegetable matter are strong reducing agents and under their action the red and yellow ferric oxides are changed to the lower gray or bluish ferrous oxide in which form it is soluble in the acids, and where there is sufficient circulation the iron may be either carried away in solution or segregated into beds of iron ore. Fragments of minerals containing alkalies and alkaline earths may be broken up by the vegetable acids into separate compounds and the alkaline substances dissolved in the water and part carried away in solution and part may be taken up by the plants and held in the carbonaceous matter of the muck of the bog of the present or the coal bed of the older period. It sometimes happens that there is better drainage into the bog than out of it, and the iron leached from the surrounding region may be carried into the bog and deposited as an iron ore.

The general order of occurrence is first the clay overlain by the ore, followed by the coal, but it frequently happens that one or more of these substances are lacking. Sometimes it is the ore, sometimes both the ore and the coal, and less commonly the clay. That is, in some places coal seams occur without any underlying clay, and in many places the clay occurs without any overlying coal. Again, it frequently happens that the clay may form one or more seams in the coal bed; thus, in the famous Pittsburg coal seam in southwestern Pennsylvania, and in West Virginia, the inclosed fire clay seams, several in number, are remarkably persistent and regular in thickness over wide areas.

We find some phenomena in connection with the occurrence of the fire clays, and the coal seams that are difficult to harmonize with the above-outlined theory of origin. Thus, if the fire clay is the soil on which grew the vegetation that forms the coal, and in so doing changed the common clay to fire clay, how are we to explain (1) the occurrence of fire clay beds free from coal of any kind, (2) that such clay is frequently of better quality, that is, more refractory than that which is overlain by coal, (3) the great thickness of some of the beds, and (4) the coal seams deposited on yellow shales or sandstones entirely independent of any fire clay?

(1) Fire clay beds not overlain by coal.---Comparatively little is given on this point in the literature, but the observations of the writer in several different coal basins lead him to think that this is a rather common occurrence. In Clearfield, Indiana, Westmoreland, Clinton, and Tioga counties, Pennsylvania, these coalless fire clay seams occur in considerable numbers.

The fire clay in these cases might have been formed in the usual way, and the absence of the coal explained by the fact that (a) the carbon might have been oxidized, owing to long exposure before the overlying sediments were deposited, or (b) the carbonaceous material may have been eroded before the deposition of the next stratum. (c) Another and, in some instances more probable explanation, is that the clay was fire clay before it was deposited in its present position, that is, it was changed to fire clay in some other locality and was then eroded and transported as sediment and deposited in its present position in much the same condition as it is at present.

(2) The clays that occur free from the coal seams are apt to be more refractory than those underlying coal seams.---It is a matter of observation that the most refractory clays in the Coal Measures are found among those which have no coal overlying them. This may be due partly to greater original purity and partly to a leaching subsequent to the elevation of the land. Thus the secondary deposition of the clay would tend to remove a greater percentage of the soluble bases that form the fluxing constituents and after the elevation of the land the leaching by the meteoric waters would tend to still further remove the soluble materials. The texture of clay is not favorable to the rapid percolation of water, but the slow circulation through a long period of time may accomplish the same result. The accumulation of the iron carbonate ("the ore balls") so abundant in some places, shows that the water does percolate through the clay to some extent. Where the clay is overlain by coal, the tendency is often the opposite to the above and iron is carried into the clay from the oxidizing pyrite in the overlying coal.

(3) The great thickness of some of the claybeds.---In some places the fire clay deposits are thirty feet or more in thickness. One can hardly conceive how the vegetation growing on the top of a deposit of this thickness would extract the iron and the alkalies from the entire body of the clay. If it were formed in this way one would naturally expect the upper part to be the purest, and at least some considerable portions of the middle and lower portions to be unchanged. Instead we find, so far as there is any difference, that the lower part is likely to be the best clay and the poorest part at the top.

At Bolivar, Pa., the flint fire clay is over twenty-five feet thick and overlying it between the clay and the coal there are several feet of shale. How would it be possible for the plants of this coal seam to leach out the iron and alkalies from twenty-five feet of clay when there are several feet of unchanged shale lying between them?

At Blossburg, Pa., there is a bed of fire clay 15 to 25 feet thick, with no coal or carbonaceous matter associated with it, and no fossil plant remains in so far as known. The laminated structure of this deposit is additional evidence in support of the belief that the clay was fire clay at the time of its deposition and not clay that has been changed in situ.

(4) Coal without under clay.---In most cases the coal is underlain with clay of some kind, but in many instances it is not fire clay in the sense of being highly refractory. In some instances there is no under-clay of any kind, but the coal is both underlain and overlain by a ferruginous sandstone. While in some instances casts of plant roots and stems occur in the underlying sandstone, it frequently happens that there is no evidence of vegetable remains nor any of the leaching action of the reducing acids.

In view of the above statements it appears to the writer that the occurrence of a not inconsiderable portion of the fire clays is better explained by considering them as transported clays reduced before deposition. This does not invalidate the common supposition that many of the fire clays are formed in situ by the action of the vegetation of the coal beds, but not all of them are satisfactorily explained in this way. Furthermore, the refractory quality of many of the clays has been increased probably since the elevation of the land areas by a leaching out of the fluxing materials due in part to the topographical position of the beds near the hilltops and in part to a stratigraphical position that permits the access of the acidulated waters.

• Polystrates in Coal

ON THE DISCOVERY OF SOME FOSSIL REPTILLIAN REMAINS.....
Lyell, C.; *American Journal of Science,* 2:16:33-41, 1853.

The entire thickness of the carboniferous strata, exhibited in one uninterrupted section on the shores of the Bay of Fundy, in Nova Scotia, at a place called the South Joggins and its neighborhood, was ascertained by Mr. Logan, to be 14,570 feet. The middle part of this vast series of strata having a thickness of 1400 feet abounds in fossil forests of erect trees together with rootbeds, and thin seams of coal. These coal-bearing strata were examined in detail by Mr. J. W. Dawson of Pictou, and Sir C. Lyell in September last (1852), and besides other results of their investigations they obtained satisfactory proof that several Sigillariae standing in an upright position, or at right angles to the planes of stratification, were provided with Stigmariae as roots. Such a relation between Sigillaria and Stigmaria had, it is true, been already established by Mr. Binney of Manchester, and had been suspected some years before on botanical grounds by M. Adolphe Brongniart; but as the fact was still doubted by some geologists both in Europe and America, it was thought desirable to dig out of the cliffs, and expose to view, several large trunks with their roots attached. These were observed to bifurcate several times, and to send out rootlets in all directions into the clays or ancient soils in which they had grown. Such soils or underclays with Stigmaria afford more conclusive evidence of ancient terrestrial surfaces than even erect trees, as the latter might be conceived to have been drifted and fixed like snags in a river's bed. In the strata 1400 feet thick above mentioned, root-bearing soils were observed at sixty-eight different levels; and like the seams of coal which usually cover them, they are at present the most destructible masses in the whole cliff, the sandstones and laminated shales being harder and more capable of resisting the action of the waves and the weather. Originally the reverse was doubtless true; for in the existing delta of the Mississippi the clays in which innumerable roots of swamp trees, such as the deciduous cypress, ramify in all directions, are seen to withstand far more effectually the excavating power of the river or of the sea at the base of the delta, than do beds of loose sand or layers of mud not supporting trees.

This fact may explain why seams of coal have so often escaped denudation, and have remained continuous over wide areas, since the roots, now turned to coal, which once traversed them would enable them to resist a current of water, whilst other members of the coal formation, when in their original and unconsolidated state consisting of sand and mud, would be readily removed.

The upright trees usually enclose in their interior pillars of sandstone, or shale, or both these substances alternating, and these do not correspond in the thickness of their layers, or in their organic remains, with the external strata, or those enveloping the trunks. It is clear therefore that the trees were reduced while yet standing to hollow cylinders of mere bark, (now changed to coal,) into which the leaves of ferns and other plants with fragments of stems and roots were drifted, together with mud and sand during river inundations. The stony contents of one of these trees, nine feet high and twenty-two inches in diameter, on being examined by Messrs. Dawson and Lyell, yielded, besides numerous fossil plants, some bones and teeth which they believed were referable to a reptile; but not being competent to decide that osteological question they submitted the specimens to Dr. Jeffries Wyman of Harvard University in the United States. That eminent anatomist declared them to be allied in structure to certain perennibranchiate batrachians of the genera Menobranchus and Menopoma, species of which now inhabit the lakes and rivers of North America. This determination was seen afterwards confirmed by Professor Owen of London, who pointed out the resemblance of some of the associated flat and sculptured bones, with the cranial plates, seen in the skull of the Archegosaurus and Labyrinthedon. In the same dark-colored rock, Dr. Wyman detected a series of nine vertebrae, which from their form and transverse processes he regards as dorsal, and believes them to have belonged to an adult individual of a much smaller species, about six inches long, whereas the jaws and bones before mentioned are those of a creature probably two and a half feet in length. The microscopic structure of these small vertebrae was found by Professor Quekett to exhibit the same marked reptilian characters as that of the larger bones. (pp. 33-35)

RATES OF SEDIMENTATION IN THE LANCASHIRE COAL MEASURES

Broadhurst, F. M.; *American Journal of Science*, 262:858-869, 1964.

Fossilized Trees and Rates of Sedimentation. In 1959 Broadhurst and Magraw described a fossilized tree, in position of growth, from the Coal Measures at Blackrod near Wigan in Lancashire. This tree was preserved as a cast, and the evidence available suggested that the cast was at least 38 feet in height. The original tree must have been surrounded and buried by sediment which was compacted before the bulk of the tree decomposed, so that the cavity vacated by the trunk could be occupied by new sediment which formed the cast. This implies a rapid rate of sedimentation around the original tree.

Since this particular tree at Blackrod was described more than fifty trees fossilized in position of growth have been observed in Lancashire, mostly on opencast coal workings. These trees are found at various horizons between coal seams, and they occur, also, in partings within coal seams. Where trees occur in the roof beds of a coal seam the root system is developed in the beds above the top of the coal; in no case has a tree been observed to pass from the roof into the coal itself. In most of the trees examined the only part of the original tree to be preserved as a fossil is the outermost region of the trunk which is preserved as a thin layer of coal. Occasionally, however, the original inner cylinder of woody tissue has also been preserved. Identification of many of the trees is difficult, partly on account of the rarity of woody structures preserved fossil and partly because in the Carboniferous Lycopsida the characteristic forms of the leaf bases were lost on the lower part of the trunk due to the production of large amounts of periderm.

Reference to the literature shows that many fossilized trees in position of growth have been found in Lancashire. It is clear that trees in position of growth are far from being rare in Lancashire (Teichmuller, 1956, reaches the same conclusion for similar trees in the Rhein-Westfalen Coal Measures), and presumably in all cases there must have been a rapid rate of sedimentation. This sedimentation occurred, without doubt, in water that could not have been fast-flowing since the trees were left in standing position. It is possible that the land surface with its trees was inundated by flood water (possibly on numerous successive occasions) from adjacent waterways, the flood water bringing with it large amounts of sediment. This mechanism has been advocated to explain the occurrence of trees in position of growth in the Coal Measures of Germany and in the Trias of Colorado. The significance of the upright trees in Lancashire, so far as this study is concerned, is that they were all found enclosed by fine sandstones, siltstones, and coarse-grained mudstones but not by the fine-grained sediments, including those containing shells. The most likely explanation of the apparent absence of such trees from these sediments is that the latter accumulated too slowly; any trees decayed and collapsed before they could be enclosed by sediment. (pp. 865-866)

[The implication is one of very rapid sedimentation---that is, catastrophism.]

• Fusain, Mineral Charcoal, Mother-of-Coal

NATURE OF THE SUBSTANCE KNOWN AS MOTHER OF COAL

Jeffrey, Edward C.; *Geological Society of America, Bulletin,* 24:715-716, 1913.

Abstract. In the greater number of coals there is present a substance variously known as "Mother of Coal," "Fusain," "Faserkohle," etcetera. This has generally been interpreted as the charred remains of wood or as the remains of woody structures which have escaped the process of carbonification, to which the woody tissues in general are subjected in coal. As the result of the investigation of coal by improved methods, which permit of the preparation of successful sections, even of the most resistent

coals, such as anthracites, etcetera, the author has satisfied himself, by the examinations of coals of wide geological and geographical range, that the so-called mother of coal is in reality the charred, or partially charred, vestige of woody structures. Its presence in the coal is accordingly an interesting problem. It has been made out in all the cases yet examined that mother of coal is invariably accompanied by large quantities of flattened spores, and the general structure of the coals in which it has been studied is such as to warrant the conclusion that they have been laid down under open water. It follows that coals containing mother of coal are not derived from the transformation of peat bogs into coal, as it almost universally assumed, but owe their origin to sedimentary deposits of vegetable matter in open ponds or lakes. Since the presence of mother of coal in coals other than cannels and boghead or oil shales is almost universal, it follows that our ideas of the conditions under which coal has been formed must be very radically modified. It follows also that the question of the conservation of coal deposits has an added importance from the realization of the extreme slowness with which they have been formed. The paper is illustrated by a number of colored photomicrograms of coals of the United States, Europe, and Australasia.

ON THE CONDITIONS UNDER WHICH THE VEGETABLE MATTER OF THE ILLINOIS COAL BEDS ACCUMULATED

Savage, T. E.; *Journal of Geology,* 22:754-765, 1914.

Two main explanations have been proposed to account for the origin of mineral charcoal. One of these, held by many paleobotanists and chemists in recent times, explains the mineral charcoal as formed from charred plant tissues resulting from forest fires sweeping over land areas, the charred fragments being subsequently swept by flooded streams into the basins, where they were deposited with the mass of vegetable matter there in process of accumulation.

This explanation assumes that a considerable part of the vegetable matter of the coal was transported material, which assumption is open to all of the objections to the transport theory mentioned above. It assumes that a very important proportion of the coal was derived from plant tissues that had been charred by fires previous to their accumulation, and that these charred fragments had been carried into the coal basin by streams in such enormous quantities as to cover the surface of practically the entire area of the present coal beds, 5,000-8,000 square miles or more in extent; that this process took place not only once but was repeated as many times as there are persistent dull, charcoal-bearing laminae, requiring scores of recurrences of such charcoal deposition during the accumulation of the vegetable matter of each of the large coal beds. It assumes such a depth of water above the accumulating vegetable matter that the charred fragments brought in by the streams could be freely floated out above the mass of vegetable matter already present to every part of the basin, and, most impossible of all, that the streams that carried such vast quantities of charred vegetable matter carried little or no mud or mineral sediments. If it is assumed that the water of the basin was so shallow that the clay and sand brought down by the streams were strained out in the meshes of the tangled plant debris at the margin, then the same vegetable sieve would catch the charred plant fragments and not permit them to be distributed to every part of the accumulating coal beds. This explanation is not in harmony with the facts of the vertical and horizontal distribution of the mineral charcoal bands in the coal beds.

The modification of this view assumes that the mineral charcoal represents partially burned vegetable matter resulting from fires sweeping over the surface of the marshes in which the vegetable matter of the coal beds was accumulating. It is not probable that fires started by lightning would travel over water-covered swamps with only the living undergrowth and green leaves and branches of the trees to support the flames, and if they did, they would not leave such uniform and thick layers of charcoal as occur in well-developed dull laminae. If it is assumed that the surface of the vegetable matter that had accumulated in the swamp had been exposed and dried before the fires swept over it, then the conditions involved would be similar to those under which the charcoal is interpreted as having been formed by the partial atmospheric decay of the upper surface of the vegetable material of the bog exposed during periods of unusual low water.

It seems to the writer that the explanation of mineral charcoal as resulting from the temporary exposure and partial atmospheric decay of the surface portion of the vegetable matter in the bog, instead of the assumption that it must have been charred by fire, is much more consistent with the following facts: (1) the frequent repetitions of the dull laminae containing such large amounts of mineral charcoal; (2) the larger number of plant spores in the dull laminae than in the bright coal; (3) the numerous pinnae and pinnules of ferns in the midst of the mineral charcoal fragments; (4) the absence of layers of ash that would result from the burning of the vegetable matter at the surface of the bog; and (5) the changes that take place in the vegetable matter at the surface of shallow marshes during periods of drought and exposure at the present time. (pp. 757-759)

• Coal Jelly

JELLY-LIKE CARBONACEOUS MINERAL RESEMBLING DOPPLERITE.....

Cooper, T.; *American Journal of Science,* 3:22:489, 1881.

An article by Mr. T. Cooper in the number of the Engineering and Mining Journal for Aug. 13, contains the following interesting facts: The remarkable material was discovered in excavating for the new courthouse of Scranton. This building-site is in the heart of the town, upon a square which formerly was a swamp, but some years ago was filled with cinder from the iron-works. On excavating for the courthouse foundations, the cinder, which was five or six feet deep, was first removed. After this, came a bed of excellent peat, varying in depth from eight to twelve feet. Below the peat, a stratum of muck separated the peat from the hard-pan below. In the muck were veins of the tough black jelly, resembling coal in aspect, except its gelatinous character. When dried slowly it solidifies into a hard, brittle substance, which would be considered by an ordinary observer real anthracite coal. After hardening it does not again soften in water, hot or cold. It burns at a red heat, and leaves an ash resembling the red ash of some coals. It flames on first ignition. The jelly is acted on by alkaline solutions.

A letter to the editors, from Mr. H. Wright, secretary of the Wyoming Historical and Geological Society, dated Wilkesbarre, Aug. 27, 1881, states that an analysis made by the State Chemist afforded

Water, at 212°F	66,758
Volatile matter	9,826
Fixed carbon	4,012
Ash	19,404
	100,000

• Paper Coal

OCCURRENCE OF PAPER COAL IN INDIANA

Neavel, Richard C., and Guennel, G. K.; *Geological Society of America, Bulletin,* 69:1622-1623, 1958.

Abstract. The term "paper coal" has been used to describe a deposit, consisting chiefly of stem and twig cuticles of lepidodendralean affinity, accurring in the Moscow Basin, USSR. Recently, a coal which fits the term "paper coal" was discovered in a strip-mine high wall in Parke County, Indiana. Of the 20-inch thick seam, the top 8 inches, where interstitial attritus and anthraxylon have been removed by weathering, consists of flexible, brown, paperlike cuticular remains.

The Indiana cuticles differ drastically from the Russian material in that they are the cutinized coatings of parts of fernlike foliage assignable to Sphenopteris. The envelopelike cuticles of entire pinnae and "twig" fragments, some more than 4 cm in length, have been isolated.

Tentative stratigraphic information places the paper coal in the upper part of the Brazil formation (upper Pottsville). Preliminary chemical analyses, reported on an ash-free basis, indicate that the upper cuticular portion of the seam is high in volatile matter (62 per cent), but the lower, noncuticular portion is about average for Indiana coals (48 per cent). Further chemical tests, particularly on pure cutinite, are in progress. The coal is principally an attrital coal, high in cutinite, and containing thin anthraxylon derived from the fleshy parts of the cutinized tissues.

Because of the remarkable preservation of the plants parts, it is expected that significant information regarding the paleoecology of coal-forming swamps can be obtained.

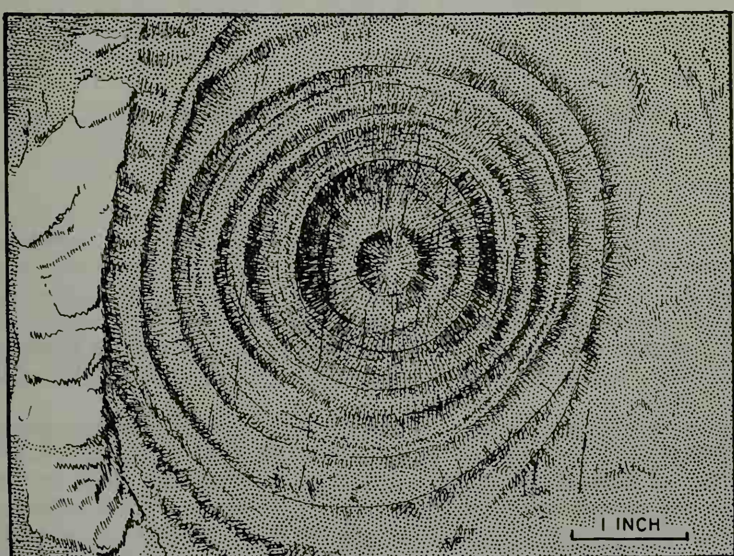
• Birds-Eye Coal

BIRD'S-EYE COAL FROM GREYMOUTH, NEW ZEALAND

Gage, M., and Bartrum, J. A.; *Journal of Geology,* 51:320-329, 1943.

Description of Eye Coal from Greymouth. Perfect development of the "eyes" have been noted in only one mine of the Greymouth coal field although somewhat similar structures, possibly related genetically to the others, are occasionally found in the coals of other mines of the field. In Boote and Party's mine there is eye structure in abundance in a finely laminated, fairly bright bituminous early Tertiary coal belonging to the Paparoa beds, which are the basal members of the Tertiary succession of the region. Structures which at first sight appear similar in character have been recorded from brown coal of the Waikato coal field in the North Island of New Zealand by J. A. Bartrum, but they differ from "eyes" in the smallness and uniformity of their size and in the closeness of their grouping both horizontally and vertically. Bartrum has suggested that they represent pit and mound structures.

In a perfect example the "eyes" are composed of concentric circular rings, the outermost ranging in diameter from less than 1/3 inch to as



Structure of bird's eye coal from New Zealand.

much as 1 foot in the largest specimen observed. The larger examples invariably occur on pronounced fracture planes following the cleat. In general, each individual ring is a miniature ridge due to the reversal of direction of slope at its crest of alternate, gently inclined concentric fractures: on one side of the crest the fracture surface slopes radially inward; on the other, outward. This reversal is not universal, however, more particularly in smaller examples; and, in addition, there is frequent irregularity in the inclination of the surfaces. The distance between the crests of successive rings varies with the diameter of the whole structure, for it is much less in small examples than in large. A further feature is that the inclination of the fracture surfaces is reduced toward the periphery of each structure. Occasionally, the direction of inclination of what appears to be one and the same surface is reversed at opposite ends of a diameter.

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Conclusion. Perfect examples of eye structure in early Tertiary bituminous coal have been described from Greymouth, New Zealand, by the authors, who believe that their origin is bound up with the local formation in coal of almost homogeneous nature and special physical character of conoidal shears by compressive forces acting both horizontally and vertically. The hypotheses of origin proffered attempt to explain certain peculiarities of the concentric rings that comprise the "eyes."

• Vein Coal

AN OCCURRENCE OF COAL WHICH BEARS EVIDENCE OF UNUSUAL CONDITIONS ACCOMPANYING ITS DEPOSITION

Hyde, Jesse E.; *Journal of Geology,* 20:316-330, 1912.

The occurrence is in a deep cut on the B. & O. Railroad at Sommerset, Perry County, Ohio. At either end of the cut a highly fossiliferous marine limestone is exposed, but throughout most of its length the bottom of the cut is not deep enough to reach it. This limestone, about 3 feet in thickness, is probably the Lower Mercer member of the Potsville formation. It is generally present in this region 75 or 85 feet abofe the base of the Pennsylvanian.

Above the limestone is a bed of soft gray clay shale which is some 12 to 15 feet thick. It is overlain by a massive coarse sandstone whose thickness is estimated at 20 to 25 feet. The upper part of the shale and this sandstone are exposed throughout the cut. The contact between them is very irregular, rising and falling as much as 6 or 8 feet. In pockets at this contact, well shown for 300 yards in the deeper part of the cut, the coal under consideration is found.

Above the sandstone there is a bed of shale 1 or 2 feet thick, overlain in turn by a second coal seam. Both of these are inaccessible. The upper seam is continuous and regular in thickness (perhaps 10 inches), so far as observation shows, from one end of the cut to the other.

The massive sandstone and the upper coal seam can be traced for many miles in the region and seldom lose their identity. The coal seam at the base of the sandstone, on which interest centers for the moment, if present generally, is seldom observed; the sandstone does not tend to form cliffs, and outcrops of this horizon are scarce.

The base of the sandstone which rests sharply either on the coal or on the shale when the coal is absent, rises and falls irregularly through several feet, and suggests strongly the existence of an erosion surface. This suggestion is supported especially by the distribution of the coal which is present only where the base of the sandstone is high, and disappears where it is low. It is not unusual to find coal seams overlain by a sandstone, which are thinner or wanting entirely in places because, as commonly expressed, the sandstone "cuts out" the coal. It has generally been supposed that such an interruption is due to erosion, and doubtless it is in some cases; but in the present one, this is not the correct explanation. At only one point, and that for but a few feet, is there any evidence of erosion, and even that is not conclusive in view of the irregularity found at all other points.

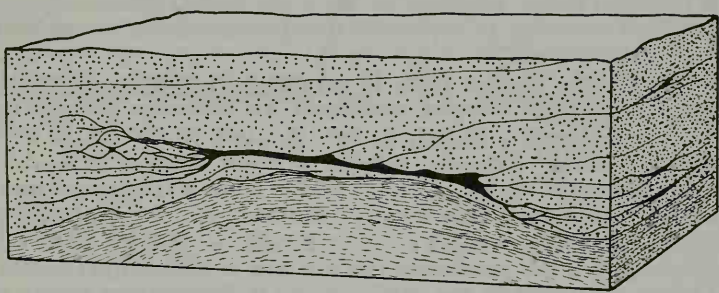
Occurrence of the Coal in Pockets not due to Subsequent Erosion but an Original Character. There are some 10 or 12 shale crests in the 300 yards which are clearly exposed, each with a bed of coal on the crest. In the sandstone-filled "troughs" which intervene there is no coal. The thickness of the coal, where present, varies from a fraction of an inch to 35 inches, rarely exceeding a foot. Horizontally, the coal may persist for only 2 or 3 feet on a small crest, or it may persist for 40 or 50 feet over a larger one. The sandstone troughs are of about equal width. But the coal is not truncated by the sandstone as it descends on either side of the crest. The coal seam splits and disappears on either side by interfingering with those portions of the sandstones which fill the "troughs." The seam may split abruptly into two or three thin streaks, and each of these in turn into as many or more within a few inches. Not infrequently two partings will reunite around a thick lens of sandstone.

There appears to be only one possible interpretation of the relation of the coal to the sandstone. The vegetable matter was accumulated in very limited patches, and coarse sands, sometimes full of large and small plant fragments, were deposited simultaneously between these patches. The vegetable mud which later formed the coal was originally of about the same thickness as the intervening sands and was intertongued into them. Subsequently the vegetable mud was compressed to only a small fraction of its original thickness, but the sands were affected to a limited extent only.

. . . .

Effect of Inclined Bedding in Determining the Amount of Reduction. The most remarkable feature of the entire deposit is found in the inclined bedding of the thick sandstones, and in its relation to the coal pockets. The inclination of the bedding throughout most of the cut is toward the north and northeast, and usually at a low angle, commonly from 5° to 10°. At the south end of the cut the inclination is changed for a few yards to southeast. At the north end, just at the point where the outcrops become obscured by the low gentle covered slopes of the shallower part of the cut, the sandstones appear to have been derived from the northeast. The occurrence shown in Fig. 4 is found where the material from the two directions met.

For a distance of 120 yards, where the sandstones are persistently inclined to the north-northeast, the tongues which split off from the upper part of any one coal pocket toward the source of the material (that is toward the southwest) rise on the surfaces of the inclined bedding planes. This relation is best understood by reference to the accompanying sketches. It is this condition which, in part, makes uncertain the figures given above as to the relative thicknesses of coal and sandstone which accumulated simultaneously. The thickness of sandstone, except in No. 4, was obtained over the sandstone "trough" adjacent to the coal and represents the maximum over that trough, perhaps 10 or 15 feet from the coal. This is about as far as the thin coal streaks can be distinctly and readily traced (except in No. 5, where they are still present at the point where measured); but the bedding planes, which are continuations of these streaks, can be



Vein-like coal.

followed up the inclinations to the southwest until they are 15 feet or even 20 feet above the base of the sandstone. While in the outcrop there may be no reason to suspect a continuation of the coaly matter upward along the bedding plane, slight bruising of the stone with the hammer edge not infrequently yields a black stain, even when the beds appear to be in contact with each other. This thin film of carbonaceous material, rising many feet along the bedding planes, beyond the coal laminae, makes it difficult to determine just what thickness of sandstone is to be considered as formed simultaneously with the adjacent column of coal. The thickness given in all but No. 4 is that of the sandstones, which are somewhat irregularly bedded and lensed as a result of the thin streaks of coal and their compression, but measured as nearly as possible where there is no appreciable thickness of coal in the measurement. If measured farther away from the coal pocket, the thickness would be increasingly greater, but the sandstones, although carrying traces of carbonaceous matter on the bedding planes, would be regularly inclined and undisturbed by the compression, because the coaly matter was too thin to cause any appreciable readjustment in them. Furthermore, the thickness, when measured at the point usually selected, agrees fairly well with the heights of the shale crests above the base of the sandstone troughs; these are believed to be a rough index of the amount of compression which has taken place in the coal.

However, the actual original thickness of the organic mud, and the exact amount of compression it has suffered, are only incidental to the subject under consideration, and are not at all essential to the interpretation of the associated structures.

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STYOLITES WITH FILMS OF COAL

Stockdale, Paris B.; *Journal of Geology,* 53:133-136, 1945.

Introduction. The rare occurrence of stylolites in rocks other than such carbonate types as limestone, dolomite, and marble has been recognized for several years. A recent discovery of a type of stylolite heretofore undescribed deserved brief mention not only because of its peculiarity but because of its bearing on the mode of origin of stylolitic phenomena.

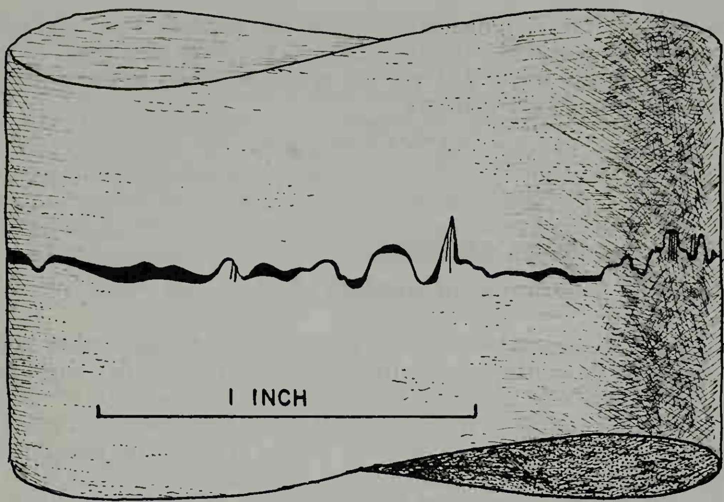
The stylolites under consideration were observed in a 2-inch drill core taken from quartzitic sandstone of Pottsville age (probably the Gizzard formation) on Lookout Mountain, near Mentone, DeKalb County, Alabama. The stylolites are peculiar because of the thin, black, coal films associated with them, as well as because of their occurrence in quartzitic sandstone. They are significant because of their structural relations, which contribute evidence in support of the solution theory of origin.

Occurrence and Description. The rock is a light-gray, medium-grained, very hard, compact quartzitic sandstone. It is virtually a quartzite. Stylolites were previously reported from similar rock of approximately the same geologic age along the Cumberland Escarpment in eastern Tennessee. The latter, however, did not carry coal films. The rock of the drill core under study contains, in addition to the quartz which predominates, scattered miniature chunks and flakes of coal. The thin films of coal sharply demarcate the stylolite-seams. The coal is highly metamorphosed, is of very low volatility, and does not ignite freely. No true graphite, however, was observed.

The rock is laminated rather distinctly. This feature is accentuated by the occasional concentration of carbonaceous material, giving rise to darker streaks, alternating with the lighter ones. The laminae lie at an angle of 25° from the plane perpendicular to the axis of the drill core, suggesting a 25° angle of dip of the strata.

The stylolites are small. Individual columns range from almost microscopic size to not over 1/4 inch in length. Some of the columns have nearly parallel sides and blunt, rounded ends. Miniature striations occur on some of the sides. Dominantly, however, the stylolites are tapered and pointed---the Drucksuturen type of the German writers.

The coal films associated with the stylolite-seams are the significant feature. Although thin in actual measure, the coal films are comparatively thick in relation to the length of the interpenetrating stylolite columns. Stylolite surfaces which are revealed by separating the rock along stylolite-seams are rough and pitted. They are typical solution surfaces. The incrusting coal films can be readily scraped off and examined.



Stylolite seam showing the coal partings and variations in the size and shape of individual stylolite columns.

THE ALBERT COAL, OR ALBERTITE, OF NEW BRUNSWICK

Hitchcock, Charles H.; *American Journal of Science,* 2:39:267-273, 1865.

The nature of the Albert coal and the mode of its occurrence in the strata have been vexed questions in geology. Its beautiful appearance attracts the eye, while its pecuniary value gave rise to the litigation which occasioned the delivery of the diverse opinions. In this as in so many other difficult subjects time has developed much truth, and shown us that we must not insist too strongly upon seemingly well-established theories.

In this communication I propose to describe briefly the geological features of the Albert coal vein and the accompanying rocks. I shall, whenever necessary, refer to the facts observed by others in this locality, but rely chiefly upon my own observations made in 1861 and 1864, as well as upon hints derived from persons of intelligence living in the vicinity. For a knowledge of many facts relating to the distribution of the different strata, I am indebted to Mr. James Blight, of Hillsborough, N. B. It is necessary to be dependent upon others for some knowledge of the internal structure of the Albert Mine, because the Company will not allow any scientists to examine their property below the surface. I use the word coal as a matter of convenience, not necessarily in strict propriety.

There are four different mining properties in Hillsborough, situated upon veins of Albertite:---the Albert, (the only one worked extensively and thoroughly proved), the East Albert, the Prince of Wales, and the Princess Alexandra. The second lies east of the first, and the others north and south of the same. Hillsborough is situated upon the west bank of the Petitcodiac river, near its confluence with the Bay of Fundy.

The rocks are of Lower Carboniferous age, and belong to the Acadian coal series. Several species of Paloeoniscus, Lipidodendron, Lepidostrobus, Spheraedra, and Stigmaria occur in the shales and sandstones. Two or three miles southwest from the Albert shaft there appear older crystalline rocks, such as syenite and metamorphic slates; constituting the easternmost point of the extension of these rocks from the vicinity of St. John. The lowest rock in the Carboniferous series is the Albert shale; but I cannot state whether it crops out near the syenite. It probably does not appear anywhere on the edges of the coal basin. Nothing similar to it occurs in the Joggins' section. It should be expected to occur near and below the numerous deposits of gypsum in the eastern provinces.

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The first outcrop of Albert coal was discovered by John Duffy, fifteen or sixteen years ago, in a deep ravine on Frederick's brook. The vein was about four feet wide, but by working upwards twenty-five feet into the bank, it thinned out to two or three inches. Duffy drifted about 300 feet on the course of the vein above the water-level, and sunk a shaft sixty feet, where the coal is said to have attained a width of ten feet. He then disposed of the property to Cairns, Allison & Co., who held it at the time of the litigation, but have now mostly transferred their shares to other parties, holding them under the same charter.

To describe the numerous variations in the course, thickness and shifts in the Albert workings, so far as known, would be unnecessarily tedious. Percival describes them for the first 200 or 300 feet of the descent, occupying more than three pages of the size of this Journal in a little more than catalogue style of enumeration. I am assured by the manager, Capt. Byers, that, from that depth to the bottom of the shaft, 950 feet, the character of the irregularities has not changed. In brief, the peculiarities of the mine are the following.

The general course of the vein is N. 65^{o} E., but the coal is repeatedly heaved southward by small faults. Its inclination is northwestward from 75^{o} to 80^{o}, often vertical. The body of the vein is extremely irregular, constantly expanding and contracting, both laterally and vertically. What is too narrow to be worked in one level enlarges to six and twelve feet, a hundred feet lower, or the reverse; but in general the width increases in following down the vein. At the time of Percival's examination, the vein was not considered workable 170 feet west from the old shaft. At lower levels the yield is renumerative 700 feet west and 2300 feet east of the new shaft, which lies several rods west of the first. In consequence of the uncertainties in the character of the vein, it is found necessary to accumulate a large supply of the coal during the suspension of navigation, so that there will always be enough stock on hand in the warmer months to load the vessels without delay. Whenever a displacement is met with the vein is not lost, because a film of the coal remains in the slip to indicate the location of the heaved portion. The widest part of the vein is said to be twenty-eight feet.

The narrow portions of the coal are invariably contained in a harder rock; where the rock is softer the vein is larger. "Horses" are common. In such cases the cavity above, out of which the horse fell, is found to be filled with coal; so that the width of the coal at that level is equal to the usual width plus the width of the horse. Numerous small branches run off into the shales from the main vein. These are short and might be described as irregular and branching spines from a main stem. Many of the fragments of rock taken from the mine show these small injections. The most striking proof of the proper character of the mass is afforded by the edges of the strata in contact with the coal; they are coated with Albertite, while the surfaces are covered only when enclosing one of the small lateral branches, a few inches long.

With the facts now presenting themselves to the explorer, I think no one would call the Albertite mass a bed. It occupies an irregular fissure along an anticlinal line, and the deep workings have failed to develop the lower anticlinal branching of the coal anticipated by the advocates of the bed theory. The numerous branches are unlike any phenomena connected with beds. There is no fire-clay to form the floor of a bed; and, in addition, the common adherence of the coal to the edges of the strata, rather than slickensides---I do not mean those in the horizontal slips---seems to complete the evidence that the coal does not occur between stratified planes. To disclaim a bedded character casts no reflections upon the observations of the distinguished geologists who have decided otherwise; because they started with erroneous premises. To them the idea of coal in a vein was preposterous. It appeared as great an anomaly as it would be now to find Niagara fossils in the Potsdam group.

The vein-character of the deposit is seen more distinctly in the smaller openings. On the East Albert property two shafts have been commenced near the anticlinal line in the conglomerate over the shale. These reveal, at the depth of thirty feet, nearly six inches width of a richer and more beautiful coal than the Albert, gradually thinning out to the width of coarse paper at the surface, and most unequivocally cutting vertically across nearly horizontal layers of sandstone. As before, we have here the phenomena of shifts constantly working the vein southward, and a slight leaning in the same direction. Following the line to the Petitcodiac, there are seen other openings upon the vein of less extent.

The two veins crossing the anticlinal are very interesting. Upon parallel lines about a mile apart, their course is N. E. and S. W. One appears to intersect the principal vein very near the Albert shaft. The intersection of the other is concealed by a great depth of alluvium. It cannot be said that the coal is likely to prove more abundant at these intersections, as is the case at the union of metallic lodes, yet the similarity of the two classes of veins is such as to warrant the exploration.

....

1. The Albert coal occurs in true cutting veins, not in sedimentary beds like ordinary coal.

2. The Albert coal was originally in a liquid state, was injected into vertical fissures, and subsequently hardened into a substance resembling jet. The liquid may have been derived from vegetable accumulations, or possibly in part from the abundant ichthyic remains in the shales. Whether the shales were originally oily, as now, and the fissures subsequently filled with a viscid fluid derived from them, or whether the charging of the fissures imparted an inflammable character to the rock, I will not

conjecture, though it is easy to satisfy one's own mind. The cavities of the Albert coal occasionally hold liquid petroleum, and those in the adjacent shales more often. A few quarts of petroleum have been brought up from borings along the line of both the Albertite veins on the east side of the Petitcodiac. With the hardening, the hydro-carbonaceous liquid received oxygen into its composition.

3. The Albert coal must be compared with the asphaltic and bituminous veins found in the Quebec group in Canada. It there "fills veins and fissures in the limestones, shales, sandstones, and even in the trap rocks which traverse these." "In other cases, it fills fissures several inches in diameter, so that it has been mistaken for coal, and attempts have been made to work it at Quebec and elsewhere. The mineral is never, however, in true beds like coal, but is always confined to veins and fissures which cut the strata." "The matter is of a shining black color, very brittle, breaking into irregular fragments with a conchoidal fracture." (Geol. Canada.) The Quebec coal is like the Albert in the small amount of the ashes, but contains more carbon.

4. These carbonaceous veins are analogous to veins of petroleum. The borings for petroleum in Ohio and Western Virginia are most successful along lines of fracture, particularly an anticlinal axis. The description of the chasm filled with oil would undoubtedly be given in words similar to those used respecting the Albert vein, if we could sink shafts and drive on the course. The views of Prof. Andrews in this Journal, ([2] xxxii, 85,) respecting the location of petroleum, are very just, and show that it often occurs along anticlinal faults. The immense yield of many oil-wells certainly suggests the presence of more than the "horse-cavities" filled with the liquid.

5. The carbonaceous veins, such as the Albert coal, Canadian asphalt and liquid petroleum, while possessing many characteristics of metallic lodes, will be found to differ from them in some respects. These particulars will be ascertained fully by the immense enterprise now manifested in sinking for petroleum. We can anticipate differences in respect to the limited depth, little variations of thickness at intersections, irregular yield, and origin of the carbonaceous veins. A proper knowledge of them may lead to some modification of terms in our definitions.

• Unusual Fossils in Coal

THE FORMATION OF COAL BEDS

Stevenson, John J.; *American Philosophical Society, Proceedings*, 50:1-116, 50:519-643, 51:423-553, 52:31-162, 1911-1913.

Foreign Bodies in Coal. The presence of tree stems in coal is normal; but the coal often contains what may be regarded as foreign bodies.

Nodules of calcareous clay-iron stone are familiar objects in coal beds as well as in the Coal Measures shales. They are from mere specks to balls a foot or more in diameter. Occasionally they are rudely spherical but for the most part the shale is irregularly oval and occasionally even plate-like. When enclosed in coal beds, the laminae are displaced about them as though the final compression had taken place after formation of the nodule; and this feature is as characteristic of coals which have not been distorted as of those which have been folded. The nodules are often fossiliferous, containing marine shells at times but land forms and plants at others---as those obtained at Mazon creek in Illinois, in which are remains of many animals as well as plants, all marvelously well preserved. Such nodules have been found in the Devonian, for Nathorst obtained some from shales of that age in Spitzbergen; Lepidodendron and apparently Bothrodendron were recognized in several of them, while others contain remains of fishes.

More than 80 years ago, calcareous nodules more or less ferruginous, occurring in the roof and coal of a thin bed in the Lancashire coal field, attracted Binney's attention and were made the subject of a memoir by Hooker and Binney. Since that time, such nodules have been discovered in many lands and have been investigated by students in Europe. In this summary, reference is made only to some of the later publications.

Coal balls were supposed for a long time to be confined, in England, to a single horizon, the thin Lancashire coal bed known as the Mountain Upper Foot. This, in the Lower Coal Measures, is at a variable distance above the Ganister coal bed, one of the most persistent members of the column. The Ganister, when separated by several yards from the upper Foot, contains no balls; but when the parting is only a few inches, the balls are in both beds. There is no regularity in the distribution. The Hard coal bed, near Halifax in Yorkshire and belonging apparently at the same horizon, also contains similar balls. These concretions have a slickensided surface and the coal laminae curve around them; occasionally a faulted specimen is found. In size they vary from an inch to a foot or even more---one, near Shore, weighs 2 tons and replaces the coal from roof to floor. These balls in the coal contain plant remains in condition of remarkable preservation.

The roof shale of this coal bed carries abundant remains of marine animals along with much fragmentary plant material. "Bullions," "baum-pots" or Goniatite nodules" occur in this shale and are as characteristic of it as the coal balls are of the coal. These 100f balls enclose shells with which there are often bits of plants, rarely well preserved but at times admitting of generic determination. Sphaerosiderites, answering to the English roof balls or bullions, have been found within the Nord (France) basin in marine shales, sometimes resting on thin coals. They, like the English balls, contain Goniatites, Productus and other forms; but Barrois does not note the presence of similar concretions in the coal.

Sphaerosiderites were obtained at collieries in the Ostrau coal field from the roof shale of the Heinrichs and Coaks coal beds; in each case the shale is marine. The balls from the higher shale are occasionally fossiliferous but those from the roof of the lower bed seem to be without fossils. The lower part of this shale, however, is crowded with small balls of pyrite, many of which are fossiliferous, while many shells in this portion have been replaced with pyrite. The balls, for the most part, are small, very irregular in form and often are polished, so that they might easily be mistaken for erratics. Sometimes several are united but ordinarily they are separate and are scattered throughout the shale. They are encrusted with powdery matter, one to two millimeters thick, which is removed readily by washing. When exposed to the weather, their concretionary structure soon becomes apparent.

The Coaks bed contains great numbers of coal balls or plant-sphaerosiderites; Stur obtained several hundreds in a large block of coal shipped to him from the mine. These are especially abundant in the upper bench and on the west side of the area, where the roof balls also are most numerous. The remains of plants in the coal balls are always well-preserved but those in the roof balls are in bad condition.

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Except at the Bacup locality, dolomite is not the important constituent of the coal ball. Strahan's notes respecting the Wiral colliery in Cheshire seem to have some bearing on this matter. The coal there was 4 feet thick and of good quality where opened; but within a short distance bands of stone, 1 to 10 inches thick, appeared, some of them consisting of spherical pellets. Within 250 yards, the coal was replaced with this rock, but the roof and floor remained unchanged, save that the former had become reddened---this change, however, being unrelated apparently to that in the coal. The rock is black and hard, but weathers gray; the structure is pisolitic and the concretions are sometimes united, at others independent and separated by coaly matter. They consist of dolomite with some coaly material, iron, silica and clay. Some fragments are composed of small masses or irregular crystalline layers, separated by fine mud containing quartz and flakes of mica; while others, consisting partly of woody tissue filled with dolomite, may be regarded as wood fragments, impregnated with and cemented by dolomite. When this dolomite has been removed by acid, a copious residue of carbonized fibers is obtained.

These balls or sphaerosiderites are concretions formed in the coal and shale after the deposits had been made but before consolidation. The laminae of coal and shale curve around them and some of the concretions were broken during the later compression. Green in describing the Yorkshire roof balls says that the Goniatites, Aviculopecten and other shells enclosed are not flattened as are those in the shales. The plant material in the coal balls is in wholly uncompressed condition, so that the minutest details of structure can be recognized---as one may see by consulting Williamson's memoirs in the Transactions of the Royal Society. Stur found the stems of plants not only uncompressed but also, in some cases, not wholly decayed, so that the concretions were formed before the chemical change had been completed. Stopes and Watson were convinced that they had traced a stem continuously from one coal ball into another; Wild says that the Lancashire "bullions," composed of fossil wood, occasionally show rootlets working their way through the decaying wood, separating the fibers which now surround them. But vegetable fragments in roof balls are different; as Stur remarks, they are coaled and evidently much changed; they tell little of relations and less of structure.

But coal balls are not confined to the Coal Measures. Gothan having noted that the localities, where the balls had been obtained, were all within paralic basins set himself to discover them under other conditions. Petrified stems are common in Tertiary beds, where, as deposition centers in brown coal, they have given opportunity for concentration. Such silicified or at times pyritized stems occur frequently in the Halle brown coal and in the Rhenish brown coal one finds the well-known oolite wood. But these are not wholly analogous to coal balls, which are bits of petrified peat, penetrated at times by roots of vegetation growing above. In searching the survey collections at Berlin, Gothan found a piece of brown coal from the Donatus mine near Cologne, which contained spherules of carbonate of iron, the same as the material of the oolite wood. Deposition had not been confined to the wood but had reached into the actual peat. Specimens were procured from Flugel, who had mapped the area, and they proved to be part of the bed, replaced with material like that of the plant-balls described by Stur. Gothan suggests the name of Torf-Dolomite. Microscopic examination by Horich showed the close resemblance between these forms and the coal balls. As a rule, however, the plant remains are less well preserved than in the coal balls; they are so disintegrated that in many cases they are not identifiable. Roots are best preserved, probably because they entered when the surrounding mass had already become peat. They show no trace whatever of compression. Some fragments of stems have great lacunae, indicating that they are of plants belonging to a moist habitat. The great variety in the plants suggests that the deposit is a typical Waldtorf, which accords with the belief that the brown coals were deposited as Waldmoors.

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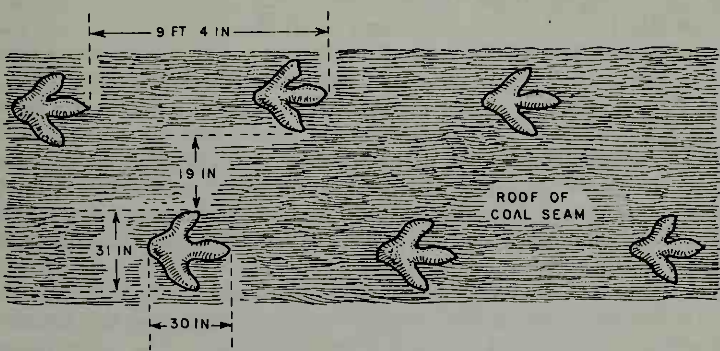
DINOSAUR TRACKS IN THE ROOFS OF COAL MINES

Peterson, William; *Natural History,* 24:388-391, 1924.

To view the tracks of ancient Cretaceous monsters is not an entirely new experience, but to view these tracks from beneath instead of from above is somewhat of a novelty. This is a privilege open to those interested in the ancient life of the Cretaceous seas of Utah and Colorado. It was the writer's good fortune to spend three summers in a detailed survey and inspection of the coal deposits of Utah. While he was examining the underground workings of many of the mines, attention was called to certain protuberances from the coal seam roof. A definite shape had been recognized in the case of some of these, though most of them were spoken of as "carbuncles," "nigger heads," and under similar terms. In areas where the coal was low these protuberances had to be removed to give room for the mine hauling, for some of them projected as much as a foot below the roof of the coal seam. In some places the projections appear in groups while in others they are solitary.

After inspecting hundreds of these protuberances, the writer agrees with some of the mine foremen and superintendents that these peculiar formations undoubtedly had their origin as tracks of ancient monsters which tramped through or around the border of the Cretaceous sea. The tracks seem to have been made at a time when the peat accumulation was covered with a foot or more of mud. The layer of mud was not sufficiently thick to support the weight of the animal walking over it. The feet sank through the mud several inches, or even more than a foot at times, into the soft, yielding peat underneath. Some mud was pushed into the peat as the animal brought down its weight, and as it drew out its foot, the footprint would be filled with mud from above. As time went on, nature's distillation reduced the peat to coal, and the mud with its track projections was converted into solid rock. In most places the coal is easily separated from the roof, leaving the track-shaped protuberance extending partially or wholly as a definite appendage from the ceiling. When the coal is completely removed, the tracks appear in various forms. In some cases the footprints project only part way through the roof and in others they project so far that a clear space is shown between the portion of the track represented by the toes and the solid roof. It is interesting to note that, as far as observed, the largest tracks are the ones which protrude farthest from the rock roof. The material filling the track varies slightly but is for the most part an arenaceous shale or argillaceous sandstone.

The animals seem to have walked for the most part along trails or definite paths. It was noted that some of these paths are twenty or thirty feet in width, and the exposures in many entries and rooms of the coal mines show them to be comparatively straight in alignment. The individual tracks in the paths are seldom clearly outlined and only when one of the animals has traveled independently does every imprint become distinct. In several places it has happened that an entry of the coal mine has followed approximately the path of a single animal, thus exposing several of the tracks for measurement and comparison. Seven consecutive tracks are shown in the old Ballard Mine on the property of the American Fuel Company, located on the Denver and Rio Grande Railroad about eight miles north of Thompson Springs. These tracks are among the largest observed and the measurements are shown in the diagram on p. 389.



A row of tracks on the roof of a coal mine.

In a different entry of the mine, tracks of similar size are found, and by courtesy of the company one of these was taken down and shipped to the Geology Museum of the Utah Agricultural College at Logan. On this page is shown a photograph of this track with a 12-inch rule placed on it for comparison. The track measures 31 inches between the spread of the outer toes and 32 inches from the heel to the front of the middle toe. Near the point of separation the toes are from 6 to 8 inches in diameter, and the toes are so pointed as to indicate the presence of rather sharp claws on the end of each toe.

In the mine at Castle Gate, Utah, a photograph was taken of one of the gracks as it appeared in the roof of the mine before removal. The photograph [not reproduced] is furnished by courtesy of Mr. Watts of the Utah Fuel Company. This track, which is similar in character to those mentioned above, is somewhat smaller than they, being only 24 inches between the spread of the toes and extending for about the same distance if measured from the heel to the front of the middle toe. Only one track smaller than this has been measured, that in the mine at Standardville in Spring Canon, the length of which is only 16 inches; however, it is similar in other respects to the Castle Gate track. Two casts of tracks have recently been obtained by workmen of the United States Fuel Company at the Panther Mine.

The tracks referred to in this article have been observed by the writer at intervals over an area more than one hundred miles in extent and in different seams of coal, which represent a stratigraphic thickness of more than two hundred feet of sandstone including three or four beds of coal. The coal seams total in thickness approximately thirty-five feet. The deposit is near the base of the Mesa Verde formation of the Upper Cretaceous. The tracks are all of the three-toed type and seem to have been made by an animal that walked only on its hind feet. In one place, where the roof of the mine was badly caved, careful examination was made for any trace of either front feet or tail track, but no evidence of either was found.

The most startling thing about the tracks is their enormous size. The writer has examined painstakingly the feet of the mounted skeletons of the Apatosaurus, Ceratosaurus, Claosaurus, Hadrosaurus, and others, but none apparently have feet large enough to fit these tracks.

Dr. W. D. Matthew of the American Museum interprets the tracks as having been made by a member of the deinodont family of dinosaurs, of which the Tyrannosaurus is the largest known type. He further describes the Tyrannosaurus as "the climax of evolution of the giant flesh-eating dinosaurs. It reached a length of 47 feet and in bulk must have equalled the mammoth mastodon, or the largest living elephants. The massive hind limbs, supporting the whole weight of the body exceeded the limbs of the great proboscideans in bulk, and in a standing position the animal was from 18 to 20 feet high as against 11 feet or so for the largest African elephant or the southern mammoth. The head was 4 feet 3 inches long; 3 feet, 4 inches deep and 2 feet, 9 inches wide. The long deep powerful jaws are armed with teeth from 3 to 6 inches long." The front limbs were small and were probably used only in capturing and gathering food. The great bulk of the body would imply slow movement, and that food was obtained from the shallow water of the Late Cretaceous sea.

THE CARBON-DUST ON FOSSIL PLANTS

Wilmore, A.; *Geological Magazine*, 30:576, 1893.

It is well known that Fossil plants when found in sandstone and generally entirely covered with a thin layer of nearly pure carbon; in the case of Calamites, etc., in the Coal-measure sandstones the layer is often not more than about 1/20 of an inch in thickness. It very readily falls away, and it is only in rare cases that it adheres to the sandstone cast. I should like to propose some questions concerning this carbonaceous covering to your readers. (1) Why is the whole of the carbonaceous residue in well-preserved fossils confined to the outside of the cast? (2) Does the carbonaceous layer represent the whole of the carbon of the tissue of the plant? (3) Why, in comparatively soft and little altered freestones, should the carbonaceous layer exhibit such a baked or charred appearance?

CYCLOTHEMS AND RHYTHMIC SEDIMENTATION

In Midwestern coal fields the same sequence of strata repeats over and over again: limestone, shale, coal, clay, etc., always in the same order, in monotonous cadence. Some geological message is inherent in these rhythmic strata but no one is quite sure what it is.

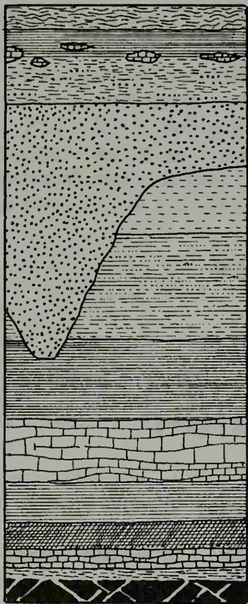
Cyclothems are found worldwide. The rock sequences differ but the beat persists in each locality. The cyclothems of the American Midwest seem the most extensive, perhaps stretching for hundreds, even a thousand miles. Some geologists deny cyclothem continuity over such great distances, but everyone admits that the repeating sheets of rock are immense.

The cyclothem phenomenon is remarkable and requires considerable inventiveness to explain. The most popular scenario envisions the rhythmic uplift and subsidence of land, which discharges different sediments in sequence into collecting basins. Localized cyclothems can conceivably be created in this manner, but this mechanism hardly accounts for cyclothems hundreds of miles in extent. Given the geological importance of cyclothems, any explanation will reveal much about our planet's internal pulsations or possibly repeating extraterrestrial disturbances.

A DILUVIAN INTERPRETATION OF ANCIENT CYCLIC SEDIMENTATION

Woodmorappe, John; *Creation Research Society Quarterly,* 14:189-208, 1978.

There exist among sedimentary rocks certain types which have very many types of rock, in thin layers, which lie one on top of another and repeat in a regular sequence. Much of the world's coal is found in such repeating layers. Each repetitive sequence (between coals and including one coal) is called a cyclothem. A diagram of an "ideal" or "complete" cyclothem found in Illinois is found in Figure 1. (The reader of this paper should continually refer to Figure 1 whenever the number or the litholo-



An idealized Illinois cyclothem. All ten members are never present in one place. The most common Illinois cyclothem is: 1, and/or 2, 4, 5, 8, 9, and 10.

gical identity of a given number is described in this text.) The numbering and termination of the cyclothem differ, reflecting the disagreement among Pennsylvania stratigraphers as to where one cyclothem "ends" and a superjacent one "begins." [Thus, some consider a new cyclothem to begin at the basal sandstone, member 1, while others consider a new cyclothem to begin with the coal (member 5)].

It must be hastily added that almost never in the earth does a "complete" cyclothem occur at any location as shown in Figure 1. A real field situation as exists might have this type of layering: members 1, 2, 4, 5, 10, 1, 2, 4, 5, 8, 10, 1, 2, 4, 8, 9, 10, 1, 2, 3, 4, 5, 6, 7, 8, 10, etc. This important fact to realize is that the relative order of the members always exists and that these members do repeat themselves consistently.

The cyclothems are asymmetrical, which means that the coal or shale (or any other member), may be vastly thicker or thinner than the corresponding member of the cyclothems above and below it. Furthermore, even within one cyclothem, the thickness or thinness of one member does not guarantee the thickness, thinness, or even presence of another member in that cyclothem at all. Six or more of the then members are usually found at any given locality and their relative order is always preserved. "The average thickness of a cyclothem in the central states is less than 50 feet...."

Although cyclothems and their valuable coal beds are found in many parts of the world, this paper will concentrate on the cyclothems found in

Illinois as far as their morphology and specifics are concerned. "The Pennsylvanian sediments in the basin cover an area of approximately 55,000 square miles, chiefly in Illinois, Indiana, and Kentucky, with minor areas in Missouri and Iowa.

The maximum thickness of Pennsylvanian sediments, more than 2800 feet, occurs in the southern part of the basin in Kentucky. Shale is the predominant lithological unit of the sequence with subordinate amounts of sandstone and much smaller amounts of limestone and coal. The presence of ordered lithological sequences or cycles is the most characteristic lithological feature of the Pennsylvanian sediments. More than 50 such sequences are recognized."

Cyclothems are variable not only in terms of presence of members and thickness of members, but also in terms of lateral extent of each of the members. Some members can be traced for hundreds of miles while others wedge out (& thin out) in only a few miles or else grade into members elsewhere. "Many of the cyclothems are nearly as varied within a single county as within the entire state of Illinois.

For this reason, a detailed study of only a small area may leave the impression that the beds vary greatly, whereas a more general survey of almost the entire Eastern Interior Basin has revealed that the Pennsylvanian system throughout this region is remarkably uniform." Cyclothems, like humans, are-paradoxically-so similar yet so different from each other.

The reason why the area of cyclic sedimentation has been chosen for this study is because "No more fascinating field for research and speculation exists within the entire domain of stratigraphy." This writer has engaged in both "research and speculation" in the field of cyclic sedimentation to try to understand how the Universal Deluge caused cyclic sedimentation.

The uniformitarians have proposed a good number of theories to explain how the cyclothems formed, but "None of these theories has gained much following." This is because "Recognition of the stratigraphic facts of cyclical repetition and distribution, and deduction of the causes responsible for them are unrelated, one to another. Evidence pertinent to the historical interpretation of cyclothems is incomplete, scattered, and not fully understood. Some of it has suggested different conclusions to different persons. (pp. 189-190)

CYCLOTHEMS AND LARGER SEDIMENTARY CYCLES OF THE PENNSYLVANIAN

Weller, J. Marvin; *Journal of Geology,* 66:195-207, 1958.

Introduction. Pennsylvanian sedimentary cycles were first observed in the United States by Udden near Peoria, Illinois, but a clear description of them went totally unnoticed. When they were rediscovered some years later, a succession of eight members was distinguished and described as follows:

(This numbering scheme differs slightly from the one of the preceding article and figure. WRC)

Marine	8. Shale, containing "ironstone" bands in upper part and thin limestone layers in lower part
	7. Limestone
	6. Calcareous shale
	5. Black "fissile" shale
Continental	4. Coal
	3. Underclay, not uncommonly containing concretionary or bedded fresh-water limestone
	2. Sandy and micaceous shale
	1. Sandstone

Unconformity

This succession was named a cyclothem. In Kansas, a different type of cycle was described consisting of a large number of members that may be generalized as follows:

Shale, thick
Limestone, marine
(fifth limestone)
Shale, sandy
Limestone, marine, algal, or oolitic
(super limestone)
Shale, sandy
Limestone, marine, fusulines abundant
(upper limestone)
Shale, black
Limestone, marine, thin, dark colored
(middle limestone)
Coal or coaly streak
Shale, sandy
Limestone, marine, sandy, yellowish weathering
(lower limestone)
Coal or coaly streak
Sandstone

These two stratigraphic sequences, each of which is repeated with some variations many times, are characteristic of lower and upper parts of the Pennsylvanian system, respectively, in regions about 300 miles apart. Comparison reveals little similarity. The Kansas sequence, with its complex succession of marine limestones, was interpreted as recording several transgressive-regressive cycles, each of which was likened to a cyclothem. Because it was believed to correspond to several, perhaps as many as five, incomplete cyclothems, it was named a megacyclothem.

Later stratigraphic studies in Illinois revealed that some cyclothems in the Upper Pennsylvanian include other members, and the fully developed cyclothem was described as follows (see fig. 1):

10. Shale with ironstone concretions
9. Marine limestone
   (upper limestone)
8. Black sheety shale with black limestone concretions or layers
7. Impure, lenticular, marine limestone
   (middle limestone)

6. Shale
5. Coal
4. Underclay
3. "Fresh-water" limestone
   (lower limestone)
2. Sandy shale
1. Sandstone, locally unconformable on underlying beds

When this sequence is compared with the Kansas megacyclothem, a remarkable parallelism may be noted in the general succession of "lower" limestone, coal, "middle" limestone, black shale, and "upper" limestone. This has suggested that the Kansas megacyclothem may actually be no more than a further expanded cyclothem. Matching the fresh-water "lower" limestones of Illinois cyclothems with the marine "lower" limestones of Kansas, However, has not seemed entirely satisfactory, and the introduction of a second marine transgression in the lower part of a cyclothem complicates any theory of origin. Although this equivalence has been accepted or entertained as a possibility opinions have differed, and the uncertain relations of cyclothems to megacyclothems has posed a perplexing problem of considerable importance in connection with attempted correlations of Upper Pennsylvanian strata east and west of the Mississippi River and the interpretation of physical conditions that influenced Pennsylvanian sedimentation.

....

Conclusions. The patterns described above indicate that a twofold system of controls was required for the development of cyclothems and megacyclothems. Appeal has been made to movements in Atlantic borderlands to account for cyclothems, at least, those occurring east of the Ozark Region. The distribution of megacyclothems, however, indicates that control of this larger cyclical pattern superimposed upon the smaller one was not related to such movements and must be sought in another region. Variable movements in a geosynclinal zone north of some kind of Llanorian upland seem to afford the simplest explanation.

The still larger cycle of hypercyclothems may have been controlled by movements in this same region, but evidence is too tenuous for speculations regarding them to have much value at this time.

ORIGIN OF THE LIMESTONE-SHALE RHYTHM IN THE BLUE LIAS.....

Hallam, A.; *Journal of Geology,* 72:157-169, 1964.

Abstract. An account is given of the development of the controversy about the origin of regular small-scale alternations of limestone and shale in the Blue Lias of England. The point in dispute has been whether the alternations are original sedimentary features or products of diageneses. It is here suggested that both processes have played a role, and criteria are suggested for the distinction of primary and secondary rhythms, which may be of general application. The probable conditions controlling the sedimentary variations and diagenetic migrations are briefly examined.

Introduction. The strikingly regular alternation of bands of limestone and shale at the classic Liassic (Lower Jurassic) locality of Lyme Regis in Dorset has lont attracted the attention of geologists. This distinctive facies of the Blue Lias (Hettangian and Lower Sinemurian) is found throughout most of England and poses problems which, apart from their intrinsic interest, have relevance to rocks of a variety of ages.

Briefly, the limestones consist of argillaceous calcilutites mostly from 2 to 12 inches thick, separated by marls and shales of a somewhat wider range in thickness. Full petrographic and chemical descriptions of these rocks are given elsewhere. Petrographic study does not seem, however, to provide the key to the solution of the problem under consideration here, whether the limestones are primary (sedimentary) or secondary (diagenetic) features.

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BIOHERMAL LIMESTONE AND CYCLIC REPETITION IN ROCKS.....

Baltz, Elmer H., Jr.; *Geological Society of America, Bulletin,* 69:1722, 1958.

Abstract. A biohermal facies of the gray limestone member of the Madera limestone of Pennsylvanian age occurs in the southeastern Sangre de Cristo Mountains, New Mexico, on a shelf between the Paleozoic Rowe-Mora geosyncline at the west and Pedernal uplift at the east. Limestone, composed mainly of brachiopod shells, corals, and crinoid columnals cemented by algal limestone, is interbedded with shale and thin sandstone. Undulatory bedding in the limestone results from small mounds of coral and algal growths. Bioclastic and foraminiferal limestone is associated with biohermal limestone.

Near the Pedernal uplift, limestone forms more than half of the gray limestone member, and some beds thicken to form distinct bioherms. Limestone beds thin northwestward across the shelf and become subordinate in thickness to shale. Along the western and northern margins of the shelf the biohermal facies grades into a geosynclinal facies which is dominantly shale with thick sandstone and thin nonbiohermal limestone beds.

On the shelf the gray limestone member exhibits many cyclic repetitions of lithology ranging from 10 feet to more than 100 feet thick. From base to top each cyclic succession is: (1) biohermal limestone; (2) calcareous shale with interbedded thin undulatory limestone; (3) carbonaceous claystone, siltstone, and sandstone. The upper unit is absent locally from some sequences because of local intraformational unconformities. Cyclic sedimentation is evident also in the geosynclinal facies. Correlation of individual sequences over wide areas is uncertain because of poor exposures and similarity of lithology of all cyclic sequences.

PETROLEUM AND NATURAL GASES

The idiosyncracies of petroleum and the natural gases are combined in this section because they frequently occur together in nature. Even so, it must be recognized that they may have different origins. The creation(s) of petroleum and natural gases is in fact the subject of heated controversy. The textbook origins of both are biological in character; that is, it is maintained that these substances are derived from the remains of plants and animals. Such dogma must not go unchallenged.

No one serious proposes that coal may have had an abiogenic origin, but the sources of petroleum and natural gas are more elusive. Being highly mobile, these liquids and gases are apparently not found where they originally appeared. Science has not really determined how and where petroleum and natural gas were created or when they migrated to their present reservoirs. No wonder speculation is rampant. Furthermore, as exploration of the earth proceeds, petroleum and natural gas seem everywhere---even where geologists thought them unlikely. One current school of thought claims that the earth may still be outgassing; that is, releasing gases (possibly liquids) that were created in deep internal chemical retorts when the planet was sculpted. Now that astronomers are also finding hydrocarbons in deep space, in meteorites, and on other planets, petroleum and natural gas seem more and more like natural constituents of the solar system, formed abiogenically whenever conditions are right.

Beyond the vital question of origin, petroleum and natural gases display their shares of geological eccentricities, the significance of which is presently indeterminate.

• Natural Gases

ICE, MEPHITIC, AND OSSEOUS CAVERNS

Lowdon, Ralph; *English Mechanic,* 17:381-382, 1873.

Mephitic caverns are remarkable for the development of noxious gases, which are fatal to animal life unless quickly removed from their influence. In some, dangerous and inflammable vapours proceed from the decomposition of the rocks of which they are composed, as in those of gypsum, in which foetid limestone occurs in wavy stripes or thick beds, which gives out carburetted hydrogen, the firedamp of our mines, which, when mixed with air and exposed to flame, explodes. In others, the gases are generated in the fissures, chiefly the carbonic and sulphuric acids, a common production in sites of volcanic action, or where volcanic action, far below the surface, may be supposed to exist. The best-known cave of this description is the Grotto del Cane, near the Lago d'Agnano, Naples, the bed of which is the crater of an extinct volcano. This is a small natural grotto about 10 ft. long, 4 broad, and 9 ft. high, in which carbonic and gas collects itself. This is a colourless transparent vapour, destroying animal life, reddening litmus paper till the acid volatilises, and giving a precipitate with limewater, the carbonate of lime.

The Grotto del Cane may be entered by man with perfect impunity, because the carbonic acid gas, being heavier than common air, lies in a stratum on the floor, scarcely 8 in. thick, but small animals venturing within are suffocated. The cave derives its name from the days in which dogs were sacrificed to gratify the curious.

There can be little doubt that the carbonic acid gas in the Dog's Grotto near Naples is elaborated by the chemical process going on in that volcanic region. The spot and its qualities were known to the ancients. The elder Pliny refers to it as one of Charon's ditches, and probably the deleterious vapour was more extensively evolved in his time than at present, as he speaks of its having been fatal to human life, which cannot be now the case unless a person should throw himself prostrate on the floor of the cave. Other writers also mention the waters near the banks of the Lake d'Agnano being in a state of constant ebullition, owing to the disengagement of the gaseous element---a phenomenon which has ceased, and which sanctions the idea of the chemical action in this locality having moderated in intensity. In the crater of the extinct volcano of Negeruc in the south of France, on the banks of the Ardeche, the soil is one vast sleve, through which carbonic acid gas percolates, which has a sensible effect upon the people employed in its cultivation, and is injurjous to the vegetation.

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A DEADLY GAS-SPRING IN THE YELLOWSTONE PARK

Weed, Walter H.; *Science,* 13:130-132, 1889.

The familiar fable of the upas-tree, living in a valley of death wherein all life was killed by its deadly exhalations and the ground was strewn with the bones of its victims, has been proven, like many a traveller's tale, to be a highly colored and exaggerated account of a natural phenomenon. The upas-tree is now well known to have poisonous sap, but not poisonous vapors. But the story survives in the accounts given of the Death Valley of Java, which it was long believed no traveller could cross, "wherein every living being which penetrated the valley falls down dead, and the soil is covered with the carcasses of tigers, deer, birds, and even the bones of men, all killed by the abundant exhalations of carbonic-acid gas, with which the bottom of the valley is filled." Such is the description given by Lyell of this famous valley; while another locality is described as a place where "the sulphurous exhalations have killed tigers, birds, and innumerable insects, and the soft parts of these animals are perfectly preserved, while the bones are eroded and entirely destroyed. The researches of Junghuhn have shown that these accounts are much exaggerated, the "valley of death" being a funnel-shaped depression but one hundred feet in diameter, instead of a valley half a mile across. In the bottom of this depression there is a hole about fifteen feet in diameter, from which gaseous emanations are given out, which at times accumulate to a depth sufficient to envelop and suffocate animals on the bottom of the hollow. Repeated visits by Junghuhn, extending over a period of twelve years, showed that the amount of gas varied greatly from time to time, but rarely ever rose over two feet and a half above the bottom. At the time of his earlier visit, he found the body of a Javanese native in the depression, but experienced no difficulty or oppression while there himself. This same body was still undecomposed, owing to the preservative effect of the layer of gas, when he repeated his visit eighteen months later. The only other remains seen during his subsequent visits were the carcasses of six swine which were decomposed and putrid. At this time the absence of the gas was shown by the presence of a crow feeding upon the dead bodies.

Though thus shorn of much of its former glory, this Pakaraman, or poison-hole, is the largest and most dangerous of the gas-springs or mofettes of Java, and indeed of the world, and really deserves the title of a natural death-trap. Though such emanations are common in all volcanic regions, this has been the only place known where the gases have accumulated, and caused the death of the larger animals.

In the Yellowstone National Park, now so well known as the wonderland of America, there is a place equalling this famous death valley, and where the gaseous exhalations have proved fatal to numerous bear, elk, and many smaller animals.

This place, to which the appropriate name of "Death Gulch" is given, was discovered by the writer during the past summer (1888), while making a geological examination of the region for Mr. Arnold Hague, the geologist in charge of the survey of the park. It is situated in the extreme northeastern portion of this reservation, a short distance south of the mail-route, which, leaving Lamar River, follows up Soda Butte Creek to the mining-camp of Cooke City. In this region the lavas which fill the ancient basin of the park rest upon the flanks of mountains formed of fragmentary volcanic ejecta, the tertiary andesitic breccias, which rest in turn upon nearly horizontal paleozoic strata; while the hydrothermal forces, which are represented by the geysers and hot springs of the central portion of the park, where the lava-sheet is thicker, show but feeble manifestations of their energy in the almost extinct hotspring areas of Soda Butte, Lamar River, Cache Creek, and Miller Creek. Although hot water no longer flows from the vents of these areas, the deposits of travertine, sinter, and decomposed rock, attest the former presence of thermal springs. Gaseous emanations are now given off, however, in considerable volume, producing extensive alteration in the adjacent rocks, and giving rise to sulphurous deposits.

It is at one of these places that the fatal ravine is found. Situated on Cache Creek, but two miles above its confluence with Lamar River, it is easily reached by a horseback ride of some five miles from the mail station of Soda Butte. The region is, however, rarely visited; for hunting is forbidden in the park, while the place has not been known to present any attraction for the few visitors who pass near it on their way to the well-known Fossil Forests and the weird scenery of the Hoodoo basin.

An old elk-trail, which runs along the north bank of Cache Creek, affords easy travelling, and leads to a little opening in the pine-forest bordering on the stream. In the centre of the meadow is a shallow depression, once the bed of a hot-spring pool, now dry, and covered with an efflorescence of salt, making it attractive to the elk and other game of the region as a "lick." The banks of the creek opposite this meadow and below it are covered with the ancient hot-spring deposits, which are very dense and hard, and at the borders of the stream have been polished by the action of the water until the surface shines like glass. A hot-spring cone half washed away by the creek, and a mound of altered travertine on the opposite bank, show the character of the ancient hot-spring water, the rippled surface of the deposit being exactly like that of the beautiful terraces and slopes of the Mammoth Hot Springs. At present, however, the only thermal action is the emission of a little tepid sulphurous water at the edge of the stream. On the other hand, the gaseous emanations are very striking and abundant.

In the middle of the creek, which here forms a deep pool about thirty feet across, bordered by the polished calcite already mentioned, the water boils up furiously at several places. This water is, however, quite cold; and the "boiling" is caused by the very copious emission of gas, mainly, no doubt, carbonic acid, though containing some sulphuretted hydrogen, since its smell is quite noticeable, and the water is slightly turbid with particles of sulphur, which also coat the sides and bottom of the pool. Rising through the water of the creek, the great amount of gas given off at this place is easily appreciated, but equally copious emanations may occur from the deposits and old vents nearby, which, being invisible, remain unnoticed.

Above these deposits of altered and crystalline travertine, the creek cuts into a bank of sulphur and gravel cemented by this material, and a few yards beyond is the debouchure of a small lateral gulley coming down from the mountain-side. In its bottom is a small stream of clear and cold water, sour with sulphuric acid, and flowing down a narrow and steep channel cut in beds of dark gray volcanic tuff. Ascending this gulch, the sides, closing together, become very steep slopes of white decomposed rock, the silicious residue formed by the decomposition of the rocks by acid vapors or waters. The only springs now flowing are small oozes of water issuing from the base of these slopes, or from the channel-bed, and forming a thick, creamy, white deposit about the vents, and covering the stream-bed. This deposit consists largely of sulphate of alumina. The slopes show local areas where sulphur has been deposited by the oxidation of sulphurous vapors, but no extinct hot-spring vents were found. About one hundred and fifty feet above the main stream, these oozing springs of acid water cease; but the character of the gulch remains the same. The odor of sulphur now becomes stronger, though producing no other effect than a slight irritation of the lungs. The gulch ends, or rather begins, in a "scoop" or basin about two hundred and fifty feet above Cache Creek; and just below this we found the fresh body of a large bear, a silver-tip grisly, with the remains of a companion in an advanced state of decomposition above him. Nearby were the skeletons of four more bears, with the bones of an elk a yard or two above; while in the bottom of the pocket were the Fresh remains of several squirrels, rock-hares, and other small animals, besides numerous dead butterflies and insects. The body of the grisly was carefully examined for bullet-holes or other marks of injury, but showed no traces of violence, the only indication being a few drops of blood under the nose. It was evident that he had met his death but a short time before, as the carcass was still perfectly fresh, though offensive enough at the time of a later visit. The remains of a cinnamon bear just above and alongside of this were in an advanced state of decomposition, while the other skeletons were almost denuded of flesh, though the claws and much of the hair remained. It was apparent that these animals, as well as the squirrels and insects, had not met their death by violence, but had been asphyxiated by the irrespirable gas given off in the gulch. The hollows were tested for carbonic-acid gas with lighted tapers without proving its presence; but the strong smell of sulphur, and a choking sensation of the lungs, indicated the presence of noxious gases, while the strong wind prevailing at the time, together with the open nature of the ravine, must have caused a rapid diffusion of the vapors.

This place differs, therefore, very materially from the famous Death Valley of Java and similar places in being simply a V-shaped trench, not over seventy-five feet deep, cut in the mountain-slope, and not a hollow or cave. That the gas at times accumulates in the pocket at the head of the gulch, is, however, proven by the dead squirrels, etc., found on its bottom. It is not probable, however, that the gas ever accumulates here to a considerable depth, owing to the open nature of the place and the fact that the gulch draining it would carry off the gas, which would, from its density, tend to flow down the ravine. This offers an explanation of the death of the bears whose remains occur, not in this basin, but where it narrows to form the ravine; for it is here that the layer of gas would be deepest, and has proven sufficient to suffocate the first bear, who was probably attracted by the remains of the elk, or perhaps of the smaller victims of the invisible gas; and he, in turn, has doubtless served as bait for others who have in turn succumbed. Though the gulch has doubtless served as a death-trap for a very long period of time, these skeletons and bodies must be the remains of only the most recent victims; for the ravine is so narrow and the fall so great, that the channel must be cleared out every few years, if not annually. The change wrought by the water during a single rain-storm, which occurred in the interval between my first and second visits, was so considerable that it seems probable that the floods of early spring, when the snows are melting under the hot sun of this region, must be powerful enough to wash everything down to the cone of debris at the mouth of the gulch.

Gaseous emanations are very frequent in volcanic countries, and may be either temporary or permanent. The former are, as is well known, particularly abundant after volcanic eruptions. The gases emitted from fissures in the flanks of Vesuvius are said to have killed thousands of hares and pheasants, and whole herds of cattle have been suffocated by volcanic gas given off near Quito. The permanent emissions of gas, such as the mofettes of Italy, the Laacher See, and the Auvergne, remain unchanged, however, for centuries. Where carbonic-acid gas is evolved from a fairly uniform surface, it is quickly diffused into the atmosphere upon the slightest movement of the air; but the case is quite different when the gas is emitted in caves or hollows in the ground. In such places it accumulates, because of its density and slow diffusion, until the hollows are filled to the brim, any excess being quickly diffused as from a level surface. Small hollows of this kind occur in the travertine deposits of the Mammoth Hot Springs of the park, and near the Hot Lakes of the Lower Geyser basin. In these places, small birds, mice, etc., attracted by the warmth of the vapors, or the dead insects are often suffocated by the gases. Such hollows resemble the profettes of the Laacher See in Germany, where dead mice and birds are always found, and are common in other regions as well. The well-known Grotto del Cano, near Naples, is the most familiar example of such accumulations of carbonic-acid gas; and visitors are frequently entertained by the asphyxiation of a poor dog, while the guide, whose head rises above the gas, is not affected by it. Death Gulch is, however, without a peer as a natural bear-trap, and may well be added to the list of the wonders of the Yellowstone Park.

METHANE FROM THE BOWELS OF THE EARTH

Paterson, David; *New Scientist,* 78:896, 1978.

Professor Gold, the director of the Center for Radio Physics and Space Research at Cornell University, presented his new ideas in a lecture at London's Imperial College last week. The title "Terrestrial Sources of Carbon and Earthquake Outgassing" perhaps accounted for the rather sparse attendance. To many physics students and academics, outgassing must be one of the dullest aspects of the behaviour of materials---hardly the most intellectually stimulating topic on which to found a scientific reputation.

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But in Professor Gold's presentation, outgassing was not deadly dull. For him, outgassing was the key to understanding how the Earth's surface had come to abound in carbon deposits---notably in the form of carbonates. The starting point for the new theory was, naturally enough, the creation of the Earth and the other planets from the solar nebula 4.5 thousand million years ago. The nebula, a giant cloud of gas and dust, would surely have contained, among other minerals, large quantities of simple carbon compounds---carbon dioxide and methane---as well as the more complex kinds of carbon compounds found in carbonaceous chondrites. If the outer few hundred kilometres of the Earth's bulk had been assembled from materials including these gases and the carbonaceous chondrites, it could be reasonably expected that the heat and the pressure at substantial depths within the crust would conspire to produce a steady leakage of carbon based gases from the crust into the atmosphere.

In fact, Gold asserts that much of the carbon we see at, or near, the Earth's surface today has been laid there as a byproduct of the process of outgassing from the crustal layers. The most common form of carbon bearing mineral is limestone---carbonate rocks in which the carbon is in oxidised form. The remaining carbon---roughly a third of the total---exists in unoxidised form---hydrocarbon deposits, graphite and so on. The amount of carbon bearing gas that would have had to emerge from the Earth to provide this bulk of deposit, Gold calculates as being the equivalent of 80 atmospheres of carbon dioxide (compare this with the present day level of atmospheric carbon dioxide of 0.03 per cent by volume).

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It was to the issue of the methane leakage that Gold turned next. He read out several eyewitness accounts of the large earthquakes of antiquity; the most striking accompanying phenomenon was that of fire---"the sky was alight" or "flames shot out of the ground". This flammable material is surely, Gold argues, methane gas escaping from the ground: it must have been released in large quantities at great pressure by the Earth's upheaval. The ignition of the escaping gas would come about through the incorporation of dust particles in the jets of gas; electrostatic potentials developed by the particles' rapid movement in the gas stream would ensure spark ignition.

The most convincing modern evidence for the large-scale leakage of methane from non-biological sources deep beneath the ground comes from the phenomenon of mud volcanoes. These are seething patches of mud that emit quantities of gas and often take on the caldera-like appearance of the true volcanoes. Mud volcanoes can become quite large---extending to several kilometres in diameter: they are to be found north of the Caucasus, in Burma, in the Caribbean, in South America and also central Australia. One mud volcano that flared up recently near Baku in the Soviet Union is said to have produced a flame 2 km high and 120 m wide at its base which burned steadily for 8 hours. It is estimated that a million tons of hydrocarbons was consumed by this natural gas torch. Gold is convinced that methane flows of this kind, when integrated over the whole globe, provide outgassing rates that are consistent with the surface abundance of carbon materials. What is of prime importance to the Gold theory is that the mud volcanoes occur in some cases where there is no expectation of biogenic deposits of hydrocarbons: furthermore, gas samples taken from the mud volcanoes indicate that a rather pure hydrocarbon is emerging from the Earth's crust in this instance, whereas gas samples taken from biogenic natural gas wells tend to be "contaminated" with a variety of carbon chain compounds.

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A NATURAL GAS EXPLOSION NEAR WALDRON, IND.

Newsom, J. F.; *Journal of Geology,* 10:803-814, 1902.

Introduction. On the eleventh day of August, 1890, a natural gas explosion of much violence occurred near Waldron, in Shelby county, Indiana. The ground was disturbed, and fractures, crevices, and craters were formed over an area of several acres.

Many newspaper accounts of the explosion were published. In most cases these were greatly exaggerated. Bare mention of the occurrence was made by E. T. J. Jordan, natural gas supervisor of Indiana, in his report to the state geologist, in 1891.

In discussing a violent natural gas explosion that occurred at Coffeyville, Kan., on July 26, 1894, Haworth refers to a similar explosion that had occurred in Indiana, giving the locality as Kokomo; he says:

> One similar occurrence is known in the gas field of Indiana, near Kokomo, in which a fissure was formed in the solid limestone from which natural gas escaped with explosive violence and caught fire from a burning log heap near by.

Haworth refers here to the Shelby county explosion, which did not occur near Kokomo, however, but took place about one hundred miles south and slightly east of that city. Neither was a visible crevice formed in solid limestone, as the explosion occurred in an area that was covered with soil and gravel, though limestone crops out near by and also 1/4 miles up stream from the area of the main explosion.

Later (1899), in a report upon the Waldron shale, made to the state geologist of Indiana, Mr. J. A. Price states briefly such facts concerning the Shelby county explosion as could be gleaned from statements of the citizens of the neighborhood at that time.

Except for the brief notices mentioned above no account of this interesting explosion has appeared in any scientific publication, so far as the writer is aware, and it is with a desire to place on record the salient facts concerning it that the following map, figures, and paper are published at this time.

The writer visited the locality on August 15, 1890, four days after the explosion occurred, while its effects were still fresh, and while the gas escaping from the crevices and craters still burned intermittently when ignited. From notes taken at the time, a map was prepared and a short account of the explosion was written, and read on November 7, 1890, before the Indiana University Scientific Society. The map and facts of the present paper are taken from the paper read, but not published at that time.

The figures are reproduced from photographs obtained from J. T. Schaub, Hope, Ind., and Everett Ayers, of Germantown, Ind.

Location. The explosion occurred near the center of section 7, 11 north, 8 east; the affected area is two and a half miles south, slightly west of the village of Waldron, and two and a half miles west, slightly south of the village of St. Paul. Gas wells were reported to be producing at the time from both of these villages.

Owing to the fact that the Ogden Cemetery was at the edge of the disturbed area, the outburst of gas was known locally as the Ogden Cemetery "earthquake," "gas explosion," and "blow-out."

A total area of about ten acres was affected. The most violent explosion was limited, however, to a space of about two acres at the east side of the locality affected, and is shown approximately by the Nos. 1, 3, 5, and 6, Fig. 1. [Only Fig. 4 reproduced] The topography and relations of the area can be best understood by reference to Fig. 1.

The area that was shaken up lies at the south side of Big Flat Rock River or Creek, in an almost half circle bend formed by that stream, and is comparatively flat creek "bottom land" made up of alluvium. The south side of this area, marked "second bottom," is slightly higher than the portion, included by the Nos. 4, 3, 1, 8, 9, 10, and 11, in which the explosion occurred. At the time of the explosion growing corn covered the second bottom.

At the east and north side of the stream is a wooded bluff, of glacial gravel and clay, about forty feet high; this bluff was covered with forest trees at the time of the explosion. There were also a few trees of considerable size bordering the creek on the side across from the bluff.

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Character and results of the explosion. The explosion occurred about 9 o'clock, on the morning of August 11; it does not appear to have been accompanied by any violent report, for the attention of the people living in the neighborhood was first attracted by a roaring or whizzing sound like the escape of steam from a boiler, but much louder. Upon looking toward the river, a sheet of flame was seen extending about 250 yards

A fissure created during the natural gas explosion at Waldron, Indiana. (Fig. 4)

along the east side of the river bend. Regarding the height of the flame, estimates of those in sight at the time varied between 150 and 300 feet or more.

The height and intensity of the flame were sufficient to sear the leaves on the trees standing on the gravel bluff east of the river, and to completely burn off the leaves and small twigs from the trees standing near the fissures through which the gas escaped.

The vegetation around the openings at the west side of the area showed that the gas that escaped from those openings did not burn.

The roaring and flame continued at their height for about fifteen minutes, and then gradually subsided, and the gas burned from only a few of the crevices that had been formed.

The explosion had opened up a great number of crevices in the soil near the river bank. When the ground was visited by the writer, these fissures varied in width from a few inches to four or five feet, with a like variation in depth, the shallowness being caused by the caving in of the soft soil at the sides and from the top.

Some of the fissures had evidently been formed by the upheaval, or depression, of the surface which had been elevated in some places, and in others had sunk down as much as four or five feet. The larger fissures, however, showed that they had been formed by the soil being blown out from below, the blownout material being piled up at the sides of the fissures.

The character of the fissures is shown by Fig. 2, which shows also the "heaved up" condition of the surface. The center of the public road is shown in the foreground at the right side of Fig. 2. At this place (corresponding to the point 2 in Fig. 1) the road was so twisted and fissured as to be impassable.

The river bed from 5 to 6, Fig. 1, had been raised several feet, leaving the bottom exposed where water had stood before, while the west bank of the stream, from 3 to 4, Fig. 1, had sunk several feet. It was reported that the river flowed into the crevices between 3 and 6, Fig. 1, for some hours after the explosion.

Forest trees near 3, 5, and 11, Fig. 1, had been blown up by the roots and blown several (10–20) feet from where they had stood. The leaves on the trees and bushes from 5 to 11, Fig. 1 (about two hundred yards) were seared by the heat. On the west side of the creek from B' to 4 the smaller branches (and in some cases the bark) of the trees were entirely burned off.

Many of the trees were completely plastered from bottom to top with a fine mud, unlike anything exposed at the surface. This mud must have been thrown out with great force, as was shown by the manner in which it was plastered upon the trees and corn of the affected area. Lying about the fissures and over the surface were large quantities of this mud, which, upon drying, hardened somewhat and was easily cut into various designs, which were sold as souvenirs to visitors who came in great numbers to the locality.

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When seen by the writer, the principal fissure formed by the explosion was between fifty and one hundred feet long, about five feet wide, and five feet deep. This crevice had evidently been much deeper, but when the gas ceased escaping under sufficient pressure to keep it open, loose earth had caved into it and partially filled it. The fissure extended almost east and west, and was along the foot of the slope, between the second bottom and the lower ground. At its south side was a mass of earth, x-x', from five to ten feet high, that had been blown from the fissure.

A field of corn was growing south of the main fissure at the time of the explosion. About an acre of this corn, B, B', C, C, Fig. 1, was burned brown by the heat, while half of this burned portion, B, B, B', Fig. 1, was blown flat upon the ground, and much of the blown down corn was plastered with mud. The corn was blown over toward the south, showing that the force came from the fissure at the north side. Some of the blown down corn is shown at the right end of Fig. 2.

At 11, Fig. 1, a slice of the gravel bluff was shaken down by the explosion, and some trees were blown up by the roots.

Irregular openings or craters were blown out at 8, 9, 10, Fig. 1, but the explosion was not so violent here as at the east side of the affected area.

When visited by the writer, four days after the explosion occurred, a little gas was escaping from many of the fissures, and this would burn for a short time when ignited.

It was reported by the citizens of the neighborhood that a fire had been burning in brushwood on a small island in the river about 150 yards above the main fissure previous to the explosion, and it is probable that the escaping gas was ignited by this fire.

The accompanying figures show the nature of the fissures that were produced by the explosion.

Cause of the explosion. The explosion was supposed at the time to have been caused by gas escaping below the casing from the wells at either St. Paul or Waldron, or at both places, and finding its way between the strata to the point where the explosion took place, at which point the strata were too weak to withstand the pressure.

Whether the gas did come from these wells, whether it came up from below through a crevice, or whether it was generated at no great depth in the strata, more or less directly below the area where the explosion occurred, is not known.

It is evident, however, that gas accumulated below an impervious layer until the pressure became sufficient to rend this impervious bed, when the explosion followed. The pressure required to do this cannot be known, because neither the depth nor strength of the confining strata is known.

It is obvious that gas, under a pressure of say two or three hundred pounds to the square inch, if confined by horizontal strata, sufficiently near the surface so that the weight of the overlying material would not equal the pressure of the gas, would tend to spread laterally between the strata, and to cause these to bend upwards. If the pressure should become great enough, the strata would finally break and the gas would escape, possibly with explosive violence. Such an explosion would not necessarily indicate that a large supply of gas was involved, for a small quantity would exert as great a pressure to the square foot as a larger one.

The area affected by the Ogden Cemetery explosion covered about ten acres; the pressure on this surface at 250 pounds per square inch would have been 36,000 pounds to each square foot of surface.

Taking the weight of the shales and surface soil as 175 pounds to the cubic foot, this pressure would have equaled the weight of the overlying materials at a depth of 205 feet.

Assuming the pressure of the gas to have been 250 pounds to the square inch, then the strata which enclosed the gas prior to the explosion may have been anywhere between the surface and a depth of 205 feet.

In closing, attention is directed to the fact that the locality in which the Ogden Cemetery explosion occurred is near the southwestern edge of the natural gas area of Indiana, and that the Trenton limestone, the great gas producing formation, is about 850 feet below the surface at this point.

UNUSUAL NATURAL GASES

Lang, Walter B.; *American Association of Petroleum Geologists, Bulletin,* 10:1176-1177, 1926.

In the April issue of the Bulletin, under title of "New Zealand Oil Discovery," Mr. Frederick G. Clapp expresses a desire for information concerning the occurrence of heavy production of high percentages of carbon dioxide in oil fields having associated igneous rocks.

Although not so stated by Mr. Clapp it is inferred that he believes there is a casual relationship existing between the andesite porphyry and the high percentage of carbon dioxide.

Two rather exceptional gas analyses have come to the attention of the writer, the details of which are here given.

The Floersheim State well (elevation 5,875 ft.), drilled by the California Company, Sec. 15, T. 23 N., R. 24 E., in Colfax County, New Mexico, penetrated a sand at 1,509-1,510 feet that yielded a flow of one-fourth million cubic feet of gas of the following composition: Carbon dioxide, 67 per cent; oxygen, 4.10 per cent; nitrogen, 28.70 per cent; methane, 0 per cent; ethane, 0 per cent. The gas contains unusually high percentages of carbon dioxide and oxygen. The drill is reported to have entered granite (granite wash) at 1,979 feet and to have continued in the same formation to 2,556 feet, where the hole was abandoned.

On Wagon Mound the Arkansas Fuel Oil Company drilled the C. F. Kruse No. 1 well in Sec. 11, T. 19 N., R. 21 E., in Mora County, New Mexico. Gas was encountered at 1,140-1,163 feet and another heavy flow of five million cubic feet at 1,420-1,425 feet. Drilling was continued to a depth of 2,613 feet, with the last 400 feet in granite wash. On analysis the gas gave the following percentages: Carbon dioxide, 90 per cent; oxygen, 2.2 per cent; methane, 0 per cent; ethane, 0 per cent; nitrogen, 7.8 per cent. An exceptionally high percentage of carbon dioxide is to be noted.

The results of igneous activity in northeastern New Mexico are not an uncommon sight. Heavy flows of Quaternary lavas cover much of the Cretaceous rocks exposed in that area, which must have subterranean connection with the original sources. It is not impossible to suppose that the intruding members reacting upon the limestones may have evolved large volumes of carbon dioxide, which accumulated in the more porous sandstone beds. The stratigraphic positions of the gas-producing sands in the two wells are undoubtedly very closely related. No petroleum production has been reported from this area. Although the known geological relationships offer a plausible explanation of the presence of high percentage carbon dioxide gas as a result of possible reaction of igneous activity upon the sediments, there is, however, no definite evidence that the two factors are directly connected, and the assumption must stand the test of further investigation.

• Origin of Petroleum: Biological or Abiological?

WHENCE CAME THE HYDROCARBONS?

Link, Theo. A.; *American Association of Petroleum Geologists, Bulletin,* 41:1387-1402, 1957.

Abstract. As early as the year 1890 suggestions were made that the hydrocarbon accumulations (the oil and gas pools), which were then known to exist, had been derived from hydrocarbons brought to the earth enclosed in meteorites---or falling stars. Apparently ignorant of this, recently an astronomer of considerable standing in his profession, named Fred Hoyle, published a book entitled Frontiers of Astronomy in which he, after dis-

missing with scorn the idea of the organic theory of the origin of hydrocarbons, again suggested in all seriousness that the meteorites were the source of the hydrocarbon accumulations on our planet, the earth. He also suggested that the atmosphere of the planet Venus is a hydrocarbon "smog," and in this he has support from a writer named Immanuel Velikovsky.

A comparison of the 1916 version of the geologists' thinking regarding the organic origin of oil and gas is made with that of a 1956 version as it appeared in our Bulletin. It was concluded that there really is very little change in the fundamental ideas during those forty years with respect to the organic origin of hydrocarbons. This then posed the question, "Are we all wrong with our organic theory?" In other words, are we, instead of being in a groove, in a rut in our thinking with respect to the origin of the hydrocarbons? If not, what are we doing to enlighten the public, to say nothing of our scientific colleagues, the astronomers, chemists, and others about those problems concerning which we are certain, uncertain, or not sure at all?

To explain the detection of hydrocarbons in the meteorites it is suggested that the hydrocarbons found within them indicate that there must have been life which gave rise to the hydrocarbons on a planetary body which was disrupted, and which planet may have existed between the orbits of Mars and Jupiter. This is where many of the older and also more recent astronomers believe such a planet did exist, as evidenced by the orbits of the asteroids. The hydrocarbons within the meteorites could of course, also have had a volcanic origin on such a former planet.

Finally it is pointed out that any astronomical theory regarding the origin of the hydrocarbons, the earth, our solar system, our galaxy, and the Universe must fit into the accepted facts and observations of geology, and likewise that any geological theory with respect to any or all of its problems must also fit in with the accepted astronomical observations and theories. Because of this it is suggested that closer cooperation and exchange of opinions and data between the various sciences must sooner or later be effected, lest we repeat the mistakes made at the Tower of Babel, where as you all should know, a "confusion of tongues" wrecked the project.

PRIMORDIAL OIL SLICK

Lasaga, Antonio C., et al; *Science*. 174:53-55, 1971.

Abstract. Calculations and some preliminary experiments suggest that an early methane atmosphere would have been polymerized by solar ultraviolet radiation in geologically short periods of time. An oil slick 1 to 10 meters thick could have been produced in this way and might well have been of considerable importance in the development of life.

INORGANIC ORIGIN OF PETROLEUM

Porfir'ev, V. B.; *American Association of Petroleum Geologists, Bulletin,* 58:3-33, 1974.

Abstract. The concept of the organic origin of petroleum has been

dominant for the last 70 years. Generation of petroleum hydrocarbons has been explained by transformation of dissipated organic matter in clay-carbonate sediments under the influence of temperature and pressure increase with depth, separation of the hydrocarbons freshly generated, and their migration into porous reservoir beds. According to the organic-origin concept, the extremely low content of hydrocarbons in the rocks is unimportant, because the existence of a huge mass of "source" rocks for the petroleum generated solves the problems of petroleum-migration mechanism, petroleum accumulation, petroleum formation, and its spatial distribution.

In the course of time this concept of the organic petroleum source rocks has become a dogma, and all questions of petroleum geology and exploration are approached from the assumption that the organic origin is proved. Many works are devoted to a thorough and detailed study of the various consequences of the origin concept.

However, while the organic theory proliferated, the concept of the inorganic synthesis of hydrocarbons and plutonic origin of petroleum also grew. These concepts, associated mainly with the names of prominent scientists of the 19th century, were considered by the organic-theory protagonists to be obsolete. As a result they were shelved, as explained in detail by Hedberg and by Dott and Reynolds.

However the stream of new information coming from new exploration areas and from new ideas in the fields of geology, geochemistry, geophysics, astrophysics, and so on has contributed to appearance of new knowledge which categorically rejects all aspects and consequences of the organic theory. The struggle between the opposing theories finally focused into broad discussions---including symposia accompanied and followed by many publications on the problem, especially in the socialist countries. Unfortunately all this is unknown to foreign petroleum geologists, as can be judged by study of the works of Hedberg, Colombo, Levorsen, Dott and Reynolds and others.

The aim of the present survey is to bring to the attention of a wide circle of geologists the new ideas and a picture of the present state of the problem of petroleum formation from the viewpoint of inorganic-origin theory.

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Giant Oil Fields. Recently petroleum geologists have evinced great interest in giant oil and gas fields with paradoxically large petroleum accumulations. In a general classification these fields are called "giants" and "supergiants." According to Uspenskaya,

> from the general number of deposits being worked about 5 percent give 85 percent of the world petroleum production and contain more than 80 percent of recoverable petroleum and gas initial reserves, which in 1970 constituted a minimum of 90 milliard tons (657 billion bbl) of petroleum and 45 billion cu m of gas (2.1 quadrillion cu ft.)

It is vital to establish the principles (regularities) of occurrence of such economically significant fields. Such principles are extremely important for exploration and prospecting and naturally should be based on concepts of the nature of petroleum, the conditions of its formation and migration. Recent attempts to establish general principles, but based on the preconception of organic theory, have been made.

These generalized papers offer nothing new from the viewpoint of theory, and the principles, patterns, and regularities discussed (relative to tectonic structure and the nature of migration and accumulation in basins) do not deviate from the traditional, erroneous concept of organic theory. The possible efficiency of the supposed "source rocks" of petroleum assumed in each case is given in the most general form without any attempt to relate the sources to the real geology of both the fields and the basin containing them, as well as assumptions about possible ways of migration. In short, to repeat Welte's words once more, "If oil is found, there must also be a related source rock."

These huge petroleum accumulations more logically are explained from the viewpoint of inorganic theory, because of their size. Simple calculation of potential hydrocarbon content in sediments show that organic materials are too few to supply the needed volumes of petroleum. Of interest is the summary table from the paper by Uspenskaya. She subdivides the fields on the basis of petroleum reserves. They are divided into three groups: (1) those containing from 200 to 500 million tons (1.5-3.7 billion bbl) of reserves; (2) from 500 to 800 million tons (3.7-5.8 billion bbl); and (3) "supergiants"---from 800 to 1,000 million tons and more (5.8-7.3+ billion bbl).

The largest "supergiant" is Ghawar field with petroleum reserves of 10,710,000,000 tons (66 billion bbl), i.e., about 11 billion tons.

A geologist who is no specialist in these questions may be persuaded that the largest oil field on earth does not exceed 11 billion tons and that obviously organic-theory specialists have a certain difficulty in adjusting their explanations to fit Ghawar. However, even larger accumulations of petroleum bitumen and petroleum are known. One should consider the tarsand reserves of western Canada---Athabaska, Peace River, Wabaska, McMurray, and Cold River---with total reserves of about 102 billion tons (750 billion bbl) of heavy bituminous stagnant petroleum. But this is petroleum and not "bitumen" such as that contained in dissipated form in bituminous sedimentary rocks. This petroleum originally was liquid.

Athabaska is not an isolated case. In the southern Fergana area of Soviet Central Asia, large solid-petroleum-bitumen accumulations and asphalts are encountered in basal Paleozoic beds. Reserves are estimated by Taliyev as 30 billion tons (220 billion bbl). Petroleum bitumen accumulation in the Melekess trough of the Volga-Urals district west of the Urals, by estimation of Troyepolskiy and Ellern, and in the Olenek region of northeastern Siberia, according to the data given by Kudryavtzev, are estimated to about the same.

Surely the existence of the giant accumulations enumerated here is the decisive argument in a discussion of a choice between organic and inorganic theory. As has been pointed out, the right to make the final decision belongs to the geologists. Any geochemical scheme proposed should be accepted if it fits the geology requirements.

The cornerstone of the present-day organic theory is the "uncompromisable" concept that organic matter is widely dispersed in sedimentary rocks, and that this organic matter is the source of oil. All chemical reactions, by necessity, then have to take place under the low-temperature conditions of the sedimentary cover at the earth's surface; migration of separated hydrocarbon compounds must take place across great distances in dissipated form; migration then must assume the form of a gaseous or an aqueous solution; finally, a purely hydrocarbon phase must separate from the solution and accummulate in large volumes.

Each oil field has to be formed only in this way. Consequently, the accumulations of Ghawar (11 billion tons = 66 billion bbl), the Melekess trough of the Volga-Urals district (20 billion tons = 146 billion bbl in many fields), and deposits of heavy oil (tar sands) of western Canada (102 billion tons = 750 billion bbl) must form in the same way. The Athabaska petroleum could not have migrated in its present state. One cannot imagine the existence of a gaseous or aqueous solution of asphalt. Therefore there was twice as much as 102 billion tons of petroleum of normal physical properties, i.e. there was 204 billion tons (1,500 billion bbl). And these 204 billion tons must have been converted into gaseous or aqueous solution and transferred to the modern trap. The deadlock in logic is clear; the only acceptable solution to the problem is the concept of inorganic petroleum migration along deep faults extending into the mantle.

Thus the very fact of giant oil fields, alone and in itself, can refute the whole complex of argumentation in favor of the organic theory. The profound silence of geologists and chemists on this question is decidedly symptomatic. Such is the frightful force of inertia in blind acceptance of traditional concepts.

Conclusion. The material presented demonstrates that the organic theory of origin of petroleum does not correspond to the modern state of knowledge in the fields of geology, geochemistry, geophyaics, thermodynamics, astrophysics and other sciences; in fact it is an outmoded, outdated concept. Instead, the general inorganic theory of petroleum meets the requirements of new knowledge completely.

The combination of various factors involved in the natural process of petroleum formation leads to many problems of petroleum geology which require further investigation. But the main concepts of the new (or regenerated) inorganic theory can be formulated quite clearly.

Petroleum hydrocarbons which constitute the substance called "natural petroleum" are one of the several natural fluid mixtures. Its components ---petroleum, gas, and juvenile water formed under the thermodynamic conditions of the upper mantle---ascended under great pressure along plutonic faults close to the earth's surface where, depending on pressure and temperature, the fluid mixture separated into independent phases.

This scheme explains the regularity of patterns that are observed among petroleum and gas accumulations, as well as their spatial distribution associating them with the processes of our planet's development.

The inorganic theory explains the richness of the continental shelves where large deep faults are predictable. It also explains the paradoxical salt domes in the Gulf of Mexico, the reported petroleum occurrences in the giant rift zone in the midocean ridge of the Atlantic Ocean, and the accumulations in the Tonga Archipelago in the Pacific Ocean.

The immediate and the most important task is a thorough and critical review of existing oil fields and petroleum regional geology aimed at establishing whether this complex of geologic data fits the inorganic or organic theory. This point must be settled once and for all if intelligent petroleum prospecting is to continue.

The organic theory has the status of dogma and 99.9 percent of all fields described in the literature have been treated in the light of the organic theory. However, because petroleum is known in fissured zones of crystalline and metamorphic rocks, even of the Precambrian where it is impossible to imagine petroleum formation on the basis of organic theory, it was only logical for the organic theory to note that, close to these paradoxical accumulations, there were sedimentary rocks from which "obviously" this petroleum had migrated. For special cases when there are no sedimentary rocks in the vicinity, one might suppose that such rocks had existed earlier but later were destroyed by erosion. This sacramental approach to organic-theory contradictions is present in all works dealing with such cases. In vain one searches the literature for an example of objective geologic analysis with geologic facts to explain petroleum formation in this "adjacent" rock and its migration to crystalline rocks.

With our modern knowledge, it is insufficient to wave at some sedimentary rock and call it the "mother rock." One must produce proofs of the "mother rock's" potential ability to generate petroleum in accordance with the organic theory. Even the origin of the salt brines associated with petroleum should be critically reviewed.

The role of anticlinal wrinkles in the process of petroleum accumulation should be treated differently. The formation of fields in anticlines should be determined by the vertical migration of petroleum along faults in the axial part of the wrinkle, with the reservoir filling from top to bottom, rather than in the lateral plane of inflow along the bed and gravitational distribution of water, oil, and gas in the trap.

These new concepts of the inorganic theory are a result of reinterpreting the old data, the collection of new factual material, and the development of new ideas in geology, geochemistry, geophysics, and astrophysics. Many years of investigation of petroleum formation carried out with the blind acceptance of organic theory have been a waste and a failure. This is witnessed in the summary work by Hedberg; full of disappointment at the indefinite results of many years of scientific work on this problem, he noted that not a single question is solved, nothing is understood, and all contradictory hypotheses enjoy equal rights. He wrote:

> The need is to arrive at general principles which singly or in combination may have been the major contributors to the genesis of the great bulk of the world's petroleum.

Surely we are at the turning point in understanding not only the ways of further development of the theory of petroleum geology but also the practical problems.

In a work dealing with the question of petroleum demands in the near future Moody wrote:

> Basically, successful exploration for the future decades will depend on new and inspired concepts, conceived and applied with imagination that is rigidly disciplined to distinguish clearly between what we know to be true and what we think may be true.

New ideas in petroleum geology theory are needed and only they will indicate the ways to discover new reserves. Surely the inorganic theory provides a method---a tool---to explore for commercial petroleum accumulations in basement rocks. Yet petroleum geology scarcely has taken even the first step toward basement exploration. However, there are actual commercial petroleum and gas accumulations in fissured zones of both metamorphic and crystalline rocks, and any structure in a platform region containing petroleum is in principle a promising prospect for petroleum exploration not only of the sedimentary complex but also of the basement. This complex problem and insolution surely will require large expenditure in time and money; the important fact is that there are scientific grounds for such exploration. Further development of exploration trends in this direction is inevitable.

INORGANIC ORIGIN OF PETROLEUM: DISCUSSION

Biederman, Edwin W., Jr.; *American Association of Petroleum Geologists, Bulletin,* 59:880-885, 1975.

Introduction. Porfir'ev's article, "Inorganic Origin of Petroleum," deserves comment because there are more reasons for favoring the organic theory than he stated. The intent of this discussion is clarification and not prolonged debate. Furthermore, a point-by-point discussion is not attempted. The goal is merely to state the case clearly in those areas where the writer has had some first-hand experience.

....

Giant Oil Fields. Because the presence of giant hydrocarbon accumulations forms "the decisive argument" for the inorganic theorists, it is appropriate to discuss these accumulations from the point of view of the total resource available.

Hunt stated:

> The total amount of organic matter dispersed in fine-grained sedimentary rocks of the world's continents and the continental shelves is estimated to be 3,000 trillion tons. Associated with this organic matter are dispersed hydrocarbons (petroleum) amounting to about 60 trillion tons. The amount of petroleum actually existing in reservoirs is only about 0.6 trillion tons. These estimates are of the total oil that has been and will be found in sedimentary basins.

In Hunt's view, there is no shortage of hydrocarbons to provide large accumulations.

The Athabasca "tar sands" should be considered in terms of their likely origin because they are cited by Porfir'ev as being an appropriate example. If one looks at the distribution of the grain size associated with the saturated sandstones, it becomes clear that many of the sandstones are too fine grained to be normally productive sandstones. Carrigy studied the grain size versus tar saturation for 142 samples and found that 31.7 percent of the impregnated sandstones had median-grain diameters less than 62 μ. His conclusion was that, "Therefore, it must be concluded that in the Athabasca oil sands about one-third of the reservoir sands are finer than those from which oil has been recovered by fluid flow." If this conclusion is correct, it becomes difficult to see how the oil could have arrived either from deep faults in the Precambrian or from long-distance migration.

Hodgson et al. studied the origin of the petroleum porphyrins in the Athabasca oil sands. They pointed out that total porphyrin content ranged from about 360 to 550 ppm---which is relatively high in the spectrum of porphyrins in oils. The shales associated with the oil sands are believed to represent both freshwater and marine deposits. According to Hodgson et al. these shales have a maximum of 0.2 to 0.3 ppm porphyrin content. In an attempt to account for the total porphyrins in the tar, it is desirable to look at possible precursors. Hodgson further wrote, "The presence of the chlorophyll-type structure in petroleum pigments suggests that a chlorophyll (e.g., chlorophyll 'a') might be the initial pigment, and the abundance of this compound in nature strengthens the suggestion." The dominance of the vanadyl pigment accompanied by high sulfur content suggests a highly reducing environment of deposition. This observation, combined with the shoreline location, indicates some sort of restricted conditions of circulation at the time the beds were deposited.

Other indicators of probable origins include the presence of terpenes and calcified pollen grains; the latter are concentrated in some of the froth materials from the processing of the tar.

If one assembles this evidence, it does not appear that the deep-fault hypothesis could explain all the organic indicators or the close association with the shales.

....

Conclusions. To summarize the points which do not appear to jibe with the inorganic theory, one has the following:

1. The fact that porphyrin-like compounds have been prepared by abiogenic synthesis does not indicate that the porphyrins in petroleum were produced in this manner. The spectra still differ from the porphyrins of organic origin and are "considerably short" of specific biogenic porphyrins.

2. If oil were brought to the reservoirs through giant faults from the basement, one might expect large fields associated with areas such as the Triassic red beds in the Connecticut River Valley. This is not true. The fact that continental sediments contain many good sandstones but relatively little production is difficult to explain with the inorganic theory.

3. Both porphyrins and sulfur which are common in petroleum are indicators of a relatively low-temperature origin.

4. The amount of optical rotation in crude oils is much greater for oils from relatively recent sediments. Oils in older reservoirs show decreasing amounts of optical rotation. If all oils were injected between the early Miocene and early Quaternary, such a consistent change should not be observed.

5. Differences in the chemical composition of oils from old versus oil from young reservoirs cannot be explained by the inorganic theory as proposed by Porfir'ev.

6. If oils were produced by an inorganic mechanism, the differences in odd carbon chain lengths and overall wax contents with oils of marine versus nonmarine origin should not be observed. These differences do occur.

7. The quantity of C^{13} in crude oils should not be stratified or significantly different for oils from reservoirs of various ages, if the inorganic hypothesis is correct; however, they are different.

8. Microscopic organic debris of all kinds contained in oils should not be so common or so varied as it is if the oils were injected through deep faults.

9. Study of cores penetrating the granite wash and into the fresh granite below suggests that the hydrocarbons decrease with depth, and that they do not increase as might be expected if the inorganic theory is correct.

10. Evidence of ancient oil accumulations does exist in the literature in descriptions of the Oklahoma City and Lucien fields.

11. The fairly large amounts of hydrocarbons, asphalt, and kerogen which have been measured in ancient shales show that red and green shales are highly deficient by comparison with the black, gray, and carbonaceous shales. The very presence of hydrocarbons in ancient shales

is difficult to explain by the inorganic theory, let alone the marked contrast in hydrocarbon content associated with shale color.

12. Published estimates of the total amount of dispersed hydrocarbons in the sedimentary rocks of the world suggest that the accumulation process is relatively inefficient and large fields are not necessarily anomalous.

13. A third of the saturated sandstones of the Athabasca deposit are too fine grained for normal fluid-flow mechanisms. Hence, it is difficult to see how the oil could have been injected at some late date from deep-fault sources.

14. The organic indicators such as the large amount of porphyrins, pollen grains, and terpenes suggest that the Athabasca oil is related more closely to an organic origin.

15. Many pre-Miocene nonfaulted oil reservoirs which are surrounded completely by impermeable shales cannot be explained by the deep-fault inorganic theory.

ATHABASKA OIL SANDS: APPARENT EXAMPLE OF LOCAL ORIGIN OF OIL

Ball, Max W.; *American Association of Petroleum Geologists, Bulletin,* 19:153–171, 1935.

Introduction. In the debate on long-distance migration versus local origin of oil, some consideration may well be given to the oil sands of the Athabaska region in northern Alberta, Canada. Here are many thousands of square miles of oil-saturated sands, exposed in outcrops through a distance of 260 miles, so that they have been studied, measured, and sampled, and found to contain oil up to 100,000 barrels and more per acre, under conditions strongly suggesting that the oil in each acre originated in that acre. The total oil content has been estimated at 100 billion to 250 billion barrels; it may even approach 500 billion. The manner of accumulation of such a huge quantity of oil, if it were determined, might shed some light on the rules of accumulation elsewhere.

....

Whence Came the Oil? Here, then, is a great area of flat-lying sands saturated with a tremendous aggregate volume of oil. How did the oil get where it is?

Ruby has advanced the idea that the oil in certain sands in Utah is oil which formerly filled the reservoir of some closed structure or structures, has been released by erosion, has grown heavy through oxidation as it has been carried down the streams into the sea, and has been deposited on the sea floor, within the sands in which it is now found. In support of the application of the theory to the Athabaska sands it might be said that the oil is almost if not quite heavy enough to be deposited with other sediments, and that the absence of cementing material in the sands and the preservation without silicification of considerable quantities of wood suggest that saturation followed soon after, if it was not contemporaneous with, deposition. Such a supposition, however, only leads from one difficulty to another. From what source could such billions of barrels of oil have come; in what manner could they have been deposited so uniformly over so wide an area? Since only a source comparable to the present deposits could have supplied such quantities of oil, why not, if we must imagine such a source area, accept the present one? The work of Beckman and of Tausz, moreover, indicates that oil afloat in water is attacked and destroyed by aerobic bacteria, which would seem effectually to negative the possibility that this oil has been eroded from some previous source, transported by water, and deposited under water in its present location.

In 1915 Huntley suggested that the Athabaska oil might be the residue of large quantities of oil flushed by hydraulic movement out of the Great Plains geosyncline to the Athabaska outcrop. At that time the McMurray sand was generally considered Dakota and the Dakota was thought to be a continuous sheet sand throughout most of its Rocky Mountain and Great Plains extent. Huntley's theory was that the compacting of the Dakota sand and overlying shales and the subsequent uplift of the western and southern boundaries of the geosyncline forced great quantities of connate and meteoric water out through the Athabaska outcrop, and that this water carried with it much of the Dakota oil from the entire geosyncline, so that the oil now found in the McMurray sand is the oxidized residue of oil gathered from the Great Plains region as far south as Colorado and Kansas.

Leaving aside the evidence that the Athabaska oil is not a residuum, Huntley's theory seems to be negatived by other evidence developed since his paper was presented. Further study of the Dakota has shown that it is far from being a continuous sheet sand. In the words of Lee:

> There is no single, definite, persistent, and easily recognized sandstone such as was formerly supposed to exist and was termed the Dakota sandstone. In its place there is a group of intimately related beds....Doubtless there are many overlapping lenses that differ slightly in age.

Moreover, the McMurray sand is not now considered a member of the Dakota group. It apparently disappears toward the west and south, at least as a continuous sand body, and is apprently not continuous with any sand that underlies the greater part of the geosyncline. In the absence of a continuous sheet sand or sandy zone, the theory loses its attractiveness.

Is it not possible, however, that the oil may have been moved into the Athabaska area by "metamorphic circulation"? Parks points out, most persuasively, that metamorphic circulation, due to compacting of sediments and reduction in pore space by whatever cause, is of greater importance than artesian circulation in the accumulation of oil, and that it is as likely to take place across as with the bedding. In the Athabaska country, however, the Devonian sediments were compacted long before the McMurray sands were laid down; no metamorphic circulation took place from them into the present oil sands. After the McMurray sands and overlying shales were laid down there was, no doubt, a lively fluid movement due to compacting, but this movement probably took place before erosion had exposed the McMurray sands, and there is no reason, therefore, to think that extensive fluid movements from outside the area into the McMurray sands took place. Because the beds lie so flat the metamorphic circulation was probably chiefly vertical, with local lateral movements to points of vertical escape. Metamorphic circulation, then, seems to provide no outside source for the oil.

Some geologists have thought the oil originated in beds of Mississippian age in southern Alberta, where the Lower Cretaceous lies unconformably on the Mississippian Madison or Turner Valley limestone which contains the principal producing zones of the southern Alberta and Northern Montana oil fields, and that it floated northward in a Lower Cretaceous sea and saturated the depositing McMurray sand. This theory is akin to Ruby's, if not identical with it, and it is subject to the same objection: aerobic bacteria would doubtless have destroyed any such oil before it reached the point of deposition.

As to the alternative suggestion that oil originating in the Mississippian migrated northward into the McMurray sand along the Paleozoic-Lower Cretaceous unconformity, the Mississippian, like the Devonian, was compacted long before the deposition of the McMurray, so that there would be no metamorphic circulation from the Mississippian into the Lower Cretaceous, and there is no reason to think that artesian circulation along the unconformity has been such as to move such quantities of oil such a distance.

If we must rule out Ruby's theory that the oil was deposited with the sand, Huntley's theory that the oil has been funnelled into the Athabaska region through a continuous Dakota sand, and the suggestions of others that the oil has been brought in by metamorphic or artesian circulation through the McMurray sand or along the Paleozoic-Lower Cretaceous unconformity, how about the possibility of migration from some remote region through deeper-lying "carrier beds"? Dismissing all questions regarding the geographic and geologic location of a source for so much oil, and all questions regarding the relation of such migration to the long period of exposure of the Devonian surface before the deposition of the McMurray, we still encounter two formidable difficulties: (1) the pre-McMurray beds contain, so far as we know, no continuous sandstones or other continuous zones of porosity to act as "carriers"; (2) the Devonian beds were doubtless compacted and indurated to their present degree of impermeability long before the McMurray beds were laid down, and though fractures are known to extend short distances downward into the Devonian, the region seems to be devoid of deep-seated faulting or of other vertical lines of porosity that would permit migration upward from Devonian or older "carrier beds" into the McMurray. Courses along which the oil could have moved into the area and along which it could have moved upward into the sands seem both to be lacking, so that we are forced, however reluctantly, to set aside this theory also.

The more we study the facts, and the more we try to imagine some other answer, the more we seem to be forced to conclude that the source of the oil was co-extensive with its present location. The oil is apparently a young oil, not yet subjected to the vicissitudes of heat and pressure, rather than the residuum of larger volumes moved in from some outside source. The beds are too flat, it would seem, to have induced migration. There is practically complete absence of water pressure, or of any indication of artesian movement. There is nothing to suggest that during compaction of the sediments fluids moved into this area from without. The McMurray sand appears to be saturated throughout most or all of its extent; there seems to be no additional larger area of the sand whence the oil in the saturated area could have been derived. No deeper-lying porous beds which might have brought oil into the area from remote sources, or vertical channels into the oil sands from such deeper-lying porous beds if they existed, are known. The evidence may be mainly negative, but point by point it indicates that the oil originated in its present location.

Whether or not it originated in the McMurray sandstone is another question and not particularly important in the present discussion. It may have originated in the shales above, which are similar in character to shales ordinarily considered the source of much Rocky Mountain oil---a theory supported by the fact that the saturation and the shales immediately overlying the sand seem to be co-extensive. It may have originated in the underlying Devonian; the fact that several wells drilled into the Devonian report gas or oil showings may be significant, but if so, why did the oil not migrate upward during the long interval when the Devonian was exposed to erosion? It may have originated in the sands themselves, though the amount of organic material that must have been required for its production would seem to demand too great a volume for such a sandstone to contain. It may even have had an inorganic origin in the pre-Cambrian rocks---an idea with which one of our distinguished members seems to be flirting in Mid-Continent fields---though it is hard to see how, if so, it passed upward through the Cambrian and Devonian sediments in a region devoid, so far as we know, of deep-seated fracturing.

The point is that whether the oil originated in overlying beds and migrated downward, or originated in underlying beds and migrated upward, or originated in the sands themselves and stayed there---however it may have moved up or down, it probably has not moved far sidewise.

Whatever may have happened in other areas, in the Athabaska country the theory of local origin in its most extreme form seems to be sustained.

INDIGENOUS PRECAMBRIAN PETROLEUM

Murray, Grover E.; *American Association of Petroleum Geologists, Bulletin,* 49:3-21, 1965.

In June, 1963, Exoil Pty. Ltd. and partners abandoned their Ooraminna No. 1 Well in the Amadeus Basin of Central Australia. This test was not only the initial exploratory drilling venture in that basin but it represents, to my knowledge, the first well ever deliberately programmed to search for oil and gas in Proterozoic sedimentary rocks outside of Russia. It commenced in the basal Cambrian Arumbera Sandstone, entered Proterozoic sedimentary rocks at 1, 525 feet, and was bottomed in Proterozoic salt at total depth of 6, 105 feet.

The Proterozoic rocks consisted, in descending order, of (1) thick black to green shale, parts of which yielded sufficient hydrocarbons on analysis by Olexcon International of The Hague to be considered commercial source rock of moderate quality; (2) a variable sequence of limestone, sandstone, siltstone, and shale, containing a basaltic flow; (3) cherty dolomite; and (4) rock salt with red shale inclusions.

A drill-stem test of 18 feet of dolomitic limestone between 3, 768 and 3, 784 feet yielded an estimated 12 MCF/D of methane with minor amounts of propane. Unfortunately, this limestone constituted the only effective porosity in the Proterozoic sequence penetrated by the Ooraminna well. Had any appreciable porosity been encountered, commercial quantities of hydrocarbons could well have been present.

This flow of gas constitutes the first irrefutable evidence of indigenous hydrocarbons in the Precambrian of Central Australia, and, although small quantities of residual hydrocarbons had been obtained earlier from samples judged to be Precambrian, their geological relationships were such as to leave some uncertainty as to the age of the residual hydrocarbons.

These indigenous hydrocarbons in Proterozoic rocks, together with reported widespread evidences of indigenous hydrocarbons in the Upper Precambrian (Riphean) deposits of the Russian and Siberian platform, focus attention on the possibilities of commercial accumulations of oil and gas in unmetamorphosed Precambrian sedimentary rocks in various parts of the world.

Many strata of this age have been involved in one or more episodes of orogeny and, accordingly, may be complexly deformed or metamorphosed. On the other hand, great thicknesses of unmetamorphosed sedimentary rocks of Precambrian age are known in Africa, Australia, Eurasia, North America, and South America. In certain areas these conformably underlie earliest Cambrian strata and do, in fact, constitute segments of a continuous depositional sequence ranging from Proterozoic to Paleozoic in age. The lithic character of many of these Precambrian strata is similar to that of appreciably younger sedimentary rocks.

Now let us examine some of the known facts relating to Precambrian life.

The best available radioactive datings indicate that the solar system is at least 4.5×10^9---and that the minimum age of the earth is something more than 3 billion years. For the greater part of this enormous period of time there are virtually no known fossil remains. They first appear in appreciable numbers in Lower Cambrian rocks, whose age can now be shown to be about 5.5×10^8 years; from these strata hundreds of species of organisms have been described. Obviously, numerous others left no fossil record and many more undoubtedly remain to be found. Although all major groups of organisms except the bryozoans, chordates, and higher plants are known from the Lower Cambrian, the life of that time was considerably less diversified than that of later periods.

The real implication of this earliest Paleozoic assemblage, however, is that the major part of organic development and differentiation of animals, but not of plants, took place in Precambrian time.

If so, what of the earlier record?

The exact origin of the earth is lost in antiquity and, in all probability, its true history will never be fully reconstructed. Yet, certain reasonable inferences can be drawn from the preserved record and from astronomical studies of other planets and solar systems.

At the time of its development into a solid body more than 4 billion years ago, however that occurred, we can infer that the earth very probably had an atmosphere composed primarily of hydrogen, oxygen, carbon, and nitrogen in their reduced or hydrogenated state. By escape of certain gases and through other combinations and reactions the atmosphere eventually evolved into one containing molecular nitrogen, hydrogen, oxygen, methane, ammonia, and water.

....

In any event, the general absence of organic remains in unmetamorphosed Precambrian strata appears primarily attributable to the general absence of hard parts associated with the population of that time. Still another important consideration may be that the resolution powers of our microscopes have not, until recently, permitted us to identify submicroscopic and molecular aggregates in the Precambrian strata.

Lest doubt linger in your minds in regard to the probable abundance of organisms, I direct your attention (1) to the widespread nature of reported Precambrian fossil occurrences and (2) to the relationship of these occurrences to the major shield areas of the world. Although some of these reported fossils may be questionably organic, whereas others may be of questionable Precambrian age, the array is imposing.

Until a relatively few years ago, the known or supposed evidences of Precambrian organic life consisted largely of trails and burrows, a few medusoid impressions, some disputed inarticulate brachiopods, various algal and stromatolitic structures, and certain types of limestone and graphite.

More recently the discovery of sponges; various coelenterates; annelids; echinoderms; odd, bilaterally symmetrical forms of unknown taxonomic affinity; iron-secreting bacteria; certain carbonaceous structures with a carbon isotope ratio suggestive of organic origin; organisms comparable with primitive aquatic fungi and blue-green algae; possible foraminifera, radiolaria and flagellates; traces of amino acids from cherts whose age is nearly 2×10^9 years; and so on, demonstrate beyond doubt that a diversified association of relatively highly developed organisms inhabited the late Precambrian seas.

Particularly important finds have been made during the last two decades in:

(1) The late Proterozoic of the Ediacara Hills, about 300 miles north of Adelaide, South Australia, where more than 600 specimens representing several phyla have been described by Sprigg and Glaessner;

(2) The middle and late Proterozoic of the Pildara area of West Australia, where calcareous algal structures belonging to <u>Collenia</u> and related genera occur through at least 1,000 feet of dolomites (H. S. Edgell, in press); and

(3) The late Proterozoic iron-bearing strata of the Hamersley Ranges of West Australia where hydrozoans similar to those of the Ediacara Hills fauna occur in considerable numbers (H. S. Edgell, in press).

Other rich and varied assemblages are reported to have been found in the U. S. S. R.

In conclusion, I ask---

(1) If the basic elements constituting petroleum existed in the early phases of the earth's history;

(2) If unmetamorphosed sedimentary rocks of Precambrian, especially Proterozoic age, are lithically similar to younger ones, thereby indicating analogous sedimentary conditions;

(3) If the population of these Precambrian seas was anywhere as near rich and varied as certain recently discovered fossil assemblages suggest;

(4) If the commonly accepted organic origin of petroleum is valid;

(5) If oil is a widely disseminated and integral part of normally deposited sedimentary rocks, as has been advocated by Pratt, Levorsen, and others;

Why then have we as geologists been hesitant to explore unmetamorphosed Precambrian strata in search of oil and gas?

Is the answer, at least in part, due to the still widely prevalent notion that Precambrian rocks are merely a metamorphic and igneous complex which forms the core of continental areas and serves as a foundation for the superficial accumulations of Paleozoic, Mesozoic, and Cenozoic ages?

On the other hand, does the answer lie in our uncertainty regarding the existence of sufficient organic material to generate hydrocarbons?

Or, more significantly, are we simply too restricted in our thinking to admit that sedimentary processes and ecological conditions were sufficiently analogous to those of later geologic times to result in source and reservoir rocks which could generate and entrap hydrocarbons?

• Curious Occurrences of Petroleum

HYDROCARBON FLUID INCLUSIONS IN QUARTZ

Murray, Raymond C.; *American Association of Petroleum Geologists, Bulletin,* 41:950, 1957.

Fluid inclusions as large as 2 mm. in diameter within euhedral quartz crystals occur at a depth of 8,990 feet in Oilwell Operators Ltd., Harmattan 9-5, Alberta, Canada. These quartz crystals line solution vugs in the Mississippian Rundle formation. The host rock is dolomite, and euhedral dolomite crystals have grown on the free surface of the vug walls prior to the quartz. All the fluid inclusions observed were two-phase, liquid and gas, with the gas phase occupying approximately 60 per cent of the volume at room temperature. Chemical analyses by mass spectrometer indicate the inclusions are filled with a hydrocarbon system. On heating the crystals, the gas phase expands and completely fills the inclusions at 100°C. ± 5°C. At this temperature the crystals decrepitate, breaking along the first order rhombohedron. The presence of liquid hydrocarbon inclusions in fluorite has been reported previously by Grogan and Shrode.

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FREE OIL IN AMMONITES, COLUMBIA, SOUTH AMERICA

Etherington, T. J.; *American Association of Petroleum Geologists, Bulletin,* 28:875-876, 1944.

Abstract. In the Cretaceous section of Colombia free oil has been noted in various parts of the stratigraphic section, but the most striking occurrence is in the Oxytropidoceras zone of the middle Albian.

This zone is abundantly fossiliferous, especially in limestone concretions interbedded in dark gray shales. No evidence of oil can be detected on the outside of the concretions, but, when they are broken with a hammer, free oil can be obtained from the hollow central part of the individual chambers of the ammonites. These chambers are completely separated both by the septa and a layer of secondary calcite which lines

each chamber. As much as 1/2 teaspoon of light green oil has been found in the larger chambers.

This zone is known to extend over an area of 120 miles by 40 miles in the upper Magdalena Valley on both sides of the Magdalena Basin. In isolated areas near Simiti a similar condition is present, but the ammonites are lower Albian in age.

Isolated occurrences in the upper Magdalena Valley are in the Turonian but there the concretions are associated with highly petroliferous shale.

OCCURRENCE OF FREE OIL IN LIMESTONE CONCRETIONS IN PUERTO RICO

Glover, Lynn; *American Association of Petroleum Geologists, Bulletin,* 41:565-566, 1957.

Small amounts of free oil have been discovered in limestone concretions that occur in tuffaceous shale of Upper Cretaceous age in the volcanic complex of the central part of Puerto Rico. The concretions are mostly ellipsoidal, as much as a foot in length, and lie parallel with the thin bedding of the volcanic shale. Generally the concretions are structureless but a few of the more calcareous ones have a network of calcite veins, some of which are partly open. A fetid odor emanates from the concretions when they are struck with a hammer, and a few of the concretions show a small amount of free oil seeping from the openings in the calcite veins.

The shale and concretions crop out about 3 miles by airline northeast of the town of Coamo, which is in the southeast-central part of the island. At this locality the shale dips about 25° SW. Although organic matter has been previously recognized in the volcanic rocks of the interior (Hodge, 1920; Meyerhoff, 1933; Mitchell, 1954), most geologists have believed that any oil that may have been formed was dissipated during deformation, intrusion, and metamorphism. These volcanic rocks dip seaward under the less deformed coastal formations of Tertiary age that are believed to contain permeable rocks.

PECULIAR PHASES OF OIL SATURATION IN CERTAIN SANDSTONES

Ruby, Glen M.; *American Association of Petroleum Geologists, Bulletin,* 7:473-481, 1923.

The writer knows of only one deposit of oil as a solid body interbedded in sediments, in the United States. This is found near the north end of Great Salt Lake, where at depths of a hundred feet and more, thick, viscous oil has been found in sheets. It is not in a sandstone but occurs in much the same manner as a seam of coal. Several of these "oil beds" have been found by drilling and digging wells and their nature is such that their presence may be explained by assuming the oil came into the lake as a sediment.

Oil-bearing formations were involved in the territory occupied by the Wasatch Range, east of Great Salt Lake, and this oil came in, either in the form of basic sediment in a stream emptying near present location, or it floated from another quarter to this location. Needless to say, drilling for commercial oil wells under such conditions cannot be destined for success.

An occurrence somewhat similar to that in Great Salt Lake is found in the Province of Angola, Portuguese West Africa, where the solidified oil has been mined for fuel and classed by English geologists as "oil coal." Dr. Arthur Holmes has ascribed for it an origin similar to coal, although chemical and physical analyses show it to be essentially petroleum. In regard to this deposit, the writer has had considerable correspondence with Mr. Harry L. Baldwin, a geologist who spent three years in this district, and he has, also, gained additional information from a Portuguese bulletin in which the "oil coals" are described. A brief description of their nature and occurrence is given here since the origin is probably sedimentary.

This sedimentary oil is termed "oil coal" and also "Libollite," from its occurrence in the district of Libolo. Its age is supposed to be Cretaceous and probably older than the Cenomanian beds. The "oil coal" strata are interbedded in sandstones and conglomerates which rest unconformably on the Archean complex. There is no indication of the presence of shales or other sediments in sufficient amount to which the genesis of this oil can be ascribed. The following excerpt describes one of the strata of "oil coals."

> This asphaltic deposit is found bearing the following characteristics: (a) Asphaltic calcareous sandstone forming the "roof" of the deposit, its thickness exceeding two meters. (b) Asphaltic material, commonly known as "coal" with thickness varying from 0.5 to 1.5 meters. (c) Argillaceous sandstones impregnated with asphalt, closely resembling the bituminous shales of Scotland and forming the floor of the deposit. Its thickness exceeds 0.5 meters though the general thickness is unknown. There is, so to say, no differentiation between the "coal" seam, the hanging and foot wall, there being a gradual transition from the "coal" product into sandstone and asphaltic shale.

Nearly all analyses show an ash content in excess of 20 per cent. One sample shows nearly 3 per cent sand in the "coal." Considering these circumstances, it would seem that the "asphaltic deposit" could well have been in the form of a flow into the local lake and the sands both above and below it could have received their saturation by capillary action. Mr. Baldwin states that the underlying "shale" is really a fine sand and not in any sense a true oil shale.

A brief description of the Calucala field and adjacent territory shows that the beds associated with the "oil coal" are unconformable on the Archean basement.

> The carboniferous asphalt field is found in a basin surrounded by phonolitic rocks, some appearing folded forming anticlines and synclines, owing to pressure action.
>
> Bed A. Asphaltic, argillaceous, calcareous, and micaceous sandstone ofter interfoliated by small veins and pockets of "coal," with average thickness of three meters.
>
> Bed B (lower bed). Asphaltic, calcareous, sandstone, contain-

ing garnet, feldspar and fragments of gneisses and schists, the thickness varying from five to fifteen meters. (Rests on Archean basement.)

The occurrence of the "coal" in bed A in veins and pockets, strongly suggests sedimentary deposition. In this bed there appears no logical, indigenous source for the oil.

The two following paragraphs quoted furnish a more comprehensive understanding of this peculiar occurrence.

> The asphaltic coal appearing as lenticular-like veins and pockets, without any well defined direction, follows the argillaceous, micaceous sandstone, same occurring sometimes converted into a sort of viscous bitumen.
>
> We may conclude from what has been explained above that there is a connection between the known oil field of Angola and these carboniferous asphaltic deposits. It appears we are in presence of oil migration; the loss of the more volatile gases was probably produced by phonolitic eruptions transforming the liquid asphaltic oil into a special asphalt, both the hanging and foot wall of the "coal" deposit being equally impregnated by asphaltic matter. It is proved by analysis that Angola "coals" are essentially oil-producing materials and accordingly the right classification would be "oil coals."

The foregoing conclusion shows an opinion at variance with the previously mentioned theory of Dr. Holmes that the oil coal has an origin somewhat similar to true coals. The behavior of the oil coal, which melts and runs through the grates when fired under a boiler, tends to prove its true asphaltic nature. While the conclusions reached suggest some connection between the oil coals and the true oil field, and further, mention a degree of metamorphism of the asphaltic deposits, the present writer believes this metamorphosis from asphalt to its present form is due, in most part, to oxidation from contact with the air while being transported from oil-bearing beds to its present site, and later, to contact with the water of these local lakes.

It is not probable that the oil coal was transformed in situ from an oil deposit to oil coals by phonolitic eruptions and dikes. This may have caused some local metamorphism, but had the effect been regional so as to produce the almost general and uniform change claimed for it, there would have been no resultant bed of asphalt, if we may judge by similar effects in regions subject to more detailed study. Finally, the writer is unable to conceive of a solid body of oil, existing as a liquid, and in an individual and intercalated stratum, having its origin within any of the associated beds. It would seem that a free body of oil whether found as liquid or solid, or in intermediate stages, and interbedded in sandstones and conglomerates, or any other substance not subject to solution by percolating waters, or having natural cavities, must be classed as a sediment and given an extraneous origin.

If there is any truth in this hypothesis it would follow that mere oil saturation in a sandstone under favorably structural conditions would not insure a commercial well. If only the interstitial spaces are filled with oil and no unnatural, oil-filled cavities exist in the sand series, true petroleum may be expected where structure is favorable to accumulation. On the other hand, if the sand shows "oil rolls," or asphaltum or paraffin exists as sheets or lenses, this sand series will not be productive of oil and only viscous wax can be recovered and in very small amounts, unless there are true oil-forming formations closely associated with the sands.

This should be kept in mind, especially in drilling continental Tertiary formations of the Rocky Mountain region, where the source of the oil causing the saturation is problematical. (pp. 478-481)

SALT STRUCTURES AND EVAPORITES

Historians say that the Romans used salt for money. Modern drilling for oil and geological research has discovered enough subterranean salt to make everyone a millionaire. The salt beds under and around the Gulf of Mexico boggle the mind. Where did all the salt come from? From the ocean, of course. But hundreds of oceans would have to dry up to create the observed deposits. Furthermore, salt is only one kind of evaporite. Gypsum and other precipitated chemicals occur in thick strata, too. Apparently, the earth's chemical factories, fuelled by internal and solar heat have been very productive down the eons.

The widespread occurrence of evaporites requires that geology account for the repeated drying and refilling of seas and ocean basins. Changes in sea level may have been measured in miles. What environmental changes transpired, and where did the water go and (it is assumed) return from? If such great sea-level fluctuations did occur, perhaps they were synchronous with the cutting of some of the submarine canyons and wave erosion of submerged guyots.

SALT STRUCTURES OF GULF OF MEXICO BASIN—A REVIEW

Murray, Grover E.; *American Association of Petroleum Geologists, Bulletin,* 50:439-478, 1966.

Introduction. Although a remarkably accurate geological description of salt domes was published nearly 100 years ago in a paper on Galicia, it was not until the 1920s that a reasonably modern interpretation of the nature and origin of salt diapirs in the Gulf of Mexico basin was widely accepted.

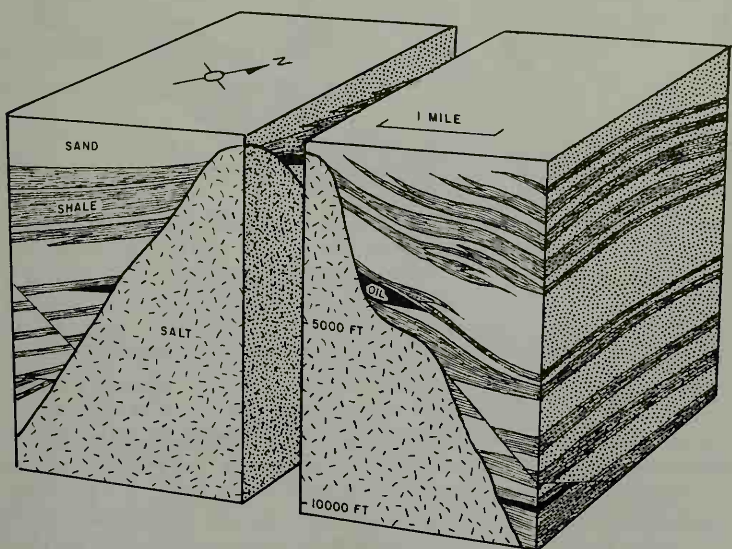
Today, in the Gulf basin, more than 300 salt diapirs are known in Alabama, Mississippi, Louisiana, Arkansas, Texas, Nuevo Leon, Veracruz, Tabasco, and Cuba. Possibly an equal number exist beneath the continental shelves off Louisiana-Texas and Veracruz-Tabasco. In addition, M. Ewing et al., Nowlin et al, and Ewing and Antoine have found structures in the Sigsbee Deep whose growth pattern is similar to that of salt diapirs.

Diapiric salt structures are unknown (1) on the higher parts of the large structural anomalies in the Gulf of Mexico basin and (2) in the carbonate platforms of Florida, the Bahamas, and most of Yucatan. Instead, these structures are concentrated in areas of greater than normal sedimentary thickness, and their times of growth appear to be related to periods of greater than normal sedimentary accumulation. Their absence in certain areas is taken to indicate either thinness or absence of salt because of (1) non-deposition of sodium chloride in those areas or (2) regional flowage of the salt from structurally or topographically high areas to lower ones. Salt structures similar to those in the Gulf of Mexico basin also are known in Colorado, Utah, the Canadian Arctic Islands, Arabia, France, Germany, India, Iran, Russia, Spain, Africa, Australia, and other areas.

Numerous additional domal and anticlinal structures also are present in the Gulf province. On the basis of geological and geophysical data, many of these are considered to be salt-controlled. It is well known that under proper conditions any plastic medium may flow and form diapiric anomalies similar to those effected by salt flowage. For example, structures resulting from the flowage of thick clay-shales are widely present in the Louisiana continental-shelf area.

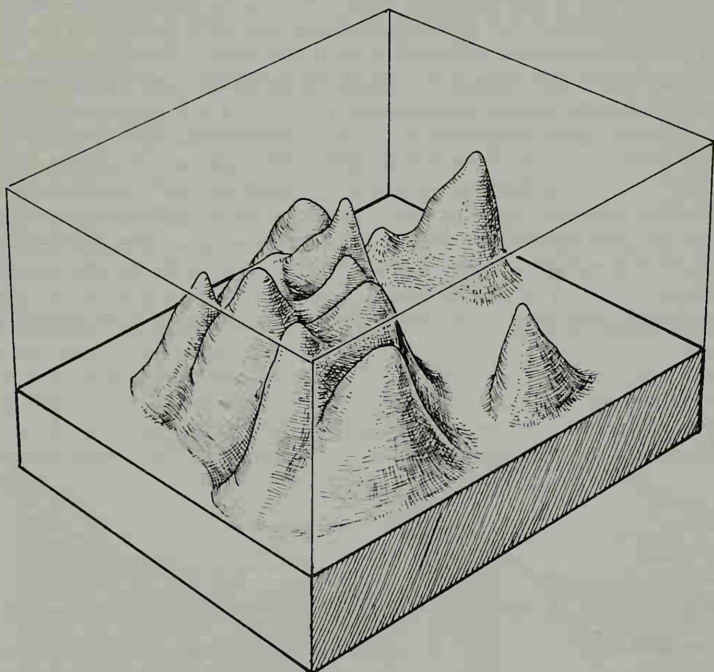
Prominent anticlinal folds caused by, or involving, salt flowage are present in Arkansas (U.S.A.), Nuevo Leon, Coahuila, Veracruz, Tabasco, Chiapas, and Campeche (Mexico), and in El Peten Province of northern Guatemala. Similar structural forms resulting from salt flowage are known from other parts of the world, e.g., the Zechstein basin of northwestern Germany, the Paradox basin of Colorado and Utah, and the Amadeus basin of central Australia.

Geometry and Patterns. Geophysical and drill data disclose that salt



Configuration of salt structures in the Saline Basin, Veracruz, Mexico.

diapirs in the Gulf of Mexico region differ appreciably in geometry and growth patterns. Essentially, the salt of these diapirs has moved vertically upward through the enclosing strata for distances up to 8 miles, forming masses fundamentally identical with those known in the Zechstein basin of Germany, except possibly for the separate droplet type and the salt-wall. In contrast, great salt anticlines or ridges, and irregular salt masses will spinose to cone-shaped apophyses rising from them, are relatively better developed in the Gulf basin. Characteristic of these are (1) the salt mass in Veracruz and Tabasco; (2) the East and West Hackberry ridge, Louisiana; and the Caillou Island-Timbalier Bay-Bay Marchand complex, also in Louisiana.



Salt structures from the Zechstein Basin, Germany.

The upper parts of salt stocks are most commonly circular to elongate, to the depths to which they have been explored; or their form is some modification of these, such as quadrate or rounded-triangular. The basin shape may be distorted by the formation of lobes or shoulders, by mushrooming or bulging, or by the growth of spines protruding from the main salt mass.

Many salt structures originally believed to be individual rod-like stocks are now known to rise as spines, stocks, or apophyses from great ridge-like or anticlinal masses of salt.

....

Volume and Origin of Salt. If a single, continuous salt bed is the source of all salt structures in the northern Gulf region, it has an areal extent in excess of 200,000 square miles. If isolated beds are the source of the supply, their areal extent could be in the order of 125,000 square miles, more or less. The salt-dome region of Veracruz and Tabasco is underlain by salt with an areal extent of at least 25,000 square kilometers; the total may exceed 60,000 square kilometers.

Current knowledge indicates that the mother bed of salt must be several thousand feet thick for diapirs to form. Nettleton suggested a thickness of the order of 2,000 feet, but, on the basis of experimental data, Parker and McDowell concluded that a thickness of about 5,000 feet is more likely. If the thickness of the salt averaged at least 1,000 feet throughout the area of known structures before growth commenced, the salt bed or beds would have had an original volume of approximately 40,000 cubic miles. If the thickness averaged 5,000 feet, it would have had an original volume in the order of 200,000 cubic miles.

Precipitation of such a great volume of sodium chloride poses numerous problems. It would require the evaporation of immense quantities of sea water, presumably in some sort of isolated basin or basins which would receive fresh supplies of saline water from time to time. Furthermore, it is necessary to account for the apparent absence of sulfate and carbonate in quantities commensurate with the volumes which should have existed in the vast quantities of sea water needed to produce so much sodium chloride.

....

THE DAY THE MED DRIED UP

Stubbs, Peter; *New Scientist*, 74:704-705, 1977.

[Digest. In 1970, the U.S. drilling ship Glomar Challenger first discovered thick layers of salt at the bottoms of the deep basins in the Mediterranean.]

So intriguing was the problem that the DSDP sanctioned a second trip to the Mediterranean in 1975 during which the ship put down seven carefully selected holes. The first detailed report of the results of this cruise, by Kenneth Hsu of the Geological Institute, ETH, Zurich, and an international team of co-authors who were also members of the 1975 Leg 42A shipboard team, appeared early this month (Nature, vol 267, p 399). It underscores heavily the theory that the Mediterranean basins dried out almost completely a mere 5-1/2 million years ago. Hsu and his colleagues speculate on the likely consequence of this extraordinary happening, one of which may even have been to promote the evolution of our ancestors the hominids.

[One problem posed by the evaporites is their thickness, which is often thousands of feet. The evaporation of 1000 feet of ordinary sea water leaves a layer of salt only about 15 feet thick. Therefore, whatever geological process created the thick salt layers must have provided several times the quantity of sea water now stored in the Mediterranean. A second problem is that the evaporites have all the earmarks of being deposited in shallow waters. Since these layers now exist about 5000 feet below the sea level of the nearby Atlantic, the Straits of Gibraltar must have formed an effective dam against the Atlantic. The salt deposits are interbedded with fossil forminifera of deep-water origin, suggesting several cycles of evaporation and refilling. The refilling could, of course, have come as the Atlantic surged over the natural dam at Gibraltar. Hsu believes that 8 or 10 invasions of the Atlantic could have brought in the requisite salt.]

The change to a salt-forming milieu happened abruptly. There is, however, no indication of any concomitant sudden switch in the climate. Rather, it seems, we must attribute the event to the mountain-building processes which isolated the Mediterranean from the Atlantic and Indian Oceans. The Mediterranean is a relic of the old Mesozoic trough which formerly separated Africa from Europe, and India from the Asian land mass. Into this trough were tipped the thick sediments which were later to be crumpled up to build the Alps, Carpathians, and Himalayas. Seventy million years ago, after Africa had become joined to Europe, this Tethys had declined to a shallow sea linking the Atlantic to the Indian Ocean. Some 20 million years ago this connecting sea began to be squeezed out. The Earth movements which pushed up, first the eastern Alps, and then the Swiss Alps separated the Mediterranean in the west from another inland sea, the Paratethys, in eastern Europe. The two became severed finally only some 14 or 15 million years ago.

[When the Mediterranean was mostly dried up, rivers like the Nile would have cut deep channels in the exposed sea floor. Such channels are observed, filled with river gravels, and capped with Marine Pliocene rocks off Egypt and southern France. At Aswan, 1200 km upstream the Nile cut a gorge 200 m below sea level during this period. It is interesting to relate these incisions in the sea floor to the enigmatic submarine canyons of subsection ETS.]

SALT DIAPIRISM IN SOUTHERN IRAN

Ala, M. A.; *American Association of Petroleum Geologists, Bulletin,* 58:1758-1770, 1974.

Abstract. More than 200 piercement salt plugs are present in southern Iran and in the Persian Gulf region. Recent investigations have shown the salt, the Hormuz Series, to be largely of Precambrian (late Proterozoic) age. The diapirs are famous for their tonguelike projections, known as "salt glaciers," and for their associated igneous, metamorphic, and sedimentary exotic blocks. In many places the salt plugs form spectacular mountains, rising up to 4,000 ft above the adjacent valley floor. The diapirs generally are associated with anticlines, and in many areas pierce the structure at the plunging end or on the flanks. Diapirs in synclines also are present.

Four stages in the evolution of the Hormuz diapirs have been recognized. These stages are represented by bulging folds, pierced and collapsed structures, and large solution cauldrons.

There have been at least two periods of salt mobilization and intrusion: a pre-Zagros (pre-Alpine) phase, possibly dating back to the Triassic; and a late Tertiary syn- to post-orogenic phase. The rate of intrusion is a highly fluctuating quantity, amounting to about 2 mm per year in the most actively rising diapirs.

The regional pattern of salt structures is related to north-south-trending regional fractures in the underlying Precambrian basement.

ABYSSAL OIL?

Anonymous; *Scientific American,* 221:54, July 1969.

Navy oceanographers have discovered that there may be oil-bearing formations in the deep-ocean floor of the Atlantic, well beyond the continental shelf. According to Eric Schneider of the Naval Oceanographic Office, seismic-reflection records made by the research ship Kane last July disclosed the existence of geologic structures resembling salt domes in sedimentary layers of the ocean bottom at a depth of 15,000 feet northwest of the Cape Verde Islands. Salt domes are widely associated with oil deposits on land, in shallow seas and on continental shelves. The Cape Verde structures also resemble an oil-bearing salt dome discovered at oceanic depth in the Gulf of Mexico last summer by the deep-drilling ship Glomar Challenger.

The presence of salt domes in the deep-ocean floor is something of a surprise because it contradicts the prevailing geological view of such structures.

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REMARKABLE UNCONFORMITIES

A geological unconformity is an apparent gap in the stratigraphic record. It marks a hiatus in time when deposition ceased or erosion interrupted the continuity of the sequence of strata. The most remarkable unconformity separates Precambrian and Cambrian strata; but many other significant breaks exist all over the world.

If unconformities represented nothing more than a short break in sediment deposition or minor erosion, there would be no need for this section. However, many unconformities seem to record widespread catastrophism and geological revolutions of great significance in terrestrial history. Potentially more important to geological thinking are those unconformities that signal large chunks of geological history are missing, even though the strata on either side of the unconformity are perfectly parallel and show no evidence of erosion. Did millions of years fly by with no discernible effect? A possible though controversial inference is that our geological clocks and stratigraphic concepts need working on.

MORE GAPS THAN RECORDS

Ager, Derek; *The Nature of the Stratigraphic Record,* Macmillan, London, 1973, pp. 30-31.

Having a sentimental attachment for them, I cannot resist mentioning the Cotswold Hills of western England where the formation still quaintly known by William Smith's original name of the 'Inferior Oolite', reaches what is for us the tremendous thickness of about 100 feet. This constitutes the Bajocian Stage in the Middle Jurassic and compares favourably with its equivalent on the Dorset coast of southern England, where the limestones of this age are condensed into a mere 11 feet with two obvious breaks (plate 3.3). But it has long been known from careful palaeontological studies that even in the thick development in the Cotswolds, there is evidence of two major breaks and a period of folding in what otherwise was a very peaceful period in British geological history. What is more, if we look farther afield, our magnificent 100 feet dwindles into insignificance. In Alaska we read that the Middle Bajocian alone amounts to some 4000 feet.

Again, the childlike wonder appears when we read for example of nearly 7000 feet of Kimmeridgian (Upper Jurassic) in New Zealand or 10000 feet of Frasnian (Lower Upper Devonian) in Arctic Canada, or 17000 feet of Arenigian (Lower Ordovician) in western Ireland. What I think of as a few steps along the beach in the Isle of Wight suffices to pass the Middle Oligocene, but I find this amount to untold thousands of feet of sediment in New Guinea.

For any tiny part of the stratigraphical column of which we are particularly fond in our own backyard, we can almost always find somewhere else in the world where that same division is a hundred or a thousand times thicker. We are only kidding ourselves if we think that we have anything like a complete succession for any part of the stratigraphical column in any one place. (pp. 30-31)

ORIGIN OF THE CAMBRIAN-PRECAMBRIAN UNCONFORMITY

Olson Walter S.; *American Scientist,* 54:458-464, 1966.

The article by George B. Field on the Origin of the Moon in American Scientist for September 1963 outlines a theory which has far-reaching implications concerning the early history of the earth. If the moon as an independent planet was captured by the earth's gravitational field and approached within a few earth radii, it would have raised catastrophic tides which could hardly fail to leave tangible evidence in the geologic record. If the approach took place around a billion years ago, which is a reasonable possibility, the evidence should be particularly striking.

An examination of the geologic record discloses a set of phenomena which may be explained by such abnormal lunar tides. The tidal theory in fact seems to give a more logical, comprehensive explanation than the currently accepted theory which postulates a period of world-wide glaciation as the cause. The glacial theory has been questioned by competent geologists on entirely different grounds even though no satisfactory alternative has been provided. A critical examination of the facts is surely justified. This should be of a scope much broader than can be attempted in these few pages, which are merely intended to outline the problem.

The phenomena in question are those related to the Cambrian-Precambrian unconformity. This is the most striking and universal break in the succession of rocks covering the earth. The event which they represent has been used to divide the history of our planet into two unequal and contrasting parts. The continental nuclei at that time were largely stripped down to the crystalline basement. Ancient mountain systems were worn down to their roots, reducing the continents more nearly to a plain than they have ever been before or since, leaving a clean slate on which the record came to be written which is usually called historical geology.

The Infracambrian. The period of world-wide erosion immediately preceding the Cambrian was called the Lipalian interval by Walcott (1910), who found it a cause of wonder and speculation to account for the great difference between the rich fauna in the Cambrian and its near absence in older formations. He looked in vain for marine deposits of this period which would contain the evidence of faunas ancestral to Paleozoic life. The deposits of this period are plentiful but enigmatic, and strangely barren in organic remains.

Walcott's Lipalian interval was called Infracambrian by Pruvost (1951). The limits of this interval correspond in North America to the Beltian and Purcell orogenies of Eardley (1962). The lower limit is a profound unconformity and the upper limit is in most places either an unconformity or disconformity. In many parts of the world, especially in the interiors of the continents, the Infracambrian deposits are missing and the two unconformities combine as they do in the Grand Canyon area.

Pruvost suggests a date of 700 million years ago for the beginning of the Infracambrian. The end corresponds with the beginning of the Cambrian, now generally accepted as 600 or 630 million years before the present.

Character and Distribution of the Deposits. The Infracambrian formations present a unique combination of lithologic characteristics and infrared stratigraphic environments over their entire extent. The predominant type is a coarse, clastic, arkosic deposit which may be cross-bedded with alternating beds of siltstone and mudstone. The distinguishing characteristic is the presence of angular boulders and conglomerate layers in a poorly sorted matrix. In these characteristics they resemble ground moraine, fluvioglacial deposits, and boulder clay or tillite which are products of Pleistocene glaciers. For this reason they have been interpreted by Coleman (1926), Howell (1937), and others are representing an ancient widespread period of glaciation. This event is explained by Termier (1952) as having taken place between 700 and 680 million years ago.

Associated with these conglomerates and supposed tillites are limestones and dolomites of very substantial thickness, in some cases up to 10,000 feet. These carbonates are fine grained, often banded or ripple marked, with little evidence of organic remains except stromatolites (algae). They are inferred to be essentially chemical precipitates.

This association of coarse clastics, including inferred tillites, with carbonates is practically world-wide. Good descriptions will be found in Rodgers (1956), Haughton (1963), Furon (1963), and David (1950). They include the Hekla Hoek series in Spitsbergen, the Sparagmite in Norway, the Dalradian in Great Britain, the Tillite Canyon and Cape Oswald formations in Greenland, the Uluksan Group in the Canadian Arctic, the

McCoy Creek series in Nevada, the Ocoee series in Tennessee, the Bukoban and Uha systems in Tanganyika, the Kundelungu system in the Congo, the Sinian system in Siberia, the Kuken series in Korea, and the Marinoan series in Australia. In Asia we may add the Vindhyan system in the Himalayas described by Gansser (1964). In South America we have the supposed tillites of the Orapu system in French Guiana and Surinam traced by Choubert (1956), the Lavras and related series in eastern Brazil described by de Oliveira (1956) and in more detail by Guimaraes (1964). Some of these extend into Paraguay, eastern Bolivia, and northern Argentina.

Volume of Sediments. The significance of this Infracambrian period of erosion is readily apparent when an attempt is made to calculate the volume of the deposits, although at best this can only be expected to show the order of magnitude. In Africa, for example, these deposits extended from the Central African Republic to the Cape according to Furon. They originally must have covered an area of approximately 1,800,000 square miles. The measured thickness ranges from 10,000 to more than 15,000 feet. Considering that, in many cases, the base is not known and the top is unconformable, the average thickness as laid down may be close to the greater figure.

The area of Africa which was eroded to supply these sediments may have been 9,000,000 square miles, approximately five times the area of deposition, and the average thickness removed accordingly would be 3,000 feet. This is approximately equal to the average elevation of Africa above sea level, usually given as 2,500 feet.

In northwest Europe, the Caledonian geosyncline, in which the Infracambrian series were deposited, stretches 1,800 miles from Ireland to Spitsbergen. The width was probably 200 miles before the Caledonian folding, and the average thickness of Infracambrian may have been 15,000 feet. The total area of Europe is given as 3,750,000 square miles, about ten times the area of the Caledonian geosyncline. Assuming that all this area had been undergoing erosion, which is unlikely, the average thickness removed would be 1,500 feet which is somewhat more than the average elevation of Europe, given as 1,100 feet.

Similar calculations could be made for North America and Greenland. It may be sufficient to recall that Barrell (1925), speaking only of the Ocoee series, estimated that a volume of rock was eroded to supply these formations which was roughly equal to the volume of Sierra Nevada above the level of the sea. Adding the volumes of the rest of the Appalachian, Cordilleran, and Arctic geosynclinal deposits of this period makes it appear that the average thickness of rock eroded may have equalled the present average elevation of the North American Continent.

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UNCONFORMITIES IN THE SEDIMENTS OF THE INDIAN OCEAN

Davies, Thomas A., et al; *Nature*, 253:15-19, 1975.

Until recently it was believed that sedimentation in the deep oceans is essentially continuous. One of the more unexpected results of the Deep Sea Drilling Project (DSDP) has been the discovery of large gaps in the sedimentary record at many sites. Major hiatuses of regional significance have now been identified in the Atlantic, Caribbean, Pacific, Antarctic and Indian Oceans. Data from sites drilled on DSDP Legs 22-27 and part of 28 (Figs. omitted.) show that in the Indian Ocean gaps in the sedimentary record have been encountered in a broad spectrum of terrigenous, pelagic, biogenic and volcanogenic sediments encompassing late Mesozoic and Cainozoic time. The hiatuses were encountered at more than half the 48 sites and are developed on a wide variety of topographic features over a broad range of depths. They seem to show temporal groupings centred in the Oligocene, early Tertiary, and late Cretaceous.

Here we use the term unconformity to refer to a significant gap (demonstrated or inferred) in the stratigraphic record (disconformity or paraconformity). Unconformities are considered to represent active erosion or complete non-deposition of sediment. At many sites undated intervals were encountered, barren of microfossils, usually with a lithology of detrital or pelagic clay accompanied by zeolites and other indicators of extremely slow sedimentation. These intervals, which may be considered dissolution facies, represent slow sediment accumulation beneath the carbonate compensation depth (CCD). They may or may not contain unconformities, but this cannot easily be resolved because of the lack of biostratigraphic control. There is indirect evidence that in many cases the undated intervals do encompass unconformities.

The descriptions of unconformities from the results of some of the earlier legs of the drilling programme have been somewhat equivocal because of the often large unsampled intervals between cores. Fortunately, in the Indian Ocean programme, continuous coring or instances of greater than 50% coring were frequent. So we have considerably more confidence in recognising unconformities and in determining their extent. The Oligocene unconformity can be recognised with certainty at 15 of the 33 sites sampling that time interval and there is good evidence for its presence at 11 further sites making a total of 26 out of 33 sites. Corresponding figures for the early Tertiary and late Cretaceous unconformities are 18, maybe 27, out of 30 sites, and 9, maybe 13, out of 13 sites, respectively. It is clear, therefore, that these unconformities are of oceanwide significance. We believe that they can be explained as the consequence of climatic events in Antarctica and subsequent variations in the circulation pattern of the whole Indian Ocean.

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Significance of the Hiatuses. Attempts to explain the cause or causes of these hiatuses must consider numerous variables, including tectonism and continental drift, world climate, oceanic productivity, and oceanic circulation and oceanic chemistry, all of which are interrelated in a complex way. In perhaps the simplest cases (the early Tertiary unconformity on Broken Ridge (Site 255) and those near Owen Ridge (Sites 223 and 224)) the unconformities are clearly the result of tectonic uplift and subsequent erosion. On the other hand Kent has drawn attention to the fact that hiatuses in the sediments of the south-west Indian Ocean, while seemingly corresponding to tectonic events on land, are more likely to have been the results of variations in oceanic circulation and sediment supply rather than being directly attributable to tectonic events. The same may be said of the gaps found in the sedimentary record on the Naturaliste Plateau; for the sites in the deep basins remote from tectonic activity the links between hiatuses and such activity must be even more tenuous, if not non-existent. Even if we exclude locations for which there is a clear case for a tectonic origin for the unconformities, we are still left with the task of explaining the occurrence of oceanwide gaps in the sedimentary record. Recognising the limited data available and the complexity of the problem, we will limit our speculations to the Oligocene and early Tertiary hiatuses.

The following observations might be considered facts regarding these hiatuses which require explanation:

(1) Both hiatuses are expressed over a wide depth range.

(2) Well developed unconformities appear in the western Indian Ocean and south-west Pacific whereas undated intervals, probably containing unconformities, are more common in the eastern Indian Ocean.

(3) The early Tertiary and Oligocene hiatuses have similar regional extent in the Indian Ocean and south-west Pacific.

(4) The Oligocene hiatus is not found in the central Pacific as is the early Tertiary hiatus.

(5) The Oligocene unconformity in the Indian Ocean and south-west Pacific occurs in concert with high calcareous sedimentation rates in the South Atlantic and central Pacific.

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ARLINGTON UNCONFORMITY

Hares, C. J.; *Geological Society of America, Bulletin,* 49:1884, 1938.

Abstract. The normal stratigraphic section along the eastern foothills of the Medicine Bow Mountains, Wyoming, is absent because an unconformity cuts out 12,000 feet of beds, rather than that these beds are hidden by an overthrust fault as interpreted by former writers. It involves much older formations than the 20,000-foot unconformity beneath the "Upper Laramie" discovered in 1906 by Veatch in Carbon Basin.

The unconformity at the base of the Hanna (Eocene) formation, at the north end of the Bows, cuts into the Basement complex and ascends across formations to the Lewis shale (Cretaceous) at the south end.

The basal conglomerate, containing many quartzite, limestone, and crystalline boulders over 3 feet in size, forms a prominent wooded strike ridge along the foothills. The conglomerate dips normally 45 degrees eastward under the Laramie Plains. Significant mountainward remnants with some boulders over 12 feet in diameter, covering the highest divides except Snowy Range, the small central massif of the Bows, give an even greater areal extent for this unconformity.

Well-striated boulders beyond and higher than the Wisconsin terminal moraine occur 3 miles south of the Snowy Range, and, being on the highest divide, preclude Wisconsin age. More study of these is necessary to determine their age.

Coarse deposits occur 30 miles south of Snowy Range Cap Independence Mountain, North Park, Colorado, altitude 9600 feet, the most southeasterly peak of the Sierra Madras. Similar deposits should occur on the Front Range, Colorado.

This important unconformity with its abundantly preserved attendant

data indicates quite a different geologic history than previously assigned the Medicine Bow Mountains. It may bear significantly on the Cretaceous-Tertiary boundary.

"INVERTED" STRATA AND THRUST FAULTS

Whenever older rocks (as dated by contained fossils) are found resting upon younger rocks, geologists invoke the overthrust or low-angle thrust fault. When an overthrust occurs, nearly horizontal forces shove old strata over nearby young strata like so many playing cards. That this phenomenon has actually transpired frequently is proven by the existence of ground-up rock debris along the surface of contact in many thrust faults. Some "inverted" strata, however, show no signs of having been forcibly pushed many miles over high-friction surfaces. When thousands of square miles of rocks, thousands of feet thick, are shoved bodily for up to 50 miles, there should be ample evidence of motion. Indeed, the rock layers themselves might be expected to buckle. But they do not; and geologists are still unsure of the mechanism involved.

Scientific creationists have seized upon these poorly understood thrust faults as evidence of gross anomalies in the fossil record. No horizontal motion occurred, they say, the fossil time markers are in the order in which they were deposited. Progressive evolution is disproven. This is, of course, an extreme conclusion to base on a single class of observations. Nonetheless, major overthrusts in the American Rockies (particularly the Heart Mountain and Chief Mountain areas), Scotland, and Europe continue to confound geologists.

LOW-ANGLE FAULTING

Chamberlin, R. T., and Miller, W. Z.; *Journal of Geology,* 26:1-44, 1918.

Introduction. In the literature of structural geology it is commonly stated that rigid materials subjected to non-rotational strain tend to fracture along planes which are inclined approximately 45° to the direction of applied force. This conclusion has been developed partly from a mathematical analysis of stress and strain relations and partly from results observed in the familiar practice of crushing cubes of building stone to determine their strength. That 45° is the angle at which rigid materials normally fracture under direct compressive stress appears to be very generally accepted. This angle, therefore, has come to be regarded by structural geologists as the theoretical angle at which thrust faulting, under ordinary conditions, should occur.

But if the actual angles of dip of a large number of thrust-fault planes in the earth be tabulated and averaged, it is found that the mean inclination is less than 45° from the horizontal. According to Leith an average compiled from folios of the United States Geological Survey gives a dip of 36° for planes of thrust faults and 78° for planes of normal faults. An inspection of numerous cross-sections from various other countries gives results in fair agreement with these figures. The average dip angle of thrust-fault planes, as they occur in nature, is considerably less than 45°.

While the most prevalent type of thrust-fault plane, that of the ordinary reverse fault, dips somewhat less steeply than 45°, it still does not depart widely from that governing angle. Nevertheless, in notable variation from this, field studies in the last few years have brought to the attention of geologists impressive evidence of the prevalence and the great importance of what may well be called a different genus of fault, namely, the great low-angle overthrust. Its generic characteristics are the very low inclination of its fault plane and the extraordinary horizontal displacement often attained. Such low-angle overthrust faulting has been well described, as it is strikingly shown in the Northwest Highlands of Scotland, where the Moine, Ben More, Glencoul, and other remarkable thrusts form classic examples of the genus. In the extreme north of Sutherland the various rock groups overlying the Moine thrust plane can be shown to have been driven westward for a distance of ten miles. Horizontal shiftings of comparable magnitude occurred along the Ben More, Glencoul, and other planes of thrusting which lie beneath the Moine thrust and add to the remarkable nature of the phenomena. Though since thrown into gentle folds, in many places it is clear that these planes of slippage were originally not far from the horizontal. In some other portions of the British Isles analogous phenomena have been observed.

Similarly, in Scandinavia the very intense Caledonian deformation manifested itself in horizontal overthrusting of astonishing magnitude. The vertical displacement is slight, but the horizontal slip is measured in tens of kilometers.

In the southern Appalachian Mountains the Rome and Cartersville overthrusts run parallel to each other for over 200 miles. They are thought by Hayes to show horizontal displacement of not less than 4 miles and 11 miles respectively, and possibly much more. The inclination of the fault planes is here frequently as low as 5°; it is rarely more than 25°. The steeper portions of the plane as now seen are largely the result of subsequent warping. Farther north, in Tennessee, a possible continuation of the Cartersville thrust is the Buffalo Mountain fault which, according to Keith, was a low-angle overthrust whose original displacement along the shear plane was at least 20 miles. Subsequent folding and faulting have so disturbed this fault plane that its original inclination cannot be very closely determined.

More to the north, the earlier Taconic revolution also developed low-angle overthrusts. Of these may be noted the Great Western fault of eastern New York, the St. Lawrence and Champlain fault, which runs from Vermont to the city of Quebec and beyond, and possibly the Cowansville overthrust of Mississippi and Brome counties, Quebec, though the age of the last has not been closely determined as yet. In any case the measured horizontal displacement of the last is 11 miles, and it is thought likely that the actual displacement was much greater. It is a nearly horizontal overthrust, whose plane is very close to the present surface, and along which the Georgian slates on the east have been shoved over the Trenton slates and limestones of the Farnham series to the west.

The Rocky Mountains of Montana and Alberta are bordered on their eastern front, throughout at least 350 miles of their extent, by great overthrusts whose planes dip in under the mountains at low angles. McConnell has estimated that on the South Fork of the Short River in Alberta the horizontal displacement of the Cambrian strata---which here rest upon the Cretaceous---has been about 7 miles, while the vertical displacement amounts approximately to 15,000 feet.

In the Glacier National Park of Montana, Willis found the Proterozoic strata which make up the outermost range (here called the Lewis Range) overthrust at least 7 miles upon the Cretaceous of the foothills. The dip of the thrust plane, as determined by Willis by graphic construction, ranges from 3^{o} to 7^{o} 45'. More recently Campbell has been able to show that where the Great Northern Railroad crosses the range this great mass of strata has been shoved at least 15 miles northeastward along the Lewis thrust plane, and were the original position of the mountain mass known the distance might prove to be much greater.

At the International Boundary the northward continuation of the Lewis thrust has been termed the Waterton Lake thrust by Daly. The known extent of the bodily movement here represented is about 8 miles, as measured on the perpendicular to the line tangent to Chief Mountain and the outermost mountains of the Clarke Range. But the actual movement, according to Daly, has probably been 10 miles or more, and may be as much as 40 miles, for "it is not impossible that the entire Clarke Range (the equivalent of the Livingston Range of Willis) in this region represents a gigantic block loosened from its ancient foundations, like the Mount Wilson or Chief Mountain massifs, and bodily forced over the Cretaceous or Carboniferous formations."

The Willard thrust discovered by Blackwelder in the Wasatch Mountains of Utah has a displacement, so far as exposed, of about 4 miles, though this is probably but a small fraction of its total displacement. Though the fault plane locally has a dip as high as 50^{o} owing to later warping, it averages about 15^{o}.

The Bannock overthrust, recently described by Richards and Mansfield, when traced through southeastern Idaho and Utah along its course, now made sinuous by erosion, has a length of approximately 270 miles, and involves a horizontal displacement of not less than 12 miles. The thrust plane itself is a gently undulating surface nowhere steeply inclined, sometimes dipping to the east and sometimes to the west. If this slight plication be the result of subsequent folding, the shear plane must originally have been very nearly horizontal.

In eastern Wyoming the Absaroka and Darby faults are really of the overthrust variety, although what remains of these planes shows a higher angle of inclination than most of the preceding. The fault plane of the Darby thrust is, in general, not far from parallel to the bedding of the overthrust sheet. East of Yellowstone National Park the Hart Mountain overthrust is thought by Dake to show a displacement of not less than 22 miles, making no allowance for recession of the eastern front by erosion. Assuming average thickness for the beds involved, the vertical displacement is over 6,000 feet.

In the Alps, so long and carefully studied, some of the most remarkable structures known to geologists are still in process of being worked out. As yet there is lack of perfect accord as to some of the features of their interpretation. They have commonly been interpreted as extraordinary and wonderfully drawn-out overfolds (nappes de recouvrement). Among certain geologists there has developed a disposition to substitute, in interpretation, overthrust sheets of the Scottish Highland type for these extreme overfolds. If this be the true explanation, it would add to our list this remarkable structure of the Alps as a most pronounced and complicated case of low-angle faulting.

Similar structures have been reported from Spain, Euboea, the Balkans, and the island of Timor; in the last case an extensive sheet of shallow water strata, ranging in age from Triassic to Eocene, has been thrust over what appear to be deep-sea deposits of nearly the same age.

Detailed studies elsewhere---practically the world over, indeed---are bringing to light overthrust faults of great displacement along gently inclined planes. This sort of faulting seems, therefore, to constitute a phenomenon of a definite, independent type. It seems to belong to a genus of its own, distinct from the ordinary reverse fault, though the two are no doubt connected by composite types that bind them together. The common reverse fault is defined by displacement along planes neighboring 45^{o} or a little less, and is confined to more limited movement on these planes, while the great overthrusts slide along planes that approach horizontality and involve displacement of astonishing magnitude. Though each great low-angle overthrust is commonly attended by a retinue of reverse faults of lesser magnitude---a fact which suggests that there may be a kinship between them---nevertheless an inspection of any good section, as in the Scottish Highlands, shows a radical difference between the two types. Some distinctive feature seems to be added to simple straight compression to form the low-angle overthrusts. (pp. 2-7)

• The Appalachian Thrust Faults

THIN VIEW OF APPALACHIAN FORMATION

Anonymous; *Science News*, 115:374, 1979.

Old theories often fall to new technology. In a recent example, reported at the AGU meeting, a powerful tool called deep seismic reflection profiling may have overthrown current beliefs about the formation of the Appalachian Mountains. The Appalachians, which run from Newfoundland to Alabama, were probably formed not by upward thrusting, as previously believed, but by a thick conglomerate of oceanic and continental rock that was shoved horizontally at least 250 kilometers over existing sediments, according to researchers from Cornell University and Florida State University.

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The Tennessee-Georgia profile shows, as expected, that the upper 6 to 10 km of the crust is made of fragments of ocean floor, parts of island arcs and continental rock. But beneath that jumble of rock, says Cook, lies a younger, flat, thin (1 to 5 km thick) layer of sediments that "no one thought existed." The unbroken, wide extent of the layer---researchers estimate it covers 150,000 km^2 from near the coastal plain to the western edge of the Blue Ridge---and its similarity to sediments found on the East Coast indicate that the mountains "couldn't have been pushed up." More likely, the researchers suggest, the accordion-like conglomeration of rocks was bulldozed over the younger sediments by repeated collisions of Africa and North America between 450 million and 250 million years ago.

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• The Heart Mountain Problem and The Lewis Overthrust

HEART MOUNTAIN AND SOUTH FORK DETACHMENT THRUSTS OF WYOMING

Pierce, William G.; *American Association of Petroleum Geologists, Bulletin,* 41:591-626, 1957.

[The famous Heart Mountain thrust fault in Wyoming has perplexed geologists for many years. The following excerpts from Pierce's paper describe the fault (if that is truly what it is) and illustrate the difficulties encountered in trying to find conventional explanations]

Abstract. In broad outline the Heart Mountain fault of Wyoming is a nearly horizontal thrust whose overriding sheet was derived from a source without any known roots, and whose frontal part has ridden across a former land surface. The suggestion is here made that this thrust and the near-by South Fork thrust are detachment thrusts or decollements, that is, they are sheets of sedimentary rocks which have broken loose along a basal shearing plane, have moved long distances probably by gravitational gliding, and have been deformed independently from the rocks below the fault plane.

The present remnants of the Heart Mountain thrust sheet include more than 50 separate blocks which range in size from a few hundred feet to 5 miles across and which are scattered over a triangular area 30 miles wide and 60 miles long. The rock formations represented in the thrust blocks comprise a very limited stratigraphic range, none being older than the Bighorn dolomite (Ordovician) and none younger than the Madison limestone (Mississippian). The maximum stratigraphic thickness of the formations involved is 1,800 feet, but these include the most competent group of beds in the sedimentary sequence in this area.

In the northwestern part of its known extent the Heart Mountain thrust plane follows the bedding of the rocks and lies at the base of the massive and resistant Bighorn dolomite and above the underlying Grove Creek for-

mation (a thin unit at the top of the Cambrian sequence). Near the center of the area here described this bedding thrust plane changes abruptly to a shear plane that cuts stratigraphically upward across the Bighorn and younger formations; the thrust plane then passes south-eastward onto and across a former land surface. The present thrust remnants on this surface are separated blocks that rest on rocks ranging in age from Paleozoic to Tertiary.

In the area of the bedding thrust the displaced sheet was broken into numerous blocks which became detached from one another by movement, with large spaces or gaps separating them. Thus by tectonic denudation the thrust plane was exposed at the surface. Associated with the events accompanying the thrusting was the rapid formation of a stream channel deposit, here named the Crandall conglomerate. Next there followed the deposition of the "early basic breccia." This blanket is volcanic rock, which is now in the process of being eroded, has preserved much of the geologic record pertaining to the development of the Heart Mountain thrust since middle Eocene time.

The concept is here advanced that, near the close of early Eocene time, the Heart Mountain thrust originated as a detachment or shearing-off of strata at the base of the Bighorn dolomite. Near Dead Indian Hill the advancing southeastern edge of this bedding thrust sheet passed upward into a shear thrust and thence southeastward onto and across the land surface as an erosion thrust.

The South Fork thrust sheet, which underlies and is slightly older than the Heart Mountain thrust sheet, likewise has the character of a detachment thrust in that the plane of the thrust sheet extends downward to a stratigraphic horizon in the Sundance formation, but goes no farther. In three test wells which started in the South Fork thrust sheet, the plane of the thrust was found at depths of 550 to 1,040 feet, and the beds below are essentially undeformed.

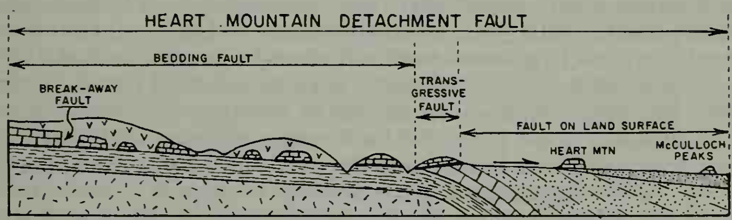
Characteristic features of the South Fork thrust mass, which suggest a detachment thrust (decollement), are: (1) tightly folded anticlines and synclines and overturned, recumbent, and faulted folds; (2) the base of the thrust mass is in most places at or near a stratigraphic horizon: (3) so far as known, it has no "roots" from which it could have come as a deep-seated thrust; (4) the thrust mass contains no rocks from below the plane of detachment. Although the South Fork thrust mass reacted to deformation quite differently from the Heart Mountain thrust blocks, the differences are readily accounted for by the great lithologic differences of the rocks of the two sheets.

To test further the proposed interpretation for the Heart Mountain and South Fork thrusts, additional field observations should be made to shed more light on the mechanics of the deformation.

Introduction. The writer first began field work in the region of the Heart Mountain and South Fork thrusts in 1935. Detailed field mapping on a scale of 1:31, 680 was undertaken, and the work was continued through four succeeding field seasons. The war years then intervened and it was not until 1950 that work was resumed briefly in the area, followed by field work during parts of the summers of 1952, 1953, 1955, and 1956. The present paper presents the structural data bearing on the problem of these two thrusts, obtained during those ten seasons or partial seasons of field mapping.

The Heart Mountain thrust has long been structurally perplexing because there are no known structural roots or source from which it could have been derived. If the thrust had roots and originated as a deep-seated fault in the basement rocks some Precambrian and Cambrian rocks should occur in the thrust sheet, but thus far none has been found. Furthermore, there is no known surface fault or fault zone within or adjoining the region from which the thrust sheet could have been derived, although the possibility can not be eliminated that such a zone exists but is entirely concealed by the volcanic rocks in the Absaroka region.

In broad outline, the structural features of the Heart Mountain thrust are those of a nearly horizontal thrust fault, which in its frontal part has ridden out upon an erosion surface. It has long been recognized, however, that this fault has uncommon features which can not be accounted for by the tectonic movements ordinarily accompanying low-angle thrust faulting. The features which have been observed seem to fit into the structural pattern of a detachment thrust or decollement similar in certain respects to the Jura Mountains of Switzerland. The term decollement (or a shearing-off) as applied by Buxtorf (1916) in the Juras refers to a kind of folding in which a sheet of sedimentary rocks has broken loose or become unglued from the underlying formations and folded independently. The rocks composing the South Fork thrust have folded independently from the underlying beds and thus resemble in that unusual aspect the results of Jura-type tectonics.



The rocks composing the Heart Mountain thrust blocks are not folded but the same basic principle seems applicable, namely, that a sheet of sedimentary rocks has broken loose from the underlying formations and moved independently. Hence, they also are considered as a detachment (decollement).

The term "thrust" as used here is applied without genetic connotation to low-angle faults in which the major component of movement is horizontal in the upper block. Detachment fault, or "detachment along a basal shearing-plane", is a more applicable designation in the genetic sense.

Heart Mountain Thrust. Areal extent.---Remnants of the Heart Mountain thrust occur over a triangular area, about 30 miles wide and 60 miles long, with the apex of the triangle near the northeast corner of Yellowstone Park. The easternmost remnants are at McCulloch Peaks, the southwesternmost are in the vicinity of Sheep Mountain, and the northwesternmost remnants which have been mapped are near Pilot and Index peaks, although reconnaissance examination indicates additional extension to the northwest. About 50 separate blocks have been mapped, ranging in size from blocks only a few hundred feet across to large masses 4-5 miles across.

Rocks composing thrust blocks.---The formations represented in the Heart Mountain thrust blocks cover a very limited stratigraphic range, consisting of Bighorn dolomite, of Ordovician age, Jefferson dolomite and Three Forks shale, of Devonian age, and Madison limestone, of Mississippian age. They have a total stratigraphic thickness of 1,500-1,800 feet. In terms of strength and rigidity, however, they are the most competent group of beds in the entire sedimentary sequence. The Madison, Jefferson, and Bighorn formations are composed almost entirely of limestone and dolomite, largely in massive and resistant beds. Less than 150 feet of the entire sequence is shale, and this occurs mostly in the Three Forks formation. The lower 100 feet or more of the Bighorn dolomite is the most massive and resistant unit in the section.

The rocks in the thrust blocks are cut by a number of high-angle faults. Some of these faults are shown on the map but many can not be shown because of the small scale of the map. Presumably it was movement along these faults, in part at least, which produced angular discordance between the beds above the thrust and those below. Such discordance is observable at many places in the region west and northwest of Dead Indian Hill. Although the normal sequence of the beds above the Heart Mountain thrust, in ascending order, is Bighorn, Jefferson, Three Forks, and Madison formations, in many places this sequence is broken, and one or more of the lower formations may be absent. At Sugarloaf Mountain, for example, Bighorn dolomite forms the base of the thrust block on the north (upper right), but on the south (upper left), the Jefferson dolomite forms the base of the thrust block. Still greater stratigraphic displacement is shown at "Steamboat", where in places Madison limestone forms the base of the thrust. On the north side of the North Fork of Crandall Creek, both faulted and fractured and massive blocks of Madison limestone form the base of the thrust. Were it not for the broken sequence and absence of some formations at places such as these just mentioned, the presence of a fault might not be recognized in the northwestern part of the area. An unusual structural problem, to be discussed later, is posed by this relationship whereby the Bighorn, Jefferson, and Three Forks formations are faulted out of the section. As a generalization with several exceptions, a "normal" section with Bighorn dolomite at the base of the thrust block more commonly occurs where the thrust block is less broken by high-angle faults. The smaller thrust blocks, measuring a few hundred feet across or less, are most commonly Madison limestone.

Tripartite nature of thrust.---The Heart Mountain thrust embodies three types of thrusts: a bedding thrust, a shear thrust (or initial shear thrust), and an erosion thrust (or surface thrust). From the northwest corner of the mapped area southeastward to Dead Indian Creek it is a bedding thrust in which the fault plane follows a very restricted stratigraphic interval---approximately the base of the Bighorn dolomite---and throughout that area the thrust blocks rest on the Grove Creek formation which is at the top of the Cambrian shale and limestone sequence. Between Dead Indian Creek and Dead Indian Hill, the Heart Mountain fault passes from a bedding thrust to a shear thrust, and the rocks underlying the thrust range upward through the stratigraphic succession from Bighorn dolomite through the Jefferson and Three Forks formations to the Madison limestone. From Dead Indian Hill southeastward it is an erosion thrust, in which the thrust blocks moved over a former land surface, and rest on rocks ranging in age from Paleozoic to Tertiary. a view of two types of the thrust, that is, the bedding and shear thrusts, is shown in Figure 5, in a view looking northward down Dead Indian Creek along the zone of shear thrusting. (Figs. omitted.)

The fault contact or fault plane is usually concealed or at best is poorly exposed where it is an erosion thrust or a shear thrust, but the bedding thrust contact is well exposed in places. The fault contact of the bedding thrust may either be clean-cut and sharp, with essentially no brecciation of the beds above or below the fault, as observed at several places, or it may have a zone of broken limestone and limestone debris, such as observed at the northwest end of Sugarloaf Mountain. There the broken limestone zone is about 30 feet thick; its lower contact with the Grove Creek formation is sharp, but its upper contact is indistinct.

[In other words, there is little evidence of sliding of one huge rock mass over another.]

Structural interpretation. As can be seen from the preceding description, the Heart Mountain thrust is an exceptional feature in several respects, and to account for it requires some new and perhaps unorthodox reasoning and deductions. These might be best presented by first considering the geologic setting at the time of thrusting.

As deduced from the gragments in the Crandall conglomerate, the area encompassed by the bedding thrust had been eroded down to the upper part of the Madison limestone, which formed an immense dip slope, inclined in general toward the southeast. On the northeast, erosion had removed much of the Madison and older sedimentary rocks and in places had reached the Precambrian granitic rocks in the Beartooth uplift. On the east the sedimentary rocks dipped eastward into the Bighorn basin, and successively younger rocks were exposed at the surface farther eastward. The fault and uplift along the eastern edge of the Beartooth Mountains were already of large proportion, as revealed by the record of early Eocene sedimentation. None of the volcanic outpouring of the "early basic breccia" had yet taken place, nor was there to be any until after the emplacement of the Heart Mountain thrust blocks.

It is believed that the areal relationships which have been determined by detailed geologic mapping show that the Heart Mountain thrust consists of three parts: (1) a bedding thrust in the northwestern part of the area that extends southeastward to the vicinity of Dead Indian Creek, where (2) it passes into a shear thrust which rises steeply southeast and emerges along a line extending southwest from Dead Indian Hill, and (3) from this line of emergence it becomes an erosion thrust, wherein the fault blocks continued to move generally southeast.

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This picture of fault blocks, separated in some as yet undetermined manner, with the fault plane exposed only briefly in the areas between the fault blocks, seems fantastic if not impossible, but there are several lines of evidence that point to it; if this concept is discarded, several unusual features must be explained, of which the following are particularly significant.

1. What kind of surface does the "early basic breccia" rest on where it is in contact with the Grove Creek formation? In the area of the Heart Mountain bedding thrust are large areas where the volcanic breccia is in

contact with a stratigraphic plane yet this contact horizon can not logically be considered an erosion surface or a plane of intrusion. If it is interpreted as a fault contact, in which both the Heart Mountain thrust blocks and the "early basic breccia" have moved as a unit as postulated by Hares, one would expect an occasional fragment of volcanic rock along the fault contact between the Grove Creek and the overlying thrust blocks of limestone, but such evidence has not been found.

2. A mechanism or process is needed for displacing the sedimentary strata which normally overlie the Grove Creek formation and substituting the "early basic breccia." It is difficult to see how this could be accomplished by fault movement of a blanketing deposit of "early basic breccia," but if it could, and the sedimentary rocks above the Grove Creek limestone and the "early basic breccia" were faulted at the same time as a combined unit, the two units should be intermingled, with fault contacts between them. The areal distribution or relation of units that should prevail if there was such faulting does not occur. The areal pattern exemplified in Figures 7, 9, and 12 seems to require a sequential arrangement whereby a "void" or "tectonically denuded" space is created first.

3. The numerous occurrences of Madison limestone resting on the Grove Creek obviously represent a fault contact, with Three Forks, Jefferson, and Bighorn formations cut out by faulting. What kind of fault movement can be invoked to account for these occurrences? The thrusting of younger beds on older strata is the unusual relationship, in contrast to the common relationship of older beds thrust on younger strata. A method whereby blocks of Madison limestone can here and there be thrust down onto the Grove Creek between fault blocks of Bighorn and Jefferson formations resting on Grove Creek, becomes most difficult if not impossible to explain as long as the fault blocks are in tight lateral contact with one another. However, if the fault blocks become separated, younger rocks from the upper part of a fault block---for example, the Madison limestone---might then move along a previously developed shear or fracture and slide down into the space between fault blocks and come to rest on the Grove Creek formation. The process whereby younger beds could be placed in fault contact with older beds is shown diagrammatically in Figure 19. (Figs. omitted.)

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HEART MOUNTAIN REVISITED

Burdick, Clifford L.; *Creation Research Society Quarterly,* 13:207-210, 1977.

Abstract. At the Heart Mountain formation, Wyoming, and at other places, strata are in the wrong order, according to the uniformitarian view, supposedly older rocks being on top of supposedly younger ones. Such formations have been ascribed to the overthrusting of older rock over the younger. However, at many of these formations, including Heart Mountain, there is no physical evidence for such sliding; nor is there any proof that such motion is mechanically possible. Some recent investigation has again failed to provide any evidence that Heart Mountain was overthrusted; but there is evidence that a normal vertical fault was involved.

Introduction. Structural geologists have long recognized low-angle faults or thrust faults as one of the effects of tectonic activity in the crust of the earth, along with normal faults and strike-slip faults.

Regardless of the type of fault, where there has been differential movement along a fault plane, there is bound to be a grinding action, as is the case with the plates of any mill. Contact metamorphism may be one effect, especially where heat and pressure are involved. Other physical criteria resulting are:

1) Ground up rock, or mylonite, a layer between the moving blocks.
2) Tectonic breccia, or large fragments of broken, angular rock.
3) Slickensides, or fluting or grooves where the rough or angular projections have grooved the other plate.

Some early paleontologists were not well versed in structural geology and were inclined to ignore structure. They believed that the fossil evidence was so overwhelming that it was a waste of time to check the physical criteria; and, as one paleontologist put it:

> It may even be said that in any case where there appears to be a clear and decisive discordance between the physical and the paleontological evidence as to the age of a given series of beds, it is the former that is to be distrusted rather than the latter.[1]

What a strange infatuation with deductive reasoning as against inductive reasoning---pitting an unprovable hypothesis against field evidence! Sir Archibald Geikie,[2] one time director of the Geological Survey of Great Britain, described the so-called overthrusts of the Alps:

"The strata could scarcely be supposed to have been really inverted, save for the evidence as to their true order of succession supplied by their included fossils."

It is with this thought in mind that so-called overthrusts or low-angle faults should be examined. It is not maintained that all such structures are misnamed; but one should be on guard to examine all cases critically, to see if the physical evidence, mylonite, tectonic breccia, and slickensides along the thrust contact accompany the fossil evidence.

It is not denied that some actual overthrusts have all the physical criteria of thrusts---such structures do exist.

<u>The Heart Mountain Thrust</u>. I have spent some time in the field in northwest Wyoming examining the so-called Heart Mountain Thrust, a few miles north of Cody, Wyoming. This is an isolated capping of Madison (Mississippian) limestone.

William G. Pierce[3] of the U.S. Geological Survey has written up the Cathedral Cliffs formation. He imagined igneous rocks moving on the Madison limestone as it was supposedly thrust southeastward by the Heart Mountain detachment fault which scattered isolated blocks of Madison limestone for many miles in northwest Wyoming. Pierce has also written concerning the Heart Mountain thrust.

This thrust movement is supposed to have taken place in Eocene time, along a nearly horizontal surface; whether as a compressional thrust or as a gravitational slide is not clear, although the mechanics of either is still more obscure. Geological maps show the Heart Mountain Madison limestone resting on Tertiary limestone or dolomite. In other blocks it rests on Cambrian Grove Creek formation, the intervening Devonia, Silurian, and Ordovician formations being missing.

If the missing formations are the only criteria for calling Heart Mountain a thrust, then by the same token the Mississippian Redwall formation in the Grand Canyon could be called a thrust, though I have never heard it so called. In the case of the Grand Canyon, in most places along the trails the Redwall rests directly on the Cambrian, the intervening Devonian, Silurian, and Ordovician being missing.

Some geologists interpret the Heart Mountain structure with several missing formations as a case of gravitational gliding, where the Mississippian formations erased the intervening Devonian, Silurian and Ordovician formations, and left the Madison resting directly on the Cambrian or Tertiary as the case may be. But just as at the Grand Canyon that explanation just does not fit the case; for not a sliver of the intervening formations remain. The contact seems conformable; that is, a normal sedimentary contact in the case of Heart Mountain or the Grand Canyon.

Window Rock, Arizona. In the Window Rock area of Eastern Arizona, there is a still more anomalous contact; this time the Permian Supai formation rests on the Older Precambrian, Archeozoic quartzite. The standard explanation is that for a billion years or so the area was just enough above water to avoid both deposition and erosion.

This would appear to be a far-fetched explanation at best; for Twenhofel[4] has said that the crust of the earth is never really at rest for very long. At Glen Rose, Texas along the Paluxy river about 20 years ago I photographed some perfect dinosaur tracks. When I attempted to rephotograph the same tracks, they had been eroded away.

Difficulties with the Motion of Thrusts. A major objection to both the thrust and gravitational gliding theories is that the thrust contact is practically level; also there is no down grade to explain the gliding, nor rock competency sufficient to allow pushing these blocks over long distances without fracturing and making breccia and rubble. Furthermore, no source has been found from where such a thrust could have started. Authorities readily admit such deficiencies in the whole thrust hypothesis. They seem unable to visualize that the defect is in the fossil sequence dogma rather than in rock structure.

Isolated blocks of Mississippian Madison limestone are scattered over many miles of northwest Wyoming. According to Pierce[5], "Were it not for the absence of some formations the presence of a fault might not be recognized."

This is tantamount to an admission that a principal basis of designating this structure as a thrust is the absence of intervening formations. If that is a valid argument, then most of Arizona is a giant thrust, for in most of that state the Ordovician and Silurian rock formations are missing.

This is a monument to the power of "a priori" reasoning; as if the evolutionary order of the fossils in the rocks were as well established as the law of gravitation.

Pierce also observed:

> In most places the fault contact is concealed or poorly exposed; but where visible is clean-cut and sharp, with no brecciation of beds above or below...the lower contact with the Grove Creek formation is also sharp.[6]

Here also is a repetition, apparently, of the Lewis overthrust contact in Montana and Canada---where good exposures can be found they are usually sharp. Apparently these criteria meant little to the paleontologists of former years, before the impact of structural geology. Now it is recognized that such a major tectonic event as a giant overthrust should exhibit such structural or mechanical evidence as tectonic breccia, mylonite, or ground up rock, and slickensides. Along the contacts of all true overthrusts that the writer has observed, these criteria are evident.

How Could a Thrust Break Up into Blocks? Pierce also described the Heart Mountain thrust as involving many miles of rock movement, because it is now separated into some 50 blocks of lower Paleozoic limestone scattered over a triangular area of 30 by 60 miles. The Ordovician is represented by the Bighorn dolomite, and the Mississippian by the Madison limestone, measuring up to 1800 feet in thickness. In most places the thrust block rests on Tertiary rock.

Pierce seemed to think that the blocks became detached by movement. However, it seems a bit anomalous for a thrust block to move when the elements of the thrust block were separated by such great distances. For example the Heart Mountain thrust block is isolated many miles from the nearest like block on McCullouch peak many miles to the east.

In places the Paleozoic thrust block is covered with what geologists call the "early basic breccia"; in other words a volcanic rock, now being eroded. Another puzzle to geologists is that no volcanic fragments have been found between the thrust block and the lower Grove Creek (Cambrian). This is strange if the volcanics had been laid down before the thrust action, which is assumed to have taken place in Eocene time.

Bucher enumerated the many problems of the so-called Heart Mountain Fault:

> There are no known roots for this thrust, no known surface from which it could have been derived. Like the Juras in the Alps, a decollement? This fault has uncommon features not accounted for by tectonic movement accompanying low-angle faults.

As already mentioned the absence of the Bighorn, Jefferson, and Three Forks formation, which should lie between the Madison and the Grove Creek formations, seem to indicate to some stratigraphers the presence of a thrust or a glide block, as the only possible explanation for the absence of the missing formations. But this seems to be a very weak form of reasoning. Would it not be a more logical explanation to call in question for veracity of the must order of the fossils, that is, the assumed evolutionary order?

According to accepted reasoning, one would have to multiply many times the number of thrust or low-angle faults in the world; for there are numerous cases of missing formations or periods in the world. The Grand Canyon and the Window Rock exposures have already been mentioned.

Recent Observations at Heart Mountain. So far the task has been that of assembling geologic data compiled by other geologists, whose consensus has been that Heart Mountain is an isolated thrust plate, separated from other sections of the same overall thrust by miles. Most geologists have readily admitted the field difficulties with such a concept, but they still cling to the thrust theory on account of the fossil evidence.

Now it is urged that the time is long overdue to take into account also the structural evidence. In the case of Heart Mountain the evidence does not uphold the thrust concept, nor is there any credible support for the idea of gravitational gliding; for a sloping gliding surface is lacking.

Actually the whole area has been severely folded and deformed. Following the strata westward and to the northwest, one finds the underlying beds dipping around 10 degrees on average to the east and southeast, dipping away from the Absaroka mountain range along the east border of the Yellowstone Park.

This places the capping strata on Heart Mountain much higher stratigraphically than equivalent limestone to the west. Remember Pierce called this the Cathedral Cliffs formation and, although he placed it on top of the Madison, he believes that the formation moved along with the thrust.

Southwest of and adjacent to Heart Mountain the strata have been so severely deformed that in places they rest on edge. Due to heavy rock slides and fragmentation, the contact of the Madison on Heart Mountain with underlying beds is covered. However, I found one place, on an exposed salient at the west end of the mountain where the contact was nearly visible; except again the limestone rubble covered the actual contact.

Some geologists, I understand, have interpreted the limestone rubble as tectonic breccia, caused by thrust movement. However, this particular rubble is no different from the erosional rubble all around the steep sides of the mountain. Where the underlying sandstone was exposed it did not show brecciation or mylonite.

The so-called Madison thrust plate in more nearly horizontal than the underlying beds, indicating evidently that that formation was deposited more recently on a truncated surface of the lower beds. This is evidence against the thrust mechanism imagined.

<u>Evidence that Heart Mountain is a Normal Fault</u>. There is decided evidence of fault action at Heart Mountain, but it involves normal fault action rather than thrusting. Approaching Heart Mountain from the south one climbs a long limestone stratum that dips away from the mountain, toward the south; whereas the north side of the mountain has beds that dip the other way, to the north. This began to arouse suspicions that perhaps after all what is involved is not a thrust fault, but a normal fault, a fracture along the apex of an anticlinal fold, a very common occurrence.

In an anticlinal fold there probably was compression throughout most of the fold, except at the top of the anticline, where in fact there would be tension, resulting in a fracture along the roof of the anticline. Before the fracture took place, however, the greatest tension would have been at the top surface of the fold. Deeper down, conversely, pressure would have compressed the plastic rock, forming a sort of a vertical, longitudinal layer of rock. (I have seen this structure in many fractured anticlines, especially in freshly extruded basalt, which cracks along the top of a lava flow. An example is in the Craters of the Moon volcanic field in Idaho.)

This fracture along the apex of the Heart Mountain fault has been filled with alluvium. I looked for tell-tale evidences of vertical dike or rock slab. I found such evidence in quantity, rather close to the nearly vertical southern escarpment of the Madison formation. This just about settled the issue with me. Here is a normal or vertical fault rather than a thrust fault.

Often with a normal or vertical fault, one side moves vertically with reference to the other side, causing the edges of the strata on one side to dip up, while the other move up. I think this is the case with the Madison cap rock or strata, on top of the Heart Mountain.

The southern lip of the exposed Madison limestone dips upward at about 10 degrees, whereas the same stratum levels off to about five degrees some distance from the edge. This is more evidence of a normal fault rather than a thrust fault; although both could be admitted if the evidence warranted such a conclusion.

In conclusion I would discount the popular idea of thrust faulting at Heart Mountain, but would interpret the formation as a normal fault at the apex of an anticline.

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THE LEWIS OVERTHRUST

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Lewis Thrust Fault. This is one of the largest overthrusts in the United States; however, not all of it is contained in this country for it extends northward into Canada some 300 miles. The southern exposure is well seen along the eastern front of the Lewis range in Glacier Park. The cap rock in Glacier Park is classified as Precambrian, or the Belt Series, composed of several formations such as Kintla, Sheppard, Siyeh, Grinnell, Applekunny and Altyn.

The Altyn formation is the oldest of the Belt series, and lies at the bottom of the Belt, unconformably on the Cretaceous shale. It is a sandy dolomite with a light buff color; average thickness is 2,300 feet. On top of the Altyn lies some 3,000 feet of Applekunny green argillites. Mud cracks and ripple marks are common.

Because of their predominantly red color, the Grinnell argillites are the most conspicuous rocks in the park. This formation is also about 3,000 feet thick. Next above comes the Siyeh buff-colored limestone some 4,000 feet thick, the greatest cliff-former in the park. The Sheppard formation weathers yellow-brown, indicating ample iron, and is some hundreds of feet thick. The Kintla is another red formation and is seen only on top of the highest peaks. Purcell lava and a diorite sill form black bands around the park.

Characteristic fossils of the Belt series are various species of algae, very prominent along the highway west of Logan's pass. In fact the presence of these fossils is the main reason that the Belt series of rocks are designated as Precambrian.

Predominant algae fossils of the Belt series are Collenia, Conophyton, and Cryptozoon. They bear a crude resemblance to the head of a cabbage. They are found in colonies especially in the Siyeh formation.

The Cretaceous shales and sandstones below the Belt series contain shells such as oysters and ammonites, index fossils for that period. We were able to dig out some of these fossils along Roes creek, near the Rising Sun campground on the west bank of St. Mary's Lake, a finger lake apparently gouged out by glaciers.

The dip of the presumed fault is very gentle, anywhere from nearly horizontal to 10 degrees. However, on Marias pass the dip steepens to almost 40 degrees. Actually the fault can be traced almost 100 miles south of the park.

To give a better background of the way orthodox geology explains the Lewis Overthrust, I quote excerpts from The Geologic Story of Glacier National Park by James L. Dyson, head of the Dept. of Geology of Lafayette College. He was a ranger-naturalist at Glacier Park for eight years.

> Toward the end of Cretaceous time tremendous crustal forces, principally from the west, were directed against the geosyncline with the result that its rocks were compressed and uplifted, converting the site of the former sea into a mountainous region....Similar activity resulted in the formation of the Rocky Mountain system stretching from Mexico to Alaska....Mountain building forces continued for several million years in the Glacier Park area, finally squeezing the rocks into a great fold (anticline). Continued pressure from the west overturned the fold and put additional strain on rock layers, eventually causing them to break along a great low-angle fault. The Western limb of the fold, now a great slice of the crust, was driven upward and eastward over the eastern limb, ultimately reversing the order of rock layers by placing older on top of younger ones....These younger layers are Cretaceous shales and sandstones underlying the plains immediately east of the mountains. The mountains themselves have been carved by streams and glaciers from the Belt formations comprising the upper block of older rock, that slice of the crust which has been moved more than 20 miles toward the east....The Lewis Overthrust comes to the surface at the base of the Altyn formation along the entire precipitious east front of the Lewis Range and can be traced nearly 100 miles northward into Canada and almost an equal distance south of the park. Within the park it is tilted very gently toward the southwest, the angle of dip seldom exceeding 10 degrees....And so we see that the mountains of Glacier National Park, unlike many of the world's great ranges, have no roots, for they rest on a base of greatly different and much less resistant material, the Cretaceous shales. Cretaceous rocks with relatively low resistance to Earth stresses, were strongly crumpled and folded during the period of overthrusting.

The Lewis Overthrust is exposed in a great number of places, but only a few are readily accessible for observation. I started my study at the Marias Pass exposure on Summit Mountain, in the southern end of the park. Here the exposure plainly belies the above quotation that the soft Cretaceous shales are folded and crumpled. Contact with the overlying Belt series shows a remarkably straight even surface. If this had in fact been a thrust plane, the soft Cretaceous shale would have been deformed, folded, even metamorphosed. But the Altyn limestone rests without apparent movement on the shale.

Contact between the Precambrian Belt Altyn and the overlying red Grinnell is another story however. There is a marked unconformity between the two formations. The altyn has been eroded and gullied. Evidence of movement is not at the Belt-Cretaceous contact but rather between the Belt Altyn and Grinnell, which resulted in contact metamorphism. We were able to study this contact line at length.

Apparently the Altyn was laid down conformably upon the Cretaceous shale which appears as a straight, distinct line. Then the limestone was eroded before the Grinnell was laid down. But subsequently the Grinnell was disturbed with metamorphic movement which tore off slabs of Altyn and interfingered them with the Grinnell. There is evidence of local movement, but it is in the wrong place to uphold the overthrust concept, without which the evolutionary order of the fossils could be called in question.

At one point to the south of where we climbed the mountain I got a good view of the Cretaceous-Belt contact, which appeared as a sedimentary contact, with no evidence of movement.

Another very important structural feature is evident upon close observation. The Grinnell formation is flat-lying. The underlying Altyn limestone dips to the southwest at an angle of nearly 40 degrees. The adjustment between the two apparently caused the metamorphism. Strangely enough, the Atlyn Precambrian and the Cretaceous shale are conformable, they dip at the same angle, thus needing no adjustment. Another indication of a sedimentary contact.

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<u>Chief Mountain</u>. This is perhaps the most famous exposure of the Lewis Overthrust block, pictures of which have appeared in numerous texts on geology. It is a striking, majestic block of rock, standing alone, about 9,000 feet in height. Geologically it is considered an outlier or "klippe," or erosional remnant of the much larger Lewis thrust sheet, a mountain without roots, because Precambrian Altyn limestone and quartzite lie, apparently conformably, on top of Cretaceous dark shale. Much of the contact line is obliterated by talus, but where visible, it appears to be an <u>erosional contact</u>, without physical evidence of differential movement, such as gouge, mylonite, tectonic breccia or slickensides.

This prominent light-colored cliff lies a few miles south of the international boundary with Canada. The best approach to the mountain is by a road along Kennedy Creek, from where a steep climb awaits the prospector.

About two-thirds of the way up the mountain a sharp line of demarcation appears, which one at first glance might mistake for the thrust plane. On top of this plane are flat-lying Altyn Belt series Precambrian limestones. Below the contact are quartzites and deformed Altyn limestones. The quartzites denote metamorphism-movement under confining pressure; followed by erosion, and truncation of the rocks. The flat-lying Altyn beds were laid down on top of them.

Like Marias pass, the main tectonic activity shows up, not between the Precambrian Altyn and the Cretaceous shale, where the thrust-plane is supposed to exist, but within the members of the Altyn Formation itself. These evidences do not support the thrust-fault theory.

Roes Creek Contact. The contact at Roes Creek was easily seen and thoroughly identified by many scientifically trained persons. A section on page 18 in Dyson's work dealing specifically with the Roes Creek contact was used in verification:

> Although the Lewis Overthrust is exposed in a great number of places, very few of these are easily accessible, and at only one does a trail provide a close approach to the actual contact between Belt and Cretaceous rocks. The latter site lies along Roes Creek only a few hundred yards from Rising Sun Campground. Before reaching the fault at the base of a high cliff of Altyn limestone, the trail crosses several outcrops of Cretaceous sandstone replete with fossil pelecypods (clams) and gastropods (snails).

This was indeed the clearest exposure in all the park of a sharp contact between the overlying Altyn Belt Series, Precambrian limestone, or dolomite, and the underlying Cretaceous shale and sandstone. Cretaceous exposures were replete with fossils.

The relatively flat-lying Altyn limestone was lying atop the Cretaceous with not the slightest evidence of movement. The pieces of shale I dug from under the Altyn was compressed, but not deformed in any way as one would expect with a thrust fault or sliding plane. There was no gouge, mylonite, tectonic breccia, nor slickensides. The accompanying photographs illustrate this point [photos omitted]. This contact was alongside the path, which permitted close-up photographs of the exposure, and even enlarged photographs of the contact material.

Beyond all shadow of doubt, this contact was a sedimentary contact. Evidently identification of this contact as a thrust plane was made solely on the basis of fossil evidence with total disregard of physical evidence. However, Professor David Nelson informed me that he found a clam in the Altyn limestone. If so the classification of the Altyn as Precambrian may be in error also.

....

Conclusion. There are of course other relatively inaccessible thrust contact exposures which were not observed; however I believe that sufficient evidence was gathered from the several exposures that we studied, to throw gave doubt upon the whole overthrust theory when applied to the giant overthrusts, such as the Lewis, Bannock, Moine, and some in the Alps.

As pointed out by Burdick and Slusher in the paper mentioned above, it is relatively simple to distinguish between actual overthrusts and paleontological ones, because the true overthrusts show physical evidences of thrusting, such as gouge (rock powder), mylonite (less finely ground rock), tectonic breccia, and slickensides (similar to glacial stria). On two such thrusts in Arizona such physical evidence was found, but on the Lewis Overthrust exposures I was unable to find any such evidence.

One cannot easily dismiss the evidence that some of the giant so-called overthrusts may in fact be based merely on the order of the fossils. Engineering studies have already thrown great question marks around the large thrusting concept. I will always remember an offhand remark made by a structural geologist in a graduate class at the University of Wisconsin: "I often wonder what giant lubricator greased the underlying rocks, that enabled the thrust block to overcome the friction and slide over several miles of rock terrain?"

....

• Alpine Faults and Overturned Slabs

ORIGIN OF LARGE OVERTURNED SLABS OF APENNINES, ITALY

Hsu, K. Jinghwa; *American Association of Petroleum Geologists, Bulletin,* 51:65-72, 1967.

Abstract. Slabs with inverted sedimentary sequences are present in the chaotic terranes (argille scagliose) of the Apennines. Previous investigators suggested that the inversion of the sequences took place during the gravity sliding of the argille scagliose. The working hypothesis presented herein postulates two episodes of deformation. Recumbent folds were formed during the early Tertiary. The inverted slabs originally were a part of the inverted limb of the folds. An erosional interval ensued, during which erosion removed the upper limbs of some recumbent folds. Late Tertiary deformation was characterized by more pervasive shearing, i.e., the land-slipping movement. The previously formed recumbent folds were fragmented during this movement. Large fragments of the limbs of the folds are now preserved as slabs enclosed by the argille scagliose. Slabs which originally constituted the inverted limb contain thus only inverted sedimentary sequences; other slabs contain only normal sequences.

Geologic observations of the Monghidoro region in North Tuscany clearly indicate two episodes of deformation separated by an erosional interval. The early Tertiary recumbent folding hypothesis also helps clarify the geologic interpretations of East Liguria.

Introduction. Large rock slabs are present in the chaotic terranes of the Apennines, Italy. They are exotic blocks more than 1 kilometer thick and hundreds of square kilometers in area. Some of those slabs are overturned. The inverted sedimentary sequences within those slabs form antiforms or synforms. The bedding features within the slabs are relatively undisturbed and the rocks show little evidence of having been subjected to pervasive shearing; thus the bedding is distinctly different from the chaotic bedding of the argille scagliose (scaly shales) or scisti galestrini.

....

Merla concluded that the overturned slab, as well as the overlying Loiano Series, rode "piggy-back" style on top of the chaotic masses of the argille scagliose during an episode of late Miocene land-slipping, prior to the deposition of the parautochthonous Pliocene sediments of the Monghidoro area. The slab might have been transported as much as

100 kilometers northeastward because the Loiano Series probably was deposited near the present Ligurian-Tyrrhenian Coast.

....

Monghidoro Slab of Tuscany. The geology of the Monghidoro area has been reviewed by Maxwell. The following salient facts pertaining to the genesis of the Monghidoro slab have been presented by him.

(1) The Monghidoro slab is an overturned slab perched on top of the chaotic beds of the argille scagliose. The slab is approximately 15 kilometers long, 15 kilometers broad, and 1 kilometer thick.

(2) The inverted sequence of the slab, i.e., the Monghidoro Group, consists of interbedded sandstone, shale, and marl ranging in age from Late Cretaceous to Eocene(?).

(3) The inversion of the sequence has been proved by (a) sedimentary structures such as bottom markings, graded bedding, cross-laminations, etc., and (b) paleontological dating of the sequence.

(4) The inverted sequence of the slab is overlain unconformably by a normal Oligocene to Miocene sequence known as the Loiano Series.

(5) The Loiano Series is of molasse type. Its basal conglomerate contains abundant clasts derived from the Monghidoro Group and from the argille scagliose. The series has been correlated with the autochthonous molasse-type deposits of the same age in the Piemonte-Liguria basin.

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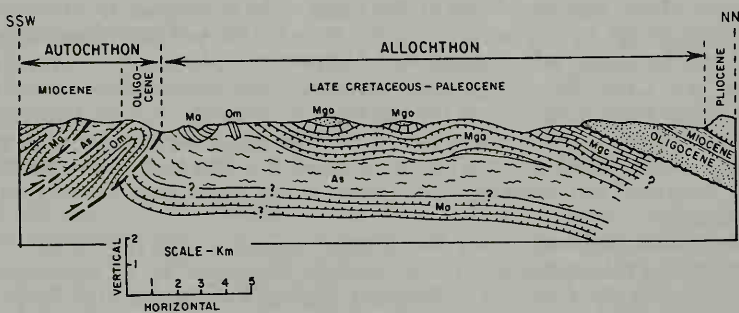

Cross section of the Monghidoro area. The Monghidoro Series is an inverted sequence unconformably overlain by an Oligocene normal sequence. As = Argille scagliose; Ma = Marnoso arenacea; mga = Arenaceous Monghidoro Series; mgo = Calcareous Monghidoro Series; Om = Macigno.

Conclusion. A very puzzling aspect of Apennine geology is the presence of inverted sequences, or slabs, in the chaotic terranes. This paper suggests that the inverted sequences represent remnants of recumbent folds, the upper limbs of which had been eroded prior to the middle to late Tertiary land-slipping. Maxwell contested the idea of recumbent folding when he stated that the upper limbs of the postulated recumbent folds are nowhere in evidence. That the upper limb of a recumbent fold was eroded prior to the land-slipping movement is clearly indicated by the unconformity between the inverted Monghidoro Group and the non-inverted Loiano Series in Tuscany. Furthermore, non-inverted sequences, such as the Pietraforte near Florence of the Monte Ramaceto Sandstone of East Liguria, are large slabs that are not inverted within the chaotic terrane; they might represent the upper limbs of fragmented folds. The writer would like to add that recumbent folds have been described in the Alpi Apuani region, and were visited by the A.G.I. group. Thus, the upper limb is very much in evidence where a recumbent fold is not fragmented by land-slipping movement.

A postulate of recumbent folding does not minimize the role of gravity sliding in Apennine orogenesis. De Sitter pointed out that a middle inverted limb is commonly preserved unthinned in a recumbent fold formed by gravity sliding, in contrast to an essentially missing overturned limb in overthrusting under compression. The presence of inverted slabs suggests that gravity sliding might be the underlying cause for both the earlier recumbent folding and the later land-slipping in the Apennines.

• Overthrusts in the Scottish Highlands

THE HIGHLAND OVERTHRUSTS

Gregory, J. W.; *Nature,* 77:272-274, 1908.

The controversy regarding the structure of the north-western Highlands was a disturbing factor in the progress of geology from 1819, when the problem was first raised by Macculloch, until it was closed in 1884 by Sir Archibald Geikie's announcement in Nature (vol. xxxi., p. 29) that the generally accepted view could no longer be maintained. The Nature article ---perhaps the most sensational announcement in geological literature--- was followed in 1888 by a report from six members of the Scottish Geological Survey, giving a summary of the evidence which they had collected as to the structure of the north-western Highlands; and it has taken another twenty years to complete the survey of the whole overthrust region and prepare the detailed observations for publication.

....

The history of the north-west Highlands controversy is summarised in a chapter by Dr. Horne, who lucidly states the results of all previously published geological work on the district. The geological interest of the area dates from the announcement by Macculloch, in 1819, of his discovery of fossiliferous rocks lying above gneisses, and covered by the gneisses and schists that form the great bulk of the Scottish Highlands. Murchison, with his keen scent for a good clue, visited the area, and he re-examined it after the discovery by C. Peach, in 1854, of the better fossils (now known to be Cambrian) in the Durness limestones. Murchison was convinced that the fossiliferous rocks were covered by the eastern gneisses, and, in accordance with the law of superposition, accepted the eastern gneisses as younger than the rocks beneath them. He regarded the fossils as Lower Silurian, and therefore did not shrink from the apparently inevitable corollary that most of the crystalline rocks of the Scottish Highlands are post-Lower, Silurian in age. This conclusion had a world-wide influence. Similar crystalline schists form vast regions in all the continents, and they were at first regarded as all pre-Palaeozoic; but if the Scottish schists are altered Palaeozoic sediments, then the similar rocks elsewhere may include rocks of any geological age. To this day vast regions of schists and gneisses are mapped as altered Silurian, in consequence of Murchison's work on the north-west Highlands.

Murchison's views were at once opposed. The common-sense judgment of James Nicol showed him the improbability of Murchison's conclusions, and his keen and careful field-work revealed that the superimposing of schists over sediments was not an original arrangement, but was due to subsequent earth movements. The first controversy was short. Nicol's interpretation of the evidence had not the fascinating simplicity of the other theory, and it was not wholly right. The eastern and western gneisses are not simply repetitions of the same series, and Murchison was apparently right in his view that the upper gneisses and schists are an independent and younger series than the Lewisian gneisses, which underlie the Cambrian band to the west. Moreover, Nicol failed to realise that the apparent bedding planes in the eastern gneisses were not original, but secondary structures due to earth movements.

Murchison, with a theory attractive by its charming simplicity and far-reaching results, and right in his recognition of the essential differences between the eastern and western gneisses, swept his critic from the field. Nicol, disheartened by the fate of views which he knew to be essentially correct, practically gave up geological research, and went to his grave, his geology despised and his conclusions rejected---by all except his wife. In 1878, the year before Nicol's death, the controversy was re-opened by that geological knight-errant, Dr. Hicks, who ran a tilt against the Murchisonian theory. It survived his onslaught, but two years later it received an almost fatal blow from Prof. Bonney, who, by work near Loch Maree, demonstrated that some of the rocks of the eastern series were the old Lewisian gneiss brought up by faults. The establishment of this fact, which is described in the memoir as "the first important advance towards the solution of the problem of the succession in the north-west Highlands since the publication of Nicol's researches" (p. 23), was not enough, although it was supported by the work of Callaway and Hudleston. In 1882-3 Prof. Lapworth mapped in detail the classic sections on the shores of Loch Eriboll; he proved that the apparent sequence was deceptive, and that the eastern gneisses were older than the fossiliferous rocks, and had been placed above them by earth movements; and it was his crowning glory to recognise that many of the fine-grained, shale-like rocks, which look like comparatively unaltered sediments are the most intensely altered rocks of the area; they consist, like ordinary shales, of fragments of primary rocks, but instead of having been formed by the usual agents of denudation and deposition, they are due to crushing along planes of earth movement.

The close of the controversy was now near at hand. In 1883 Sir Archibald Geikie arranged for the detailed mapping of the Loch Eriboll district by the Geological Survey. The work was soon found to be far more complex than had been expected; it was attacked with invincible patience and thoroughness by the surveyors under Peach and Horne; the essential conclusions of Nicol and Lapworth were confirmed, and it was promptly announced in Nature that the Murchisonian theory must be abandoned. In 1888 a preliminary report on the Survey's investigations was published by the Geological Society, but it has taken another nineteen years to extend the survey along the whole of the overthrust line, and to prepare the materials for publication.

The work is of the highest geological importance, and in spite of its necessary descriptive details, every page contains observations of interest. The account of the Torridonian series, for example, describes the oldest considerable land surface known, and some traces of fossils in these pre-Cambrian rocks. The part of most interest is the account of the movements by which the eastern gneisses have been overthrust on to the younger rocks. The movements have taken place along a line more than 100 miles in length, and have carried the rocks in places for ten miles westward. The thrusting forward of these hard rock slices has produced a most intricate system of faults, and extreme changes in the rocks, some of the fresh structures, as in the pseudo-rhyolites, simulating those of igneous rocks. The extent of the metamorphism is one of the secondary questions of most interest. Its range appears to be very variable; in places the alteration is confined within very narrow limits; elsewhere it may extend to a mile from the plane of movement; but it never appears to be regional, and evidence is given that some of the schists had their present structures before the great disturbances.

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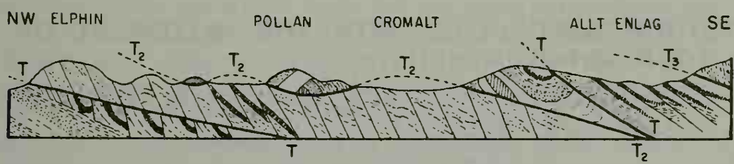

The Scottish Highland type of overthrust. Section width is about 6 miles.

• Erratic Slabs

FLOAT BLOCKS IN TERTIARY VOLCANICS OF SOUTHERN NEW MEXICO

Kottlowski, Frank E.; *Geological Society of America, Bulletin,* 64:1445, 1953.

Abstract. Two large float blocks of Permian limestone occur within Tertiary pyroclastics in the Selden Hills. The Selden Hills is an uptilted,

north-south elongated fault block bordering the Rio Grande depression in southern New Mexico, 22 miles north of Las Cruces. The float blocks are thin plates of Permian Hueco limestone that overlie mid-Tertiary latitic and andesitic tuff-breccias. The larger limestone plate is 2100 feet long, 1600 feet wide, 150 feet thick, and weighs about 42 million tons. The basal parts of the two plates are brecciated, silicified, and hematitized, while the upper parts are shattered along many small faults and are partly marbleized.

There are only a few limestone xenoliths in the tuff-breccia, the limestone is not intruded by the atite, and the dip of the limestone beds diverges about 20° from the dip of the volcanics. Lake Cenozoic deformation in the area consisted of normal faulting and gentle folding; overthrusting is not known. The limestone plates, therefore, are believed to be float blocks, moved from an initial crater rim by floating on top of and partly within a cool glowing avalanche, a clastic flow as described by Les (1938, p. 14). The nearest outcrops of Hueco limestone are 11 miles to the south and southeast. The float blocks, however, probably traveled a shorter distance, and their source is now buried under the late Tertiary sediments that surround the Selden Hills.

• Miscellaneous Overthrusts

DEFORMATION ASSOCIATED WITH THE MOVEMENT OF THE MUDDY MOUNTAIN OVERTHRUST.....

Brock, William G., and Engelder, Terry; *Geological Society of America, Bulletin,* 88:1667-1677, 1977.

Abstract. The Muddy Mountain overthrust, exposed in the Buffington window, southeastern Nevada, consists of a Paleozoic carbonate sheet thrust over Mesozoic Aztec Sandstone, with a molasse filling topographic lows. Evidence suggests that the thrust sheet moved across an erosional surface and that the molasse may have been a forethrust debris. A sharp contact with gouge marks the fault surface. The base of the overthrust sheet is a tectonic breccia containing injections of gouge that are rooted at the contact. Thrust-related changes in the underlying rocks related to proximity of the thrust plane include (1) increase in abundance of microfractures and decrease in grain size due to cataclastic deformation; (2) increase in intensity of macrofracturing parallel and at a low angle to the contact; (3) increase in degree of induration; (4) loss of well-defined bedding planes and color contrast within the Aztec Sandstone; and (5) slabs of dolomite sheared from the upper plate. Laboratory mechanical tests in conjunction with field observations suggest that the shear strength of the undeformed Aztec Sandstone was lower than the frictional strength of the sandstone sliding on quartz gouge. Therefore, cataclastic deformation within a 10- to 100-m-thick zone accompanied the initial advance of the thrust sheet. Following induration, which strengthened the cataclas-

tic sandstone, slip was localized at the thrust contact. During this later stage the high permeability of the fractured upper plate and the Aztec Sandstone suggests that fluid communication with the surface at the leading edge of the thrust was rapid and, therefore, the advance of the thrust could not have been aided by high pore pressure.

[Not mentioned in the authors' abstract is a statement from the Conclusions to the effect that "High friction along the fault contact and lack of abnormal pore pressure suggest that this fault of great width (40 km) must have been pushed down a pre-existing slope." In other words, gravity must have helped pull the old rocks over the younger strata. Apparently, we need to learn much more about these large-area thrust faults.]

....

Geologic Setting. A trace of the Muddy Mountain overthrust is found in the midst of the southern Muddy Mountains along the edge of the 13- by 3-km Buffington window. The mountains consist of an irregular mass of allochthonous Paleozoic carbonate rocks, whereas the window includes autochthonous Mesozoic eolian sandstone and molasse.

The Muddy Mountain overthrust is at the southern end of a belt of imbricated thrust sheets that extend into the Canadian Rockies. In Utah and Nevada, these imbricated thrusts comprise the Lake Jurassic through Late Cretaceous Sevier orogenic belt in which thick sections of Paleozoic geosynclinal rocks have been thrust eastward over thinner sections of younger shelf sedimentary rocks. The Muddy Mountain thrust sheet is imbricated with Dry Lake and Gass Peak thrust sheets.

The Muddy Mountain overthrust may also be exposed in the Spring Mountains, where it is called the Keystone thrust. This Muddy Mountain-Keystone overthrust extends at least 210 km along strike from the Clark Mountains, California, to the Muddy Mountains and is offset by the Las Vegas shear zone. Minimum width of the thrust sheet (distance parallel to movement) is that of the Muddy Mountains, or approximately 24 to 40 km, depending on the assumed direction of movement, but it can be as much as 88 km. Its minimum area is about 3,800 km^2. The youngest formation preserved in the thrust sheet is a Triassic sandstone in the northern area of the Muddy Mountains. Thus, the minimum thickness of the thrust sheet is about 4 to 5 km (2 to 2.5 km of Paleozoic dolomite and limestone overlain by 2 to 2.5 km of Mesozoic sandstone and shale).

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ICE FORMATIONS

Although natural ice is common enough in temperate and polar climes, given the proper seasons, this type of rock also prevails in the hottest summers in curious caves and wells. In fact, ice caves often grow more ice in summer than in winter. Seasonal changes in air circulation may account for this incongruous fact. Some observers seem to feel that low-temperature reservoirs in the neighboring rocks left over from cold winters, or even the Ice Ages, must be invoked to explain ice-cave phenomena.

On the earth's surface, icebergs and sea ice display several curious phenomena. A few such examples complete this section.

• Ice Caves and Frozen Wells

THE SWEDEN VALLEY ICE MINE AND ITS EXPLANATION

Andrews, Marlin O.; *Popular Science Monthly,* 82:280-288, 1913.

The Sweden Valley Ice Mine, one of the unexplained mysteries of nature, is located about four miles east of Coudersport, the county seat of Potter County, Pa. A similar phenomenon is situated on Dingman Run, about three miles west of Coudersport. These are natural ice-manufacturing plants, running under full head during the warm season of the year, but shutting down entirely during the cold months of winter, when there is plenty of ice and snow to be had elsewhere and when it would seem to be the most natural time for the formation of ice at these places.

....

Mr. John Dodd and Mr. William O'Neil were prospecting near Sweden Valley when, underneath four or five inches of moss, they found a thin layer of solid ice. After leveling off a space about fifteen or twenty feet square they dug a shaft about six feet square by twelve feet deep. At a depth of nine feet they found petrified wood, impressions of leaves, ferns and other vegetation, also bones which were pronounced to be human. At a lower depth a peculiar kind of rock was found which they thought might contain gold or silver. Some of this was assayed and found to be of no value. At a depth of twelve feet an aperture was found from which came a cold draught. This was thought peculiar, but nothing was done to investigate farther and the work was abandoned.

The following spring Mr. Dodd found a considerable amount of ice in the mine, but thought that it had gathered there during the winter and had not yet melted. However, as the warm weather advanced, the quantity of ice, instead of melting as was expected, began to increase, and by the middle of July the sides of the shaft were covered with a coating of ice a foot or more thick and large icicles were forming from the opening at the top.

As winter again came on, the ice began to disappear until the cave was nearly free from the summer's product. This phenomenon has regularly been repeated each year since its discovery.

....

The general skepticism regarding the existence of this phenomenon has been illustrated many times of late and has furnished the people of

Coudersport with an endless source of amusement.

In the early part of the summer of 1911 a certain man of Detroit, Michigan, came to visit relatives in Coudersport. He was, of course, taken to see the ice mine, which was in its prime at the season of the year. Upon his return to Detroit he wrote a short article for one of the Detroit papers in which he told of this wonder that he had seen near Coudersport and offered to bet any one and every one $100 or more that his fictitious-sounding story was true. A millionaire ice manufacturer took the bet and eight other business men of Detroit followed suit. Two newspaper men were selected as stake-holders to decide the bets. They visited the mine and, of course, verified the newspaper story, much to the disgust of the nine losers.

It is claimed by a great many persons who hear of this phenomenon, never by those who actually see it, in the summer time, that the ice is not formed during the summer, but is only an accumulation from the preceding winter. It was to prove the falsity of this claim that the writer visited the mine many times during the winter and spring of 1912. The existing conditions were found to be as follows:

The pit or shaft is about eight feet in diameter by twelve feet deep and, as shown in the sketches, is located at the base of a steep hill. In the winter time the pit is comparatively dry and free from ice. The temperature inside is the same as that prevailing outside. In the spring of the year, as the snow on the hillside begins to melt and the frost comes out of the ground, water naturally begins to trickle down the sides of the shaft, where, strange as it may seem, it is frozen in the form of small icicles. This freezing process continues, until by July the sides of the pit are completely covered with a coating of ice a foot or more in thickness. In the early fall the process stops and the formation of ice gradually melts. The sides of the shaft are of loose shale, in which there are numerous crevices extending back and up into the hill, the rock strata being rather sharply inclined. A draught of cold air, which at some places is strong enough to extinguish the flame of a small taper, issues from these fissures in the summer time. This draught is variable, being stronger on hot than on cool days. A heavy mist may also be seen rising out of the pit and floating off down the hill close to the ground. The temperature of the pit during the past summer varied between 25 and 32 degrees Fahrenheit.

The explanation of this phenomenon appears to lie in the cold currents of air issuing from the crevices of the rocks along the sides of the shaft. The air must gain access to these fissures at some other point, which must be at a higher altitude than that of the pit, as will be seen from the following discussion.

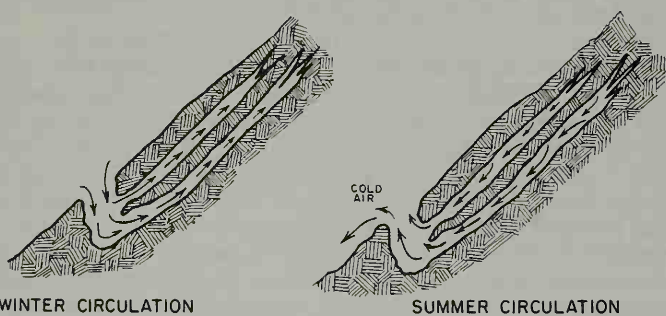
This being true, it is evident that in the winter time the column of air directly over the pit is cooler and consequently heavier than that in the rock passages. Therefore, it forces its way down into the pit and up through the rock strata, chilling the rocks to a great depth and storing up a vast quantity of "cold." We see, then, that the amount of "cold" which is stored up, or the depth to which the rocks are chilled at the beginning of warm weather in the spring, depends upon the length and severity of the winter.

As the warm weather comes on the column of air over the pit becomes heated and is displaced by the cold, heavy air flowing down out of the passages. This cold current of air freezes any surface water which flows over the edges of the pit and maintains a freezing temperature as long as the supply of "cold" in the hill lasts, after which the circulation of air ceases and the ice formation melts.

The place at which air gains access to these passages need not be a single opening, but consists, in all probability, of numerous small apertures, covered possibly by a thin coating of moss, loose shale or other porous substance.

In the summer time the warm outside air entering these apertures comes in contact with the rocks which have been chilled by the reverse currents of the preceding winter and in doing so gives up its heat to them, becoming specifically heavier. It then forces its way on down, displacing the warmer and lighter column of air above the pit.

It is evident that the rapidity with which this circulation takes place depends upon the difference in temperature of the two air columns. That is, the cold outward current is much more noticeable on hot days than on cool days in summer, and in winter the strongest inward current is noticed on the coldest days.



Seasonal changes in air circulation in the Sweden Valley ice mine.

This fact accounts for the common belief that the freezing takes place more rapidly and that the mine is colder on hot than on cool days.

The temperature of the mine, or, in other words, of the air as it issues from the crevices, remains practically constant throughout the summer, which is proved by thermometer readings. However, the difference between this constant temperature and the temperature prevailing outside the mine is obviously greatest on the hottest days and therefore, as one enters the mine, the contrast is more noticeable. This causes one to believe that the mine is colder when it really is not. It is true, however, that the ice is formed most rapidly during the hottest weather. This is not because the temperature of the mine is lower, as is generally supposed, but is due to the fact that the circulation of air is more rapid; that is, a greater quantity of cold air issues from the numerous apertures and consequently a greater amount of "cold" is available for the formation of ice.

As soon as the supply of "cold" in the rocks is exhausted the internal and external air columns become gradually equal in temperature and weight, the circulation ceases and the ice begins to melt. This generally occurs about September of each year.

If this is the true explanation of this phenomenon, we may say, with truth, that in this particular instance it is the heat of summer which causes the ice to form, but, at the same time, we can not disregard the fact that it is the severity of the preceding winter and the natural arrangement of the rock strata which make it possible for the heat of summer to produce this peculiar phenomenon.

PERMANENT ICE IN A MINE IN THE ROCKY MOUNTAINS

Weiser, R.; *American Journal of Science,* 3:8:477-478, 1874.

Geologists have been not a little perplexed with the frozen rocks found in some of our silver mines in Clear Creek Co., Colorado. I will first give a statement of the facts in the case, and then a theory for their explanation.

There is a silver mine high up on McClellan Mountain, called the "Stevens Mine." The altitude of this mine is 12,500 feet. At the depth of from 60 to 200 feet the crevice matter, consisting of silica, calcite, and ore, together with the surrounding wallrocks, is found to be in a solid frozen mass. McClellan Mountain is one of the highest eastern spurs of the Snowy Range; it has the form of a horse-shoe, with a bold escarpment of feldspathic rock near 2,000 feet high, which in some places is nearly perpendicular. The Stevens Mine is situated in the southwestern bed of the great horse-shoe; it opens from the northwestern. A tunnel is driven into the mountain on the lode, where the rock is almost perpendicular. Nothing unusual occurred until a distance of some 80 or 90 feet was made; and then the frozen territory was reached, and it has continued for over two hundred feet. There are no indications of a thaw summer or winter; the whole frozen territory is surrounded by hard massive rock, and the lode itself is as hard and solid as the rock. The miners being unable to excavate the frozen material by pick or drill to get out the ore (for it is a rich lode, running argentiferous galena from 5 to 1,200 ounces to the ton), found the only way was to kindle a large wood fire at night against the back end of the tunnels and thus thaw the frozen material, and in the morning take out the disintegrated ore. This has been the mode of mining for more than two years. The tunnel is over two hundred feet deep and there is no diminution of the frost; it seems to be rather increasing. There is, so far as we can see, no opening, or channel through which the frost could possibly have reached such a depth from the surface. There are other mines in the same vicinity in a like frozen state.

From what we know of the depth to which frost usually penetrates into the earth, it does not appear probable that it could have reached the depth of two hundred feet through the solid rock in the Stevens Mine, nor even through the crevice matter of the lode, which, as we have stated, is as hard as the rock itself. The idea, then, of the frost reaching such a depth from the outside, being utterly untenable, I can do no other way than to fall back upon the Glacial era of the Quaternary. Evidences of the Glacial Period are found all over the Rocky Mountains. Just above the Stevens Mine there are the remains of a moraine nearly a mile long, and half a mile wide. The debris of this moraine consists of small square and angular stones, clearly showing that they have not come from any great distance. And just over the range, on the Pacific slope, there are the remains of the largest moraine I have ever seen, consisting of feldspathic boulders of immense size. I conclude, therefore, that it was during that period of intense cold that the frost penetrated so far down into these rocks; and that it has been there ever since, and bids fair to remain for a long time to come.

MICROMETEOROLOGICAL INVESTIGATIONS IN A REMARKABLE ICE CAVE

Wigley, T. M. L., et al; *American Geophysical Union, Transactions,* 49:693, 1968.

Abstract. Some unique ice formations found in a cave in Southwestern Alberta are described. Many of these take the form of large multiply interlocking hexagonal ice plates up to 35 cm across, similar in habit to the much smaller ice crystals which form in clouds at temperatures just below freezing. During the Summer of 1968 series of meteorological observations were taken throughout the cave in an attempt to explain the existence of these ice plates. Rather unusual microclimatic conditions (including a Helmholtz resonator air circulation mechanism) were found to occur within the cave and these, together with their significance in relation to the formation of the ice plates, are discussed.

ICE CLIFFS ON KOWAK RIVER, ALASKA.....

Russell, Israel C.; *American Geologist,* 6:49-50, 1890.

In a recent report of a cruise of the U. S. Revenue Marine steamer "Corwin," there is an interesting narrative by Lieut. John C. Cantwell, of a boat journey up the Kowak river, Alaska. In this narrative there is a brief account of remarkable ice cliffs forming the river's bank, of the same general character as the ice cliffs at Elephant point, on Eschscholtz bay, several accounts of which have been published. Four illustrations of the ice cliffs are presented, which represent them as bold, angular bluffs, rising directly from the river to a uniform height, and covered with a layer of soil in which forest trees grow. The cliffs are in reality the eroded border of a forest-covered plateau, under which ice takes the place of rock. The character of the surface of this plateau is described by Lieut. Cantwell as follows:

"Climbing to the top of one of these ice-cliffs, Mr. Townsend and I pushed our way through the dense thickets of willow and luxuriant growth of grass into the interior for about one mile, where we found a shallow lake about a mile in diameter, and which I have no doubt had its origin in the mass of ice over which we had been traveling. It is almost inconceivable how such a rank vegetation can be sustained under such conditions. If we stood in one place any length of time, the spongy moss became saturated, and soon a pool of dark-colored water made our position untenable. Besides the moss, berries, and stunted willows, clusters of spruce trees, some measuring 6 and 8 inches in diameter, have taken root and grown in the thin strata of soil overlying the ice."

Being anxious to obtain a more detailed description of this interesting deposit, I addressed a letter to Lieut. Cantwell, indicating the facts would be of geological interest, and was favored with the reply given below. This information was requested for publication in a paper on the surface geology of Alaska, but owing to delay in the mails, it did not arrive in time to be used in that connection, and is here published in order that the interesting observations it contains may not be lost.

THE FROZEN WELL OF BRANDON, VERMONT

Anonymous; *Scientific American,* 27:248-249, 1872.

About a mile southeast of the village of Brandon, Vermont, there is situated a well, 41 feet deep, the water of which has the remarkable peculiarity of remaining frozen all the year round. In 1859 the owner of the property began the usual excavations for water. After passing through 4 feet of clay and 10 feet of soil, a bed of frozen gravel, 16 feet in thickness, was encountered, which rapidly changed to mud when exposed to heat. Further digging penetrated another bed of clay, and finally a layer of clean gravel, in which water was found. As the winter months approached, ice began to form in the well at the rate of from 2 to 4 inches over night, while during the succeeding summer, though the well remained open, an occasional skim of ice would appear on the surface.

Eventually the well was abandoned, but since it has remained unused, it is found that if the winter ice is not removed when the weather is quite warm, the water remains frozen through the hottest months. During April last, ice 20 inches in thickness was taken out, but as the atmosphere at that time was chilly freezing again took place. On July 16 of this year, the temperature in the shade was 85^{o}; at two feet from the surface of the ice in the well, the mercury sank to 32^{o}.

In 1860, four shafts were sunk in immediate proximity to the well without striking frozen ground; a fifth endeavor was more successful but the experiment was never completed, though we learn that it will be once more undertaken next summer. There is considerable speculation in scientific circles as to why this particular locality, possibly 200 feet square, should permit the winter cold to descend through from 12 to 29 feet of clay and gravel and freeze a mass of material averaging 14 feet thick, and yet not affect any other spot composed of similar strata. Professor Hager is of opinion that the phenomenon is due to glacial remains. The beds of clay, which intercept the sun's heat and besides shed off surface water, together with the favorable arrangement of the strata in connection with its dip and the proximity of the outcropping limestone, it is believed, have protected the frozen mass from thawing for thousands of years, while the remainder of the glacier has long since melted away, leaving only its moraines in the neighborhood. Mr. Clarence Sterling, of Bridgeport, Conn., who has already spent some time in the investigation of the subject proposes next year to carry down the fifth well to a greater distance.

THE FROZEN WELLS OF OWEGO

Brocklesby, John; *American Association for the Advancement of Science, Proceedings*, 9:175-179, 1855.

About sixteen years ago a letter was addressed to Professor Silliman, by Mr. D. O. Macomber, of Owego, Tioga Co., N. Y., describing certain unexplained phenomena pertaining to a well situated in the vicinity of Owego.

The communication of this gentleman (which is recorded in Vol. XXXVI of the Journal of Science) is as follows:

"The well is excavated on a table-land elevated about thirty feet above the bed of the Susquehanna River, and distant from it three fourths of a mile. The depth of the well, from the surface to the bottom, is said to be 77 feet; but for four or five months of the year the surface of the water is frozen so solid as to be entirely useless to the inhabitants. On the 23d of the present month (February), in company with a friend, I measured the depth, and found it to be 61 feet from the surface of the earth to the ice which covers the water in the well, and this ice was found it impossible to break with a heavy weight attached to a rope. The sides of the well are nearly covered with masses of ice, which, increasing in the descent, leave a space but one foot in diameter at the bottom.

"A thermometer let down to the bottom sunk 38° in 15 minutes, being 68° in the sun and 30° at the bottom of the well. The well has been dug 21 years, and I am informed by a very credible person, who assisted in the excavation, that a man could not endure to work in it more than two hours at a time, even with extra clothing, although in the month of June, and the weather excessively hot. The ice remains until very late in the season, and is often drawn up in the months of June and July. Samuel Mathews drew from the well a large piece of ice on the 25th of July, 1837, and it is common to find it there on the 4th of July.

"The well is situated in the highway, about one mile northwest of the village of Owego. There is no other well on that table of land, nor within 60 or 80 rods, and none that presents the same phenomenon. In the excavation no rock or slate was thrown up, and the water is never affected by freshets, and is what is usually denominated 'hard' or limestone water. A lighted candle being let down, the flame became agitated and thrown in one direction at the depth of 30 feet, but was quite still and was soon extinguished at the bottom. Feathers, down, or any light substance, when thrown in, sink with a rapid and accelerated motion. The above facts may be relied upon as entirely correct."

Such is the statement of Mr. Macomber. During last year I received from the Rev. Wm. H. Corning, who is settled at Owego, two letters in respect to this phenomenon, which show that it is not confined to one locality. In his first communication, dated June, 1854, Mr. Corning thus writes: "Two wells in Owego, some 60 feet deep, freeze, and within a week large lumps of ice have been drawn up from one of them. They are situated a short distance from the Susquehanna River, and are below its bed."

In my reply to this letter Macomber's well was mentioned, and certain observations and experiments suggested, which it was thought might tend towards the solution of the problem.

In the second letter of Mr. Corning, he writes as follows:

"The deep well spoken of by Macomber is situated at some distance west of the village proper, about a quarter of a mile from Owego Creek, and is on rather high ground; but no hills or mountains of any height are in its vicinity. The water of this well in the month of September is said to be quite warm; so much so as to be unpalatable.

"The other well (from which the ice was drawn) is in the centre of the village, not more than seventy yards from the Susquehanna, and is about a quarter of a mile from any hill. The distance from the surface of the ground to the surface of the water in the well is, at this date (Aug. 19th), 22-1/2 feet. The water is about 18 inches deep, and its temperature was, at noon of this day, 47^{o} Fahr.

"By letting down a lighted candle, a slightly perceptible current of air is detected, and the flame blows nearly west (the river is south). For the space of 10 or 12 feet down from the mouth of the well, there is not the least current; but for the rest of the distance, to within a foot of the water, the current mentioned is about the same in force; yet hardly strong enough to settle the question as to lateral fissures.

"The sides of the well are coated with ice from early winter, and the water apparently freezes from the bottom and sides. Sometimes the surface is frozen so hard, that it becomes necessary to drop a heavy weight to break the ice, in order that water may be drawn; this, however, is only occasionally done. The former owner was obliged to remove a chain-pump, and resort to the old windlass, on account of the ice. The ice remains on the sides of the well until the middle of May, when it gradually melts away, and by about the middle of June it is almost entirely gone. The water of the well up to the middle of May is very cold, resembling ice-water.

"The formation of this region is what geologists call alluvial, I believe. For the depth of ten feet or more below the surface of the earth there are large quantities of pebble-stones, varying in size from that of a pea to those which measure 4 or 5 inches in diameter. These are mixed with gravel and a sandy loam, and farther down are veins or layers of gravel, free, for the most part, from these stones. The hill or mountain, from which the village well is about a quarter of a mile distant, is variously estimated by the inhabitants to be from 150 to 200 feet in height. Upon it are found shells and marl."

During the early part of this summer I received information similar to the above from the Rev. James Rankine, a gentleman who resides at Owego. Mr. Rankine remarks, in addition, that "when the ice begins to form in the cold weather, it can be seen forming under the surface of the water in shape like a basin; and that during last winter a cover was put upon the well, when all its usual phenomena disappeared."

I am not aware that any satisfactory explanation has yet been given of this singular phenomenon. Without claiming to solve it, the learned editor of the Journal of Science remarks, in respect to the well of Macomber, that "possibly the escape of compressed gas deep within the earth in the vicinity of the well, and in proximity to its waters, may account for the extraordinary low temperature that there prevails"; and this view he considers as perhaps countenanced by the slight current of air that exists in the well.

It is worthy of notice, that in both the wells the phenomena of the currents is the same; namely, that the flame of a candle is swayed in one direction before it reaches the bottom, where it is still,---facts that point towards a common cause.

A well somewhat similar to the Owego wells is found at Monte Video, a villa situated about 9-1/2 miles from the city of Hartford, Ct.

This well is sunk through the loose trap rock and gravel to the depth of about 25 feet, and during the summer months the water that is drawn from it is as cool as iced water. So low is the temperature, that the teeth fairly ache with cold as the water is drank. In close proximity to this well is a lofty hill of trap, whose shelving sides are entirely composed of the debris of this rock.

In the celebrated cave of Orenburg, in Russia, we have another instance of a locality possessing in summer an extraordinary low temperature. This cavern, which is at the base of a hill of gypsum, and opens on the street of Orenburg, is partly filled with ice in the summer, the roof, which is broken by fissures, being hung with solid undripping icicles; and the hotter the weather, the more severe is the cold; while in the winter all the ice disappears.

In explanation of these phenomena, it is asserted that in summer, as in the case of mining shafts and galleries, a warm current of air descends through the channels and passages of the hill, evaporating the water that it meets with, and cooling so rapidly, that it is below the freezing point when it issues into the cave. In the winter the current would move in the opposite direction, the hill being warmer than the external atmosphere.

This explanation will not serve for the wells of Owego, though it possibly may for that at Monte Video; for the former, unlike the cave of Orenburg, are coated with ice and frozen in winter, and in mid-summer their waters are as warm as those of other wells. Nevertheless, it appears from the statement of Mr. Rankine, that evaporation aids in some way in producing the extraordinary degree of cold that prevails in these wells; for when one of them was covered, and the evaporation checked, no ice was formed within it.

The preceding facts have been presented, not for the purpose of now offering any solution of the problem they involve, but with the hope that their publicity may stimulate observation and inquiry, and elicit other facts which will lead us to a better understanding of this class of physical phenomena.

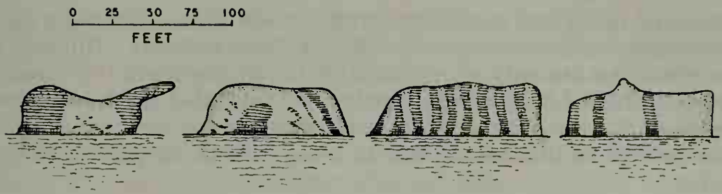
• Idiosyncracies of Icebergs and Sea Ice

BLACK AND WHITE ICEBERGS

Cole, M. J.; *Marine Observer*, 42:15-16, 1972.

R. R. S. John Biscoe, Captain M. J. Cole. Argentine Islands to Port Stanley via Signy Island. Observers, Mr. A. R. Binder, 3rd Officer and all other officers.

22nd March 1971. Between 1200 and 1915 GMT, while the vessel was



Black-and-white icebergs in the Southern Ocean.

on passage from the Bransfield Strait to Signy Island in the South Orkneys, a number of distinctly coloured icebergs were observed. During the period approx. 180 bergs were seen, a dozen of which claimed special attention because of their apparent composition of two types of ice. In these particular cases a portion (or portions) of the bergs presented a black or translucent greenish-black appearance, as opposed to the normal white colour. The edges of the portions were clearly defined but the structure of the bergs as a whole gave no indication as to why the two differing types of ice should be present; the dividing line itself bore no relation to any physical differences within the bergs.

Some of the bergs were halved black/white with large areas of each, whereas others were composed of many alternating bands. One berg in particular, approx. 100 yd long, exhibited about 20 alternating bands spaced at fairly regular intervals. On some of the bergs the white ice was discoloured and appeared to be carrying a brown sediment, but this did not seem to be connected in any way with the black ice. All of the affected bergs were thought to be inclined at 90^{o} to the position in which they were originally formed and the layers of ice were therefore vertical or near vertical.

Position of ship at 1200: 60^{o} 25'S, 48^{o} 05'W.

Position of ship at 1915: 60^{o} 42'S, 45^{o} 54'W.

Note. Dr. C. W. M. Swithinbank of the Scott Polar Research Institute, Cambridge, comments:

"I have done no work on black icebergs and I do not know anyone who has, though they are not very uncommon and there are many reports of such sightings in the literature. Samples held in the hand have been reported to consist of clear bubble-free ice, providing a conspicuous contrast with the white bubbly ice of which most Antarctic bergs are made. Until someone takes home a substantial and representative piece and subjects it to chemical analysis (organic and inorganic) all suggested explanations are no more than guesses.

"I have two alternative guesses. The first is that the black ice represents what was formerly a layer in an ice shelf or iceberg tongue that became soaked with sea water and then froze. This would account for the clean ice above and below the black ice, since brine-soaked layers are believed to be of only limited thickness. The icebergs calved from the ice shelf have later capsized, so that the layer of black ice may be at any angle.

"The alternative is that the black ice represents what was formerly water at the bottom of the ice sheet. This would explain an occasional association of rocks and rock flour with the black ice, for the water refreezes before the ice reaches the edge of the ice sheet. The fact that there is white ice not only above but also below the black ice would then have to be explained by the refrozen layer overriding more stagnant ice at the edge of the ice sheet. This is known to occur wherever such a process can readily be identified, that is to say where the ice sheet terminates on land."

WHY DOES SEA ICE HAVE ITS CRYSTALS ALIGNED?

Anonymous; *New Scientist,* 65:191, 1975.

Radar profiling experiments to measure the thickness of sea ice have recently shown that the ice is electrically anisotropic. What force is responsible for giving the ice this preferred orientation is unknown, but the effect can persist for distances of several kilometres.

....

They noticed the anisotropy on "virtually all first-year ice", and for ice varying from 25 cm to 2 m thick. The direction of maximum signal strength often persisted for distances of km. Where this direction chopped and changed the ice was rougher and composed of rotated and re-frozen plates. Multiyear ice, too, often exhibited the anisotropy, but less consistently.

Previous workers have mostly rejected the idea that sea ice can have a microstructure with some kind of alignment. In the present case the researchers took an oriented core of ice from one of the ice sheets they sampled. It revealed that the individual ice crystals did indeed possess a sub-parallel alignment in a direction approximately that of the tidal currents in the region. The minimum radar echo occurred with the aerial set up roughly along this direction.

The ice crystals may grow in this pattern in response to either water currents or large-scale stressing of the ice. The effect is probably important in determining the strength of sea ice. Further work on this electrical anisotropy is now in progress which may reveal its relationship to the growth and decay of ice sheets.

A PECULIAR FORMATION OF SHORE ICE

Case, E. C.; *Journal of Geology,* 14:134-137, 1906.

On January 27 of the current year the writer noticed that the ice along the Milwaukee shore of Lake Michigan from Lake Park to the city pumping-station, a distance of nearly a mile, was formed almost entirely of large snowballs such as are formed by children rolling the damp snow until it grows into a ball by accretion. The phenomenon was so peculiar that it led to a more careful study, and as the author has found no report of a similar condition, it seems worth while reporting.

The beach where the peculiar formation occurred is not wide, varrying from only 3 or 4 feet to as much as 50 or 60; on the landward side it terminates at the bottom of an 80-foot bluff of glacial material, composed of the unstratified bowlder clay at the bottom and stratified sands and clays above, culminating in the "red lake clay" characteristic of the Wisconsin shore of Lake Michigan. Beyond the edge of the beach the water is very shallow for a considerable distance out, so that in time of even moderate waves bowlders of 3 and 4 feet in diameter appear in the trough of the waves 100 and more feet from shore. This bench has been formed by the waves cutting into the cliff and distributing the material on the adjacent bottom. During ordinary winters this shallow water freezes to the bottom very early, so that the ice-foot is far out beyond the usual water-line. The exceptionally mild winter of 1905-6 did not permit the water to freeze far out, so that at the end of January there was only a very narrow zone of shore ice, extending out not over 50-100 feet.

At the time of the author's visit the condition was somewhat as follows: There had been several very mild days with decided thawing, and the beach presented the appearance of a compact mass of balls of semi-solid ice, which upon investigation turned out to be masses of snow crystals which, by thawing and freezing and by additions from the water of the lake, had grown to the diameter of a millimeter or two. The mass of ice had been broken along several parallel lines and displaced, showing a thickness of 3-4 feet; and this showed that the beach ice was a mass of the snowballs cemented by snow and frozen spray. The beach at this point runs slightly west of south, and the snowballs on the surface had been forced into prominence by the melting away of the softer cementing snow between them; moreover, about one-third of each ball was melted away on the south side. The southern faces which had suffered by melting presented a most peculiar appearance, which led to the recognition of the true nature of the balls. As shown in the figures, the melting had caused the contained dirt to accumulate on the surface, and it appeared as concentric rings. Close examination showed that this dirt was true beach sand and gravel. All the balls, varying in size from 3 inches to 3 or 4 feet, showed the same concentric arrangement, but in some the layers were alternately snow and clearer ice rather than snow and sand.

There seems but one explanation of this very queer phenomenon: the balls were rolled by the waves. The beach is a flat, smooth sand beach, and the water is very shallow for a considerable distance out. It seems that in some snowstorm early in the winter, before any ice-foot had formed, the beach must have been covered with 2 or 3 inches of a snow (the layers of the snowballs are from an inch to an inch and a half in their present compacted condition), in a very damp and soggy state, perhaps filling the water adjacent to the shore with a heavy slush. The water must have been very close to the freezing-point, so that there was little or no melting of the snow as it came in contact with the water. Now, a rise of the wind would produce a surge which, moving up the beach and back, started the snow in motion, and as the snow was water-soaked, and too heavy to float with any buoyancy, it was pushed back and forth until it was compressed into a small mass which began to roll. There is no distinct nucleus to the balls either of harder snow or of small pieces of ice, as might be expected, but the center seems the same as the outer parts. As the balls grew in size, it is evident that they rolled on the solid beach, gathering up a layer equal to the thickness of the snow on the beach, and including a thin layer of the sand and small gravel in the bottom of the layer.

The scarcity of the phenomenon seems amply accounted for by the peculiar conditions necessary for its production. There must be wide, flat beach such that the surge of the waves can carry them forward and back for a considerable distance; the water must be reduced to the freezing-point without the formation of an ice-foot which would hold the waves off the beach; and there must be a mass of soft, damp snow ready for the action of the waves.

• Glacier Problems

GLACIOLOGY'S GRAND UNSOLVED PROBLEM

Weertman, J.; *Nature,* 260:284-286, 1976.

Over the past two decades our understanding of the behaviour and the motion of glaciers, ice shelves, and ice sheets has progressed and increased very nicely. We know enough now to recognise a grand glaciological problem that remains to be solved. The West Antarctic Ice Sheet is this problem. Actually it is a set of inter-related problems. The base of this ice sheet over a major part of its area is 0.5 to 1 km below sea level. A major fraction of its bed would remain below sea level if the ice sheet were removed and isostatic rebound took place. How then did this ice sheet form? Why does it remain in existence? Is it growing or disintegrating at the present time? The ice in one half of the West Antarctic Ice Sheet is draining primarily through very fast moving ice streams into the Ross Ice Shelf. These ice streams apparently are not centred over any deep, fiord-like channels cut into the bedrock, and therefore could not have existed in their present position for any great length of time. The velocity of ice in the ice streams, about 1 km yr^{-1}, is comparable to that of the ill-understood surging glaciers. (Surging glaciers temporarily move, over a 1 to 2-yr period, at velocities that are one to three orders of magnitude larger than a normal glacier velocity.) Why do very fast moving ice streams form at the periphery of the West Antarctic Ice Sheet? Why do they move so swiftly? Is their existence a premonitory phenomenon to a large scale surge of the whole ice sheet? Are the ice streams the start of a process that may cause the West Antarctic Ice Sheet in the near future to flow very rapidly and to discharge about one-third to one-half of its total volume of ice into the oceans over a short time period of the order, say, of 100 years?

....

UNUSUAL WAVES AND RIPPLES IN STRATA

Wave-like structures in geology range from tiny ripples in lake sand to syncline-anticline undulations hundreds of miles in wavelength. Size was used as a criterion in this section only in the case of the giant ocean-bottom ripples found in a few ocean basins. The sheer magnitude of these structures infers ponderous currents, perhaps of catastrophic origin. The other ripples mentioned were chosen simply for their curiosity value; i.e., geometric perfection and dynamic nature.

GIANT RIPPLES TELL OF ENDURING OCEAN FLOW

Anonymous; *New Scientist,* 38:113, 1968.

Research on the detection of what he terms "palaeocurrents" has only just begun but is already starting to yield dividends, according to Maurice Ewing, director of the University of Columbia's Lamont Geological Observatory. Speaking at a recent NATO conference held at Newcastle upon Tyne University, he described studies that have latterly been made on the strange features that have come to be known as megaripples---regularly formed giant undulations, measured by echo sounders, that straddle the ocean floor with distances of three to four miles between crest and crest.

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To date they have looked at two areas in some detail. The first is the Argentine Basin in the South Atlantic where enroaching Antarctic currents have produced considerable areas of uniform giant ripples. They are too flat to be explained as the result of gravitational creep, according to Ewing, and optical tests on sediments in suspension suggest that they are a direct result of controlled deposition in which scouring plays little part.

Seismic profiling, which cuts a kind of section through the ripples, is especially revealing. Beneath the Argentine Basin is a hard layer, apparently of Cretaceous age and perhaps rather over a hundred million years old, which bounces back the seismic signal. Down to this depth stratification occurs which indicates that the ripple pattern has persisted for this great length of time.

While the pattern is unchanged, however, the crest of each ripple appears to have migrated slowly during its history. The direction of migration, Ewing believes, probably reflects the prevailing current direction in the past, deposition of fresh sediment taking place on the downstream side of the undulations just as sand accumulates on the lee sides of dunes.

....

Parallel ridges resembling giant ripple marks near Owen Sound, Ontario. Composed of till and large boulders, the ridges are perpendicular to axes of nearby drumlins. (Douglas E. Cox)

ON THE SO-CALLED "BARREL-QUARTZ," OF NOVA SCOTIA

Silliman, B., Jr.; *American Journal of Science,* 2:38:104-106, 1864.

On Laidlaw's Hill, forming the eastern division of the Waverley Gold District, has been found, in great abundance, a peculiar variety of quartz-rock which has acquired a wide reputation under the name of barrel-quartz.

Mr. Phillips, of London, has thus described it:

"The most remarkable deposit of auriferous quartz hitherto found in Nova Scotia is undoubtedly that at Laidlaw's Farm. The principal workings are here situated near the summit of a hill composed of hard, metamorphic shales, where openings have been made, to the depth of four or five feet, upon a nearly horizontal bed of corrugated quartz of from eight to ten inches in thickness. This auriferous deposit is entirely different from anything I had before seen, and when laid open presents the appearance of trees or logs of wood laid together side by side, after the manner of an American corduroy road.

"From this circumstance the miners have applied the name of 'barrel-quartz' to the formation, which, in many cases, presents an appearance not unlike a series of small casks laid together side by side and end to end.

"The rock covering this remarkable horizontal vein is exceedingly hard; but beneath it, for some little distance, it is softer and more fissile. The quartz is itself foliated parallel to the lines of curvature, and exhibits a tendency to break in accordance with these striae.

"The headings, and particularly the upper surfaces of the corrugations, are generally covered by a thin bark-like coating of brown oxyd of iron, which is seen frequently to enclose numerous particles of coarse gold, and the quartz in the vicinity of this oxyd of iron is itself often highly auriferous."

The accompanying section, which I have prepared from a sketch of the place as I saw it in December, will, together with the following perspective view of the opening, convey a clear idea of its peculiar structure.

Only the corrugations in the open part of the cut are visible; the extension of the vein to the right and left, in fig. 1, is ideal, the superincumbent mass covering it. I measured, however, the quartzite above, dipping to the right and left at a small angle, and I think no geologist would doubt that the crest of an anticlinal axis here comes to the surface and has escaped the denudation which has removed the top of the crest in most places. The corrugations, or folds, appear to be accounted for on the hypothesis of a lateral thrust producing the undulations. The perspective view of this interesting locality was taken from a stereoscopic photograph, showing the appearance of the barrel-quartz after the surface-rock (quartzite) had been removed, and before the miners had broken up the quartz layer for removal.

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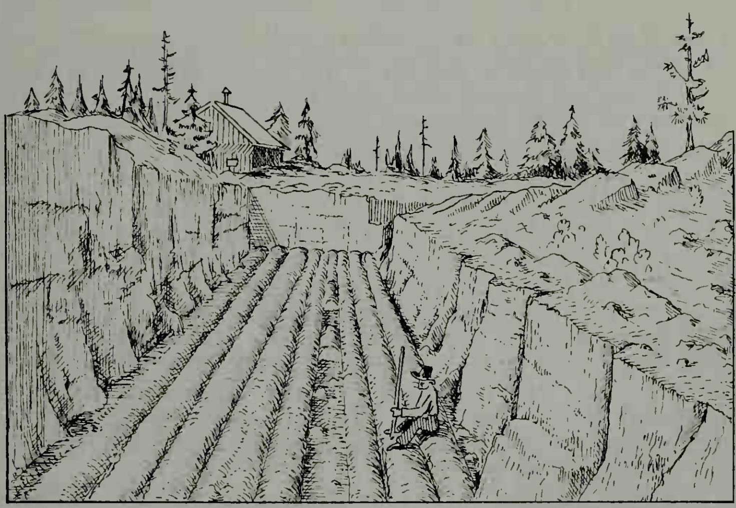


Curious barrel quartz found in Nova Scotia.

THE FORMATION OF GRAVITATIONAL WAVES IN THE CULEBRA CUT

Cornish, Vaughan; *Geographical Journal,* 41:239-243, 1913.

The annual report of the Isthmian Canal Commission which have been presented to the library of the Society contain a fund of authentic information on an undertaking of great importance to engineers, geographers, and to all who are concerned with the adaptation of the white race to the conditions of life and colonization in the tropics. Much that has been written lately upon these matters is readily accessible and need not be repeated here, but there is one unlooked-for aspect of the constructive work of special interest to physical geography, and which therefore demands our attention. This is the gravitational upheaval of the compact rocks which form the bottom or floor of the excavation between Empire and Gold Hill in the great Culebra Cut. From time to time during the last four years portions of the bottom, a few hundred feet long and perhaps as much as a hundred feet wide, have risen in a hump or weald often to a total height of 20 feet, once to a height of 30 feet. The upheaval is rapid. In one case it was 9 feet in an afternoon, in another it was 10 feet in ten minutes. The upheavals occur both in the dry and in the wet seasons. The upheaved rock comes up quite dry, and its surface is crevassed. The upheaval is accompanied or more often followed by a subsidence of the bank some distance at the back of it, forming a concave depression with a crevassed surface. Between the crevassed convex upheaval and the crevassed concave subsidence the surface generally remains without deformation. It has happened that in such an intermediate position a locomotive has remained without disturbance upon the rails of a construction track. I examined these phenomena in July and August, 1910, in the wet season, and in April and May, 1912, in the dry season, and have consulted the reports of the Commission from 1899 to 1912 for further light upon them.

Taking the position "mile 36" north of the village of Culebra as central and typical of the bad piece of the Cut, I find that no upheaval is recorded as happening during the French work when the depth on the centre line reached 45 feet. A single slight upheaval occurred in 1909, five years after the Americans began work, when the depth on the centre line was 65 feet. Next year a continuous slope was substituted for the terraced sides, and the bottom was lowered 35 feet, to a total depth of 100 feet on the centre line (and more at the sides). In this year the largest upheavals occurred, and they were very numerous. Next year benches or terraces were again cut in the sides, the slopes were greatly flattened, and the dynamite charges used for blasting were reduced. By the end of this year, during which the bottom was lowered 15 feet to a total depth of 115 feet, the upheavals had almost ceased. Finally, during 1912, maintaining the terraced form of side, working with the reduced dynamite charges, and keeping the flatter slopes, the level was again lowered by about 30 feet, the present depth on the centre line being about 150 feet, with a maximum height at the sides of about 260 feet.

During this year the upheavals recommenced, and though none exceeded 20 feet in height, they were considerable in size and numerous. The amount of material moving into the Cut from the "breaks" above has been very large. The report for the year ending June 30, 1912, which is just out, states that none of them would have prevented navigation. The latest numbers of the weekly Canal Record state that there have been large "breaks" recently. The final depth being now very nearly reached, there cannot, however, be another year in store for the engineers in which any great additional strain can be thrown upon the cohesive strength of the bottom rocks, so that the trouble, though not at an end, will, I think, diminish and ultimately cease.

My business, however, is with the explanation of what has occurred. An examination of the two sections shows at a glance how utterly unforeseen was the behaviour of the rocks. The International Board of Consulting Engineers were unanimously of opinion that the rocks would stand stably at a slope of 3 vertical on 2 horizontal even if a sea-level canal were made. Yet the bottom bursts up and the sides cave and break with a depth on the centre line 80 feet less than that of the proposed sea-level canal, and with a slope of 1 vertical on about 3 horizontal. The strata here not being tilted towards the canal, there was no fear of the upper layers gliding upon lubricated under-surfaces, neither have they done so. The point to be noticed is that a body of eminent engineers, American and European, estimated the strength of the rocks to be such that they would be stable at a depth of excavation on the centre line of 245 feet, whereas, in fact, they began to collapse when the depth was only about 65 feet. Numerous borings had been made, so that the quality of the underlying rocks was not unknown. It is hardly to be supposed that experienced engineers would overestimate by 400 per cent. the strength of rock-specimens which they could see and handle. The explanation of their mistake seems to be that certain of the underlying rocks have subsequently undergone deterioration owing to the access to them of rain-water let in by the removal of overlying material. It is stated in the Reports that the upheavals occur where there are seams of weak rock underlying the bottom. Mr. A. B. Nicholls, office engineer at Culebra, who has in his charge the rock specimens, informed me that these seams are in fact strong until they are wetted, when they quickly rot. This view is foreshadowed in an interesting manner by the report of Mr. Marcel Bertrand, of Paris, and Mr. P. Zurcher in Appendix B of the Report of the International Board of Engineers. In preparing for microscopic examination thin slices of rock freshly taken from deep shafts and apparently solid, they had to use oil instead of water, as, after an immersion of a few minutes in water, the specimens crumbled with a touch, even in the case of eruptive rocks, the material separating like marl or granulating like sand. Some of them were interspersed with clayey filaments. Combining these facts with my own observations on the spot, and the record of the relation of the occurrence of upheavals to the depth and other circumstances, I conclude that they were produced as follows. As soon as an underlying seam of lignite or of rock containing clayey filaments or oxidisable sulphide of iron (of which there is much) has its cohesion destroyed by the chemical and mechanical action of percolating rain-water, it begins to flow fragmentally from the position where the superincumbent weight is unreduced towards that where it has been lessened. The crushed and squeezed material transmits pressure in all directions, and when the floor above it becomes thin owing to the lowering of the excavation nearly to the level of the seam, it bursts up the floor. The escape of material leaves a cave under the banks of the canal which then collapse under their own weight as any extensive sheet of rock will if left unsupported. Trouble was anticipated with a weak seam underlying Contractors' hill, where the depth is greater than at mile 36, but there has been no upheaval. This may be due to the impervious character of the andesitic rock of which the principal mass of the hill is composed.

Upheaval of water-logged soil often occurs where pressure is transmitted by the water from an embankment or in a cutting, but there is no such saturation in the Culebra Cut at the end of such a dry season as that of the winter and spring of 1912, so that, although the mischief is, I think, caused by rain-water, it has acted in a novel and unexpected way, and the upheavals in the Culebra Cut are not caused in the same way as the bulging of swampy ground.

That they are actually gravitation waves in the lithosphere is illustrated by the following case which was told me by Colonel D. D. Gaillard, engineer in charge of the central division, which comprises the Culebra Cut. An upheaval of the bottom, and a collapse of the rock of the bank behind, occurred just north of Gold hill on the east side of the canal. The upheaved hump was removed by the steam-shovel. The bottom again upheaved in the same place, and a second subsidence occurred in the bank at the back of it. The second hump was removed, when the bottom bulged up a third time, and a third subsidence occurred behind. The action was repeated in all seven times on a diminishing scale before equilibrium became permanent.

I do not think that upheavals would have been a marked feature in the Cut if the rock had been merely weak but unstratified, for it would then, I presume, have given way almost entirely at the foot of the bank. A stratified arrangement is precedent to the formation of well-defined surface-waves in the atmosphere and hydrosphere. A columnar arrangement, on the contrary, prevents the formation of surface waves. Thus in the atmosphere wave-clouds are formed when a layer of warmer air travels over a layer of colder air, but when the structure of the air is columnar there are no wave-clouds but piled-up cumulus. When the wind blows directly across the regular ridges of an ocean swell and in the direction of their motion it quickly develops them into great and regular waves. But when the wind is diagonal to the swell the water becomes cut up into pyramids, the vortices of wind have their axes tilted out of their horizontal, the air thus becoming more columnar in structure, and the growth of the waves (as I have often noticed at sea) is very slow.

Stratification is the normal structure of the lithosphere, and the strata, originally plane, generally become wavy when disturbed. Wherever an underlying layer is more fluid than those above and below, it tends to flow from the place of greater to that of less pressure, forcing up the superincumbent stratum in the latter and letting it down in the former place with the formation of a waved surface.

MISCELLANEOUS STRATIGRAPHIC ANOMALIES

-Persistence of thin strata
-Lakes with old seawater on their bottoms
-Dry quicksand
-High-level gravels south of the continental ice sheets
-Stone layers in the soils of the southeastern U.S.
-Iridium anomaly
-Anomalous sands and gravels under the ocean
-Anomalous sedimentary rocks in the deep oceans
-Deep-sea ash layers
-Enigmatic magma under the Pacific

REMARKABLE PERSISTENCE OF THIN HORIZONS

Chadwick, George; *Geological Society of America, Bulletin,* 30:157, 1919.

Abstract. A very unusual case of the persistence laterally for scores of miles of numerous intercalated thin beds of black shale and of limestone, often but half an inch and seldom over a foot thick, is afforded by the upper Devonian Hanover shale of Cattarangus and Erie counties, New York. Several of these beds have been traced from Lake Erie to the Genesee River. Zones of small concretions in the green shale are euqally persistent.

THE PERSISTENCE OF FACIES

Ager, Derek; *The Nature of the Stratigraphic Record,* Macmillan, London, 1973, pp. 1-2.

In 1957 I had the good fortune to visit the geologically exciting country of Turkey, to look at some of the local Mesozoic rocks and their faunas. I was taken by a Turkish friend to visit a cliff section in Upper Cretaceous sediments near Sile on the Black Sea coast. In the Turkish literature these were described as white limestones with chert nodules and a strange-sounding list of fossils. But what I in fact saw was the familiar white chalk of north-west Europe with black flints and old fossil friends such as Micraster and Echinocorys. What I was looking at was identical with the 'White Cliffs of Dover' in England and the rolling plateau of Picardy in France, the quarries of sourthern Sweden and the cliffs of eastern Denmark. This set me thinking on the themes that are expressed in this book.

Though I thought the above observation worthy of a mini-publication, it might be said that it was not all that surprising. We have long known, of course, that the White Chalk facies of late Cretaceous times extended all the way from Antrim in Northern Ireland, via England and northern France, through the Low Countries, northern Germany and southern Scandinavia to Poland, Bulgaria and eventually to Georgia in the south of the Soviet Union. We also knew of the same facies in Egypt and Israel. My record was merely an extension of that vast range to the south side of the Black Sea.

Similarly, at the other end of the belt, Chalk was later discovered in south-west Ireland (where it must have been noticed by the early surveyors, but they had evidently been too scared of their autocratic director to record such an unlikely phenomenon). Later still it was found covering extensive areas of the sea floor south of Ireland.

Now this spread of a uniform facies is remarkable enough, but it must also be remembered that chalk is a very unusual sediment: an extremely pure coccolith limestone which is almost unique in the stratigraphical column. Nevertheless, there is even worse to come, for on the other side of the Atlantic in Texas, we find the Austin Chalk of the same age and character, and later Cretaceous chalks (still contemporaneous with the European development) are found in Arkansas, Mississippi and Alabama. And most surprising of all, much farther away still in Western Australia, we have the Gingin Chalk of late Cretaceous age, with the same black flints and the same familiar fossils, resting---as in north-west Europe---on glauconitic sands.

Some general explanation is surely needed for such a wide distribution of such a unique facies during a comparatively short period of geological time. What is more, there has been no other deposit quite like it either before or since, except perhaps some Miocene chalks which themselves are remarkably widespread: in the western approaches to the English Channel, in Cyprus and the Middle East and all the way to New Zealand. (pp. 1-2)

A SECOND LAKE WITH OLD SEA-WATER AT ITS BOTTOM

Strom, Kaare; *Nature,* 189:913, 1961.

Four years ago I directed attention to a Lake (Rorholtfjorden, part of Lake Tokke, in southern Norway) with trapped sea-water. The surface altitude of that Lake is 60 m. above sea-level, and the estimated age of its bottom waters some 6,000 years, that is, of the marine salts contained in them; the present bottom waters probably possessing one-half of the salinity of those originally isolated.

While there are a long number of land-locked waters still having some communication with the sea, there are very few where bottom waters have been completely isolated, and not washed out through admixture with fresh water layers above. Until their discovery in Lake Tokke, salt bottom waters were known only from lakes near sea-level, where isolation through post-glacial land rise must have occurred but recently.

Since my communication, work in progress on lake Tokke has led to some results, especially concerning isotope distribution in sediments.

Further research made it very desirable to find a second lake with old sea-water, and finally, my collaborator, Mr. H. V. Sovik, in January 1961, discovered such a lake, Botnavatn, in the district of Salten, northern Norway (67^{o}N.), the altitude of the lake surface being 12 m.

Lake Ovrevatn, a land-locked fjord near Botnavatn, with an average height of its water-level of about 2 m. above daily ebb, is at the point of being isolated from the sea. We can thus assume a land rise since the isolation of Botnavatn, of about 10 m., and that the isolation probably took place some 3,000 years ago.

Botnvatn is 113 m. deep, with salt waters from 102 m. downward. Hydrography is very similar to that of Lake Tokke, where salt waters extend from 134 m. to the bottom (147 m.). A comparison may be made between the salt-water layers of the two lakes:

	Tokke, 144 m.	Botnvatn, 111 m.
Chlorine (mgm/1.)	9.24	7.26
Salinity (gm./kgm.)	16.71	13.14
Temp. (^{o}C.)	5.20	4.75

As is the case in Lake Tokke, the salt bottom waters contain enormous amounts of methane, and bubble violently when brought to the surface. We thus have to face the same problem as in Lake Tokke, that with decrease in pressure the release of methane, also within the sediments, makes it very difficult to secure undisturbed samples of the bottom deposits.

A LAKE IN BRITISH COLUMBIA CONTAINING OLD SEA-WATER

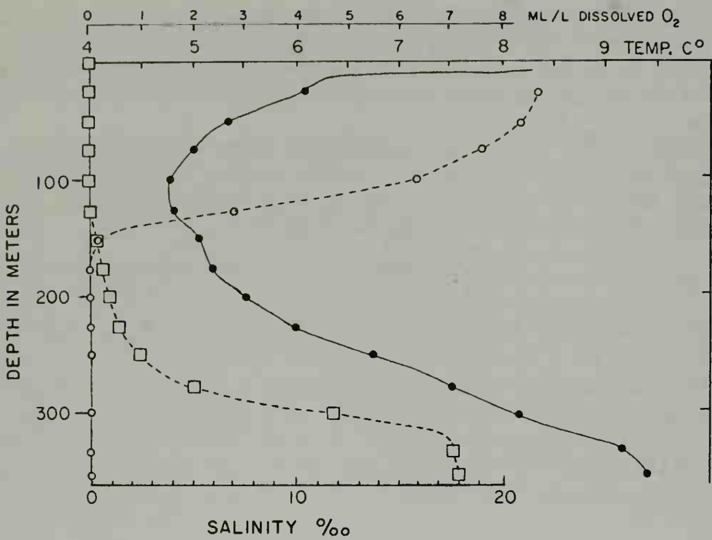
Williams, P. M., et al; *Nature,* 191:830-832, 1961.

Stimulated by Strom's reports and by N. M. Carter's speculations (oral communication), we have made a preliminary examination of Powell Lake, British Columbia, and find conditions therein similar to those described by Strom for Lakes Tokke and Botnvatn in Norway.

Powell Lake is a fjord lake about 50 km. long and 2 km. wide. The outline of the lake and the form of the mountains rising above it resemble the many fjord-like inlets along the British Columbian coast. However, the southern end of the lake (49^{o} 53'N., 124^{o} 32' W.) is separated from the adjacent strait of Georgia by a rocky sill 46 m. above sealevel.

A dam built fifty years ago downstream from the sill raises the lake-level to 56 m. above sea-level. Some 16 spot soundings made prior to our investigations indicated a maximum depth of 418 m., but the maximum which we recorded was 358 m. Of 10 soundings made by us in the southern part of the lake, a basin 10 km. long, 7 fell in the range 346-358 m. suggesting a nearly horizontal floor in this part. This lower part of the lake is separated from the upper part by two narrow straits which, judging from the few early soundings, are appreciably shallower than the basins above and below. The upper basins receive nearly all the important streams tributary to the lake. Turbidity currents which might develop directly from the muddy streams or by mudslides from actively growing deltas are likely to be trapped in the upper basins, leaving the lower basin free, or nearly so, of invasions at depth by turbid water.

The salient water characteristics which make the Lake worthy of remark are shown in Fig. 1. Results were obtained on May 29 and 30, 1961, from the centre of the lower basin where the depths exceeded 350 m. The considerable rise in temperature of nearly 5^{o} C. from 100 m. to the bottom was the first indication that the deeper water needed a significant



Distribution of temperature, salinity, and dissolved oxygen in Powell Lake, Canada.

salt content for stability. The chlorinity of the samples was determined by titration with silver nitrate and the salinity computed from Knudsen's relationship. It should be noted that this relationship is not entirely valid due to appreciable variations in the ratios of the ionic constituents of the water of the Lake from those found in modern sea-water. For example, the correction of the chlorinity titration for the presence of hydrogen sulphide reduces the salinity from 16.92 to 16.58 in the 334-m. sample. However, density and electrical conductivity values for the deep-water samples agreed closely with those for sea water of the same salinity. The presence of large amounts of dissolved gases in the bottom 50 m. of the water column was evident from the voluminous degassing which occurred while drawing the samples. These oxygen-depleted bottom waters had an in situ pH of 6.7-6.9 and showed a distinct yellow colour which increased in intensity with depth and was evidently due to dissolved organic matter. As shown in Table 1, the high hydrogen sulphide content of the bottom water results in the expected concurrent low iron (ii) concentration. Curiously enough, this is a condition opposite to that found by Strom for Lake Tokke which in comparable chemical properties was otherwise similar to Powell Lake.

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A DRY QUICKSAND

Anonymous; *American Meteorological Journal*, 3:4-5, 1886.

In the southwestern corner of the desert of southern Arabia, north of the western end of Hadramaut, and approached from the little village of Sawa, is a very remarkable spot described by Wrede from his visit in 1843, whose description is reproduced in a recent number of the Revue coloniale internationale. There are here, in the waste of yellow sand, several spots covered by a grayish white dust, which swallow up every object thrown into them. One of these spots, described by Wrede, is about two miles long and a little less in breadth. It sinks gradually toward the middle and is apparently due to the work of the wind. Wrede approached it with the greatest care and sounded it with his staff. The edge is stony and falls away suddenly. When the staff was thrust into the fine material beyond the edge, almost no resistance was felt and it was as if the staff had been thrust into water. When it was passed through the fine dust lengthwise the resistance was almost imperceptible. A stone of two pounds weight or more was fastened to a cord sixty fathoms long and thrown in as far as possible. It sank at once and with increasing velocity so that at the end of five minutes the end of the cord had disappeared. The presence of Bedouins prevented any more observations. The natives believe that great treasures are buried here and are watched over by genii who pull down into the depths the unwary treasure-seeker.

HIGH LEVEL GRAVELS OF KENTUCKY

Anonymous; *Science*, 3:276, 1896.

The rolling limestone uplands of the blue-grass region of Kentucky, rimmed around by sandstone escarpments on the south, and dissected by deep narrow valleys of streams that flow to the Ohio on the north, are strewn over at various places with gravels and sands. The distribution of the gravels is discussed by A. M. Miller, of Lexington, Ky. (Amer. Geol., XVI., 1895, 281-287). These loose materials are water-worn and bedded, and are derived mostly from the harder rocks of the enclosing escarpments; they are found chiefly near existing valleys. Miller concludes that within comparatively recent times the rivers were flooded to a height of 300 to 350 feet above their present channels. In explanation of such flooding, a glacial obstruction of the Ohio is considered as a possibility, but satisfactory evidence is not found in favor of it. 'Submergence' of unspecified nature is also mentioned without reaching any definite conclusion about it.

No consideration is given to the possibility that the gravels may have been spread over the upland surface before the present canyon-like valleys were eroded, while the whole region stood at a lower level than at present, but not submerged. This is eminently possible, for the aspect of the blue-grass region is strongly suggestive of base-levelling during a former lower stand of the land, and of dissection after elevation to the present altitude, as has been suggested by Westgate (Amer. Geol., XI., 1893, 258-259). The prepossession that the upland gravels could not endure for so long a time as would be needed to carve the canyon-like valleys is not well supported. Old river gravels lie on rock benches enclosing the gorge of the upper Ohio; and in similar position on the valley slopes of the Meuse in its transverse path across the Ardennes; even the fine loess of the upper bench of the Rhine valley in the Schiefergebirge is older than the narrow gorge of that energetic river.

A HIGH-LEVEL BOULDER DEPOSIT.....

Bretz, J. Harlen, and Horberg, Leland; *Journal of Geology,* 60:480-488, 1952.

Abstract. A narrow belt of granitic boulders weathered from a pebble and cobble conglomerate and occupying the highest mesa and butte summits of the region extends for about 18 miles out on the Tertiary plain east of the Laramie Range in Platte County, Wyoming. The conglomerate is judged to be a record of a vigorous late Tertiary river which managed to move 20-foot boulders 18 miles on a gradient of not more than 75 feet to the mile. Field evidence supports this interpretation and does not permit favorable consideration of any other hypothesis.

HIGH-LEVEL GRAVELS OF WESTERN GRAND CANYON

Koons, Donaldson; *Science,* 107:475-476, 1948.

Field studies conducted during the summer of 1946 in the vicinity of Western Grand Canyon, Arizona, and the Hualpai Indian Reservation disclosed the presence of large areas of gravel composed of pebbles foreign to the region. Depsoits are found at heights of 3,500-4,000' above present river level. An occurrence of these gravels near Frazier Well, in the Hualpai Reservation, is mentioned by Darton without discussion, and two small areas are indicated on the geological map of Arizona.

Detailed study of the gravel deposits showed that they were more extensive than had been indicated previously and that two types of gravel could be distinguished. The first is composed of poorly rounded and sorted pebbles of limestone, sandstone, and chert of local derivation and rests on steep bed-rock slopes. It is interpreted as a talus and alluvial cone deposit preserved in favorable locations during reduction of the cliffs at the bases of which it was deposited. The name 'Robbers Roost Gravel' is proposed for this group, because of its occurrence in good exposure near the mesa of the same name.

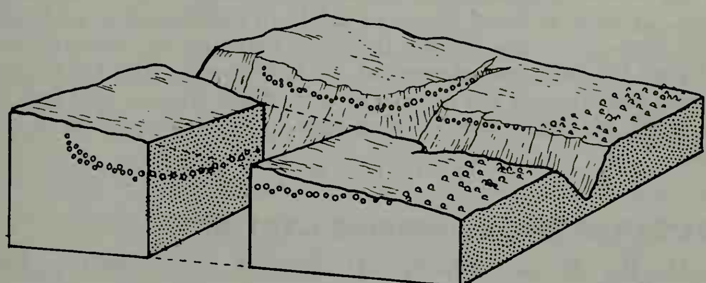
The second gravel, more extensively developed, consists of well-rounded pebbles and boulders of vein quartz, granite, gneiss, schist, red and white quartzite, and sandstone. These gravels are best exposed near Frazier Well and the name 'Frazier Well Gravel' is consequently proposed. The deposits vary in thickness from a thin veneer to more than 200', the maximum thickness being found near Frazier Well. Present elevation of the deposits varies from 5,660', 12 miles southwest of Frazier Well to 7,150', 5 miles northwest of the Well. Though the southern end of the Toroweap Fault passes between these two localities, the total displacement is insufficient to account for the present difference in elevation, and it appears that part, at least, of this difference is original, resulting from early deposition at the higher elevations, followed by later deposition at the lower elevations. Pebble counts show that at lower elevations granite and gneissic pebbles comprise up to 50% of the total, while at the highest elevation quartzite pebbles comprise up to 80% of the total and granitic pebbles are absent. Age of the deposits has not been determined, but weathering to depths of 15', with partial decomposition of pebbles, has occurred and suggests that the deposits are pre-Pleistocene.

The nearest present outcrop of this assemblage of rock types is 50 miles southeast, in the Basin Ranges northwest of Prescott and Jerome, an area which is today drained by the southeast-flowing Chino Creek. It is suggested that the Frazier Well gravels were deposited by north-flowing streams tributary to the Colorado originating in the Prescott-Jerome area and that drainage reversal followed Basin-Range faulting. If the gravels were deposited during erosion of an uplift to the south, it is to be expected that the older and topographically higher deposits would consist of pebbles derived from the sedimentary cover and that the later deposits would contain a greater proportion of pebbles derived from the underlying crystalline basement. The history of this area may thus be divided into the following stages: first, uplift of the Prescott-Jerome area, accompanied by development of north-flowing tributaries to the Colorado River and deposition of gravels in the Frazier Well area; second, development of Basic-Range faulting; third, reversal of drainage along the margin of the plateau and abandonment of the north-flowing channels.

DESCRIPTION AND ORIGIN OF STONE LAYERS IN THE SOILS OF THE SOUTHEASTERN STATES

Parizek, E. J., and Woodruff, J. F.; *Journal of Geology,* 65:24-34, 1957.

Abstract. Layers and lenses of stones are common in the soils of the southeastern states. These accumulations were formerly termed stone-lines and assigned a subsurface origin. This paper renames the features carpedoliths and describes and classifies them on the basis of cross-



Diagrammatic presentation of the various characteristics of linear carpedoliths.

sectional profiles into two categories: (1) linear and (2) lenticular.

Possible modes of origin of carpedoliths are reviewed, and it is concluded that they are former surface aggregations covered by sheet wash and colluvial deposits. Such an origin implies a sequence of events during the late Cenozoic in which the climate had changed from one favorable to aggravated erosion to one conducive to deposition. It is suggested that man through cultivation has duplicated the erosional phase, and it is further proposed that, because of the widespread extent of carpedoliths, a high percentage of Piedmont soils is, in actuality, colluvial rather than residual.

DINOSAUR DEMISE: EXTRATERRESTRIAL SOURCE?

Anonymous; *Science News*, 115:356, 1979.

In the geologic timescale, the break between the Cretaceous and Tertiary periods, 65 million years ago, is marked distinctly by the sudden disappearance of about 50 percent of the genera, including dinosaurs, that inhabited earth at that time. No satisfactory explanation has ever been proposed for such a vast extinction. No sweeping climatic changes are recorded in the sediments, and theories that dinosaurs simply lost the evolutionary struggle do not account for the extinction of a multitude of other creatures, nor for the apparent suddenness of their demise. For lack of anything else, some scientists have proposed that an extraterrestrial event such as a meteorite swarm, a giant solar flare or a supernova could---either directly, by radiation, or indirectly, by inducing climatic changes---have been responsible. But hard evidence in support of any theory, conservative or outlandish, has been lacking.

Now, data reported at the meeting of the American Geophysical Union in Washington this week, while not solving the mystery, make the extinction look "more extraterrestrial than terrestrial," according to researcher Walter Alvarez of the University of California at Berkeley. Alvarez described a sudden jump in the amount of iridium---an element that is about 1,000 times more abundant in extraterrestrial material than in the earth's crust---in the boundary layer between Cretaceous and Tertiary sedimentary rock. Because the earth's own iridium is concentrated at the core, all of the element found in the crust must have an extraterrestrial origin, drifting in from space to settle in sedimentary rock or added violently by meteors. The sudden increase found by the researchers---about 25 times the background amount of iridium---is exactly coincident with the disappearance of the dinosaurs and other species and indicates that some large extraterrestrial event may have been involved in their extinction.

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DEEP-SEA SANDS AND SUBMARINE CANYONS

Ericson, D. B., et al; *Geological Society of America, Bulletin*, 62:961-965, 1951.

Well-sorted sands at abyssal depths far from land were first discovered in the South Atlantic by the Gazelle Expedition of 1874 to 1876. Since then other occurrences have been recorded from time to time, but until recently the significance and importance of these interesting sediments have not been appreciated.

In 1947 a bottom-sediment core (150-35) was taken by the research vessel Atlantis at a point 750 kilometers (400 nautical miles) southeast of New York City where the depth of water was 4755 meters (2600 fathoms). It contained several layers of well-sorted sand interbedded with clay and globigerina ooze. In the following year another core (152-135) 9 meters long was taken in the same region. It also contained sand layers, one of which was more than a meter thick.

In the meantime much was being learned about the topography and sediments of the Hudson Canyon region. It was found that the canyon could be traced with certainty to a distance of about 280 km (150 nautical miles) southeast of the edge of the continental shelf. Beyond this point the regional topography assumed the form of a broad plain gently sloping to the southeast in which the Hudson Canyon was so little entrenched that it could no longer be followed with assurance. It was on this plain that the two cores containing sand had been taken. This association of coarse, well-sorted sediment with a topographical feature resembling an alluvial plain extending out beyond the Hudson Canyon strongly suggested a genetic connection between type of sediment and topography. In order to test the theory that the plain was in fact a submarine delta, a co-ordinated coring and topographic survey was tentatively planned. The much-hoped-for opportunity to carry out the plan came in the summer of 1950 when a scheduled survey by the R/V Atlantis in the Hudson Canyon region was interrupted for several days by unavoidable delay in the arrival of another vessel the assistance of which was required in completing the work.

By means of a piston coring tube 10 additional cores having an average length of 6.8 meters were taken on the plain. The numbers of these cores, the positions of which are shown on the accompanying chart, are included in the series 164-13 to 164-24. No cores were obtained at stations 164-18 and 164-21. Although study of these cores has not been completed, preliminary work on them has already yielded so much new evidence having an important bearing on submarine erosion and deep-sea sedimentation that a short note at this time is felt to be justified.

The 12 cores from the plain outline an area of about 15,500 square kilometers or 6000 square nautical miles. Depths of the core stations vary from 4370 meters (2390 fathoms) to 4940 meters (2700 fathoms). All the cores, except one, 164-17, contain sand layers. The layers range in thickness from mere films of clean quartz silt to beds more than 6 meters thick. On the average about 30 per cent of the thickness of sediment penetrated is sand. The sediment interbedded with the sands is largely clay of abyssal facies. The number of sand layers and their positions in the cores differ greatly from core to core. The lower contacts of the individual layers where they rest on abyssal clay are very sharply defined. Graded bedding is evident in some of the sands. In others, where graded bedding is less obvious, it can be shown to be present by sieve analyses. In exceptional layers there is complete gradation from sand through silt into gray clay containing an abnormally large amount of calcium carbonate for the depth of water of the area. However, in the majority of cases the upper contacts of the sand layers show abrupt change from sand to normal deep-sea sediment. Sorting of particle sizes within the sand layers is always good. The small proportion of clay-size material in the sand layers is shown by their remarkable fluidity while still saturated with water. When dry many layers are no more coherent than beach sands.

Although all degrees of rounding, polishing, and frosting are found among the sand particles, angularity predominates. Quartz is the most abundant mineral, but there is usually an important fraction which includes various feldspars, micas, ferromagnesian minerals, and heavy minerals. Glauconite is nearly always present, and frequently there are also a few particles of red and gray shale, limestone, chert, fine-grained sandstone, and mica schist. Staining of some of the grains of quartz and feldspar by red iron oxide is not uncommon.

A number of short cores taken in 1947 by the R/V Balanus on the continental shelf in the vicinity of the head of the Hudson Canyon have been studied at the Lamont Geological Observatory. The coarse fractions of these shelf sediments are remarkably similar in mineral composition to the sands of the deep cores. Even the iron-oxide stain on quartz and feldspar grains is present in the shallow-water sediments. The only important difference is in the poor particle-size sorting of the shelf sediments in contrast to the good sorting of the deep-sea sands.

Foraminifera, though never abundant, are usually present in the coarser sands. In addition to the usual planktonic species there are almost without exception a few species which are characteristic of the continental shelf and slope sediments, such as Elphidium incertum, Globosalimina auriculata, and Nonion labradoricum. Not infrequently particles of vegetal matter are also present.

Faunal evidence from the sands and interbedded clays shows that none of the cores reaches sediment as old as the Sangamon interglacial stage of the Pleistocene. Although most of the sand layers must have been deposited during the Wisconsin Glacial stage, there is clear proof that a few have been laid down in post-Wisconsin time. Very recent deposition of sand is shown convincingly in core 164-14. Here a graded sand layer 72 cm thick overlies 38 cm of clay of abyssal facies containing the normal post-Wisconsin assemblage of Foraminifera known to be living in the region at the present time. This 38-cm layer in turn overlies dark-red clay containing a cold-water fauna. No trace of normal deep-water sediment overlies the sand layer. Further evidence that the sand was deposited only a short time ago is provided by the thickness of the post-Wisconsin zone beneath the sand. Its thickness compared with the thicknesses of corresponding layers in other cores from this region shows that it must represent very nearly all of post-Wisconsin time.

Except for one or two doubtful cases correlation of sand layers between even the most closely spaced cores---that is, about 10 miles apart ---has not been successful. On the contrary, much disparity from core to core in the thicknesses of interbedded deep-water clay layers, presumably deposited at constant rate throughout the region, shows that the sand layers must be of only local extent, and not continuous sheets blanketing the entire area.

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Several theories of the origin of deep-sea sands which have been advanced since their discovery 75 years ago can now be dismissed. Among these is the theory that they are composed of material which has been carried out from the continent by strong winds. Even if this mode of transportation could be admitted for the sands, it cannot explain the gravels. The good sorting and graded bedding are fatal to the theory of ice rafting as a mode of transportation for the sands.

Deposition at some time of greatly lowered sea level is disproved by the fact that in so many cases sand layers in certain cores can be shown to be equivalent to uninterrupted deposition of deep-sea clay in other cores. Furthermore, some of the sands have been laid down in Recent time, a fact difficult to reconcile with greatly lowered sea level, to say the least.

On the other hand, mineral and faunal similarity to the shelf sediments points to the continental shelf as the source of a large part of the material making up the sands. The presence of gravels containing shallow-water shells in the canyon bed, but nowhere on the divides outside the canyon, suggests that the route of transportation was through the canyon. Wide occurrence of sands in the sediments of the deep plain upon which the Hudson Canyon opens and absence of sands from the sediment of the gently sloping surface in which the canyon has been cut lead to the same conclusion. In view of the evidence it is the opinion of the authors that transportation by turbidity currents most satisfactorily explains the distribution of sands in the sediments of the plain as well as the occurrence of gravel on the canyon floor.

A conservative estimate of the volume of sand underlying the area of the plain which has actually been cored is in the order of 100 cubic kilometers. The passage of such a quantity of abrasive through the Hudson Canyon can hardly have taken place without more or less erosion of the relatively soft sediments forming the bed and walls. However, it is probable that the total amount of Pleistocene sand in the sediments of the plain is many times the amount estimated. Some erosion, at least, in the course of transportation of the gravel of the canyon is proven by inclusion in the gravel of the upper Eocene chalk pebbles and cobbles of green clay from the canyon walls.

The authors believe that the new evidence from the cores strongly supports the theory that erosion by turbidity currents has been an extremely important process, if not the only process, involved in the formation of the Hudson Canyon.

Several corollaries to these conclusions should be mentioned. If there is a genetic connection between the deep-sea sands of the plain and the Hudson Canyon, there ought to be similar submarine alluvial plains off other canyons of Eastern North America. Although no other area has been so thoroughly charted and cored as that of the Hudson Canyon, there is good evidence from cores and soundings that the Hudson submarine alluvial plain is only one of a series of coalescing alluvial plains which form a zone parallel to the continental slope. By the same reasoning coarse sediments should be found in the beds of other canyons. As yet gravels have not been cored elsewhere than in Hudson Canyon, but coarse sands have been found in other canyons.

If deep-sea sands have been transported by turbidity currents, large quantities of much finer sediment must have been carried out beyond the zone of alluvial plains to be deposited in the deep basins. Evidence of the deposition of this finer material has in fact been found. Some of the deepest cores taken in the North Atlantic contain layers of gray clay of abnormally high calcium carbonate content interbedded with red clay of normal deep-water facies. Frequently the lower contacts of such gray layers are marked by thin layers of clean silt. The gray layers, like the sand layers of the plain, fail to correlate from core to core. If these more calcareous layers were due to climatic changes during the Pleistocene, their lateral extension over fairly wide areas would be expectable. Furthermore, of two adjacent cores from different depths it is usually the deeper one which contains gray layers, while the other is quite likely to contain only normal red clay.

If our conclusion is correct that large quantities of sediment are carried to great distances along the sea bottom by turbidity currents it follows that the rate of deposition even in the deep basins must be much more rapid than has been supposed hitherto. An effect of such a depth-seeking process of sedimentation would be to fill depressions in the sea bottom most rapidly, thus eventually producing broad, nearly featureless plains. Fathometer records made on board the R/V Atlantis in the North Atlantic show that deep-basin topography is often characterized by just such monotonous plains broken only here and there by abruptly rising seamounts presumably of tectonic or volcanic origin.

The evidence presented here provides an extension to the ideas on submarine slumping which have grown up during the past few decades by showing that some of the slumped material is transported to great distances by turbidity currents. Both slumping and turbidity currents have been suggested as processes active upon the ocean bottom primarily on evidence from exposed marine strata. It has now been demonstrated from deep-sea sediments that turbidity currents play a dominant role in marine sedimentation. They transport large amounts of sediment to mid-ocean, and they sort the sediments well during transportation. They deposit the sediments by a depth-seeking process, which tends to fill depressions and produce broad, almost featureless plains like those observed in the North Atlantic basin and on the flanks of the Mid-Atlantic Ridge. It follows that the rate of deposition in the deep basins must be more rapid than has been supposed hitherto, and that an important part of all deep-sea sediments has been transported, and thereby sorted, at least one time after initial deposition on the ocean floor.

COARSE SEDIMENTS ON THE EDGE OF THE CONTINENTAL SHELF

Fairbridge, Rhodes W.; *American Journal of Science,* 245:146-152, 1947.

Abstract. It is paradoxical that the coarsest sediments of the Continental Shelf are found on the outermost edge, apparently too far from the present shore for normal transportation. They have been already explained as relics of a Pleistocene shore-line, when the sea-level was considerably lower than it is today. Their continued exposure and absence of masking by Recent sediments is sometimes ignored, sometimes explained by current action, and at others by high-amplitude wave action. While admitting much activity by currents, and by waves at limited depths, it is here postulated that the soft post-Glacial sediments on the outer edge of the continental shelf periodically slip off, and slide down the continental slope by submarine slumping.

POSSIBLE INTERGLACIAL DUNE SANDS FROM 300 METERS WATER DEPTH IN THE WEDDELL SEA, ANTARCTICA

Rex, Robert W., et al; *Geological Society of America, Bulletin,* 81:3465-3472, 1970.

Abstract. A suite of orange-peel grab sediment samples collected during Deep Freeze II from the Antarctic continental shelf of the Weddell Sea contained several well-sorted sand samples. These were collected in 1957 from Berkner Bank in water depths of 282 to 300 m. Samples from greater and lesser depths show poorer sorting as well as differences in other size parameters. The well-sorted sands include both striated and fractured quartz grains with a considerable degree of polish.

Photographs and electron micrographs of grain surfaces and replicas suggest that entire grain surfaces of both the fractured surface morphology and the polished surface have undergone quartz dissolution suggesting an extensive period of exposure to seawater. Detailed studies show features characteristic of both beach and dune sand abrasion overlying glacial features.

A variable amount of rock flour is present in all samples, but is least abundant in the 290 ± 10 m depth samples. The samples from depths both greater and less than 290 ± 10 m appear to be typical of periglacial marine sediments with a poorly sorted heterogeneous assortment of minerals and rock fragments. The 290 ± 10 m samples appear strikingly different and strongly resemble quartz dune or beach sands. The very good sorting, size, and surface features suggest that these are dune sands.

These data indicate that Berkner Bank may have been exposed at the surface during an interglacial period when the Antarctic land surface stood approximately 300 m higher with respect to sea level than it does today.

JURASSIC SANDSTONE FROM THE TROPICAL ATLANTIC

Fox, Paul J., et al; *Science,* 170:1402-1404, 1970.

Abstract. The oldest sediment yet sampled from the abyssal margins of South America, late Jurassic (or possibly very early Cretaceous) shallow-water, coarse-grained, calcareous sandstone containing palynomorphs and mollusk prisms, was recovered from a depth of 4400 meters on the seaward scarp of the Demerara Plateau. The sandstone was deposited in a shallow, late Jurassic epicontinental sea after the initial stages of rifting when the newly created Atlantic began to founder.

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The sandstone is from the oldest outcrop yet sampled from the abyssal margins of the South Atlantic. If the samples are representative of an outcropping reflector near the base of the Demerara escarpment, then the Plateau has subsided 4400 m in the last 140 million years (0.03 mm/year). A subsidence history of this kind is remarkably similar to that documented for other plateaus and ridges in the Caribbean area.

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CONCRETE EVIDENCE FOR ATLANTIS?

Anonymous; *New Scientist*, 66:540, 1975.

Although they make no such fanciful claim from their results as to have discovered the mythical mid-Atlantic landmass, an international group of oceanographers has now convincingly confirmed preliminary findings that a sunken block of continent lies in the middle of the Atlantic Ocean. The discovery comes from analysing dredge samples taken along the line of the Vema offset fault, a long east-west fracture zone lying between Africa and South America close to latitude 11°N.

Four years ago two University of Miami workers, J. Honnorez and E. Bonatti, first reported the recovery of shallow-water limestone fragments from the Vema fracture zone. This limestone contained minerals indicative of a nearby granitic source unlikely to occur on the ocean floor. Neither water currents, nor more esoteric transport systems, could explain the presence of these rocks so far from the modern boundaries of the continents. The two researchers believed that, instead, the granitic grains must have been deposited close to their source.

Now, with C. Emiliani of Miami, Paul Bronniman of the University of Geneva, M. A. Furrer of Esso Production Research, Begles, and A. A. Meyerhof, a consulting geologist from Tulsa, USA, they have carried out a more searching analysis of the dredge samples (Earth and Planetary Science Letters, vol. 26, p. 8).

The limestones include traces of shallow-water fossils---foraminifera, green algae, bits of gastropods, and crab coprolites---implying formation in water, in one instance, less than 30 m deep. Furthermore, the limestones have been recrystallised from a high- to low-magnesium form of calcite. Oxygen- and carbon-isotope ratios prove conclusively that this process must have taken place subaerially "through the action of meteoric water enriched in light carbon while passing through a soil zone ..." A pitted limestone sample bears evidence of tidal action. Some 50 km east of the dredge site along the Vema fracture the team also recovered a thick-shelled, shallow-water, bivalve fossil from a depth of over 2000 m.

The coprolites in the sample indicate a Mesozoic age for the limestone which may well be the sedimentary capping on a residual continental block left behind as the Atlantic spread out into an ocean. The granitic minerals could thus have come from the bordering continents while the ocean was still in its infancy. Vertical movements made by the block appear to have raised it above sea level at some period during its history.

EXTENSIVE DEEP-SEA SUB-BOTTOM REFLECTIONS IDENTIFIED AS WHITE ASH

Worzel, J. Lamar; *National Academy of Sciences, Proceedings*, 45:349-355, 1959.

Introduction. Sub-bottom echoes have been observed since the advent of expanded scale recording sounders. Since the introduction of the Precision Depth Recorder (PDR) with a short ping (about 5 millisec) sub-bottom reflections have been recorded at many locations in the deep sea, e.g., Heezen et al. The observed sub-bottom reflections have not been systematically cored. On Vema cruise 15 (V-15) such an echo was observed over a very large area of the eastern part of the tropical Pacific Ocean. Long piston cores at eight locations penetrated to the depth of this echo in the sediment, and in most cases well beyond. A layer of clean white ash was encountered in each of these cores at the appropriate depth. The description of cores in this report is based on preliminary shipboard examination.

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Discussion. The great extent of a sub-bottom echo at depths of 0 to 40 meters below bottom in the tropical Eastern Pacific has been demonstrated. Occasionally there are two, and rarely three, sub-bottom echoes. The first sub-bottom echo is well correlated by cores throughout the area with a white ash layer. Since the layer is fairly near the surface and is not discolored and contains nothing but the glassy ash material, it must have been laid down fairly quickly. Foraminifera in clays above and below the layer promise that a date can be obtained after detailed examination of the cores. It is important to further delineate the area from which this strong sub-bottom echo is obtained and to sample the layer to determine whether it is due to the same white ash layer found here. The layer rises to the ocean floor toward the higher parts of the topography and deepens in the lower parts. It disappears on the shelves. It cannot be certainly identified in rough topography such as the walls of the Middle America and the Peru-Chile Trenches, but it is almost certainly present in the valley bottoms. It is not found on the trench floors, perhaps due to its deep burial.

If the white ash layer can be identified with the same time of occurrence in all of the cores, much can be learned of the sedimentation rates in this part of the Pacific and particularly about the variability of these rates.

The white ash immediately suggests a volcanic origin and the proximity of the Andes suggests the source. However, the great extent of the ash and its shallow cover would imply such a great amount of recent activity for a short time that it may well be difficult to ascribe it to the Andes. Until its extent, age, and identification are determined one can only speculate. Perhaps sub-bottom echoes from other areas can also be correlated with this white ash layer. If so, it may be necessary to attribute the layer to a world-wide volcanism or perhaps to the fiery end of bodies of cosmic origin.

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GLOBAL INCREASE IN QUATERNARY EXPLOSIVE VOLCANISM

Kennett, James P., and Thunell, Robert C.; *Science,* 187:497-502, 1975.

Summary. The worldwide distribution of volcanic ash has been determined from 320 deep-sea sections drilled during the Deep Sea Drilling Project. The ash distribution in the deep-sea sections, which span the last 20 million years, indicates that there has been a much higher rate of explosive volcanism from both island arc and hot spot volcanoes during the last 2 million years. This episode, and perhaps another in the Middle

Miocene, correlates with previously reported widespread synchronism in increased volcanicity in certain oceanic islands. Increased Quaternary volcanism coincides approximately with that episode of the Cenozoic marked by major and rapidly fluctuating climatic change.

ENIGMATIC MAGMA IN THE PACIFIC

Anonymous; *Science News,* 114:133, 1978.

The purpose of the cruise [Leg 61 of the Deep Sea Drilling Project] was fairly routine. Well-substantiated magnetic anomaly mapping of the Nauru Basin near the Marshall and Caroline islands predicted that sediments and ocean crust dating to the Late Jurassic (about 150 million years ago) existed there. Researchers picked the basin as a perfect spot to retrieve a continuous fossil and sediment record of the equatorial Pacific Ocean Basin and to sample the old, rapidly generated ocean crust. Drilling at only a single site, they ground through the expected layers of chert, clay, sandstone and black shales, anticipating only more sediment before striking crust. Instead, the Challenger's drill dug through 500 meters of a "huge, completely unexpected volcanic structure."

The 100-million-year-old volcanic complex---a mixture of basaltic sills, flows and volcanic sediments---represents a geologically quick (lasting about 10 million years) outpouring of magma that may cover the entire 500-by-1,000-kilometer basin. Mid to late Cretaceous sediment deposits from the nearby island reefs coincide in age with the volcanic complex, disputing the islands' supposed formation about 50 million years ago. This indicates, says Larson, that the "volcanic underpinning [of the islands] is the result of the culmination of this volcanic event.

More fundamental than pondering the islands' origin, researchers have to explain how the huge pile of mid-Cretaceous basalt got there. Similar intrusive sills are found throughout the Pacific, Larson says, but they range only 1 to 10 meters thick and are easily detected because they disrupt the underlying layers' magnetic signal. A volcanic outpouring of such size should have reheated the crust, allowing the realignment of the magnetic anomaly pattern, and should also have physically dislocated the underlying rock. But this magma mass did neither, and its uniform magnetic anomaly pattern amidst the Lake Jurassic signal made it "invisible" to the magnetometer.

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Chapter 2

MOUNDS, CRATERS, AND TOPOGRAPHICAL FEATURES

INTRODUCTION

Topographic anomalies are those hills, valleys, terraces, and other types of relief for which conventional geological explanations seem to fail. In many of the instances cited below, echoes of catastrophism are heard. The Carolina Bays, astroblemes, and huge ring structures may have been blasted out by extraterrestrial projectiles. The flat-topped guyots, high-level terraces, and submarine canyons may have been cut by oceans miles lower and/or thousands of feet higher than those that roll against today's shores. Sealevel changes of such magnitude certainly depart from the generally accepted histories of our planet. To be intellectually honest, the invocation of meteoric catastrophes and great sealevel changes must be balanced against less audacious theories involving such processes as vulcanism and turbidity currents. These more acceptable agents come close to explaining some anomalies. Nevertheless, catastrophism is becoming more acceptable with each year.

After extraterrestrial sources of catastrophism, the Ice Ages are most frequently cited as the source of unusual topographic relief. The Mima Mounds, deeply incised erosion surfaces, and some high-level terraces may owe their origin to periglacial phenomena, the locking-up of water in the supposed ice sheets, and the probable floods engendered by melting ice and ruptured ice dams. However, many of the anomalies recorded here seem to strain the Ice Age hypothesis, otherwise they would not be included.

The continents and ocean basins are macroscopic expressions of the earth's topography. Are there anomalies that challenge the prevailing hypothesis of Continental Drift or Global Plate Tectonics? There are, in fact, so many anomalies that the near-overwhelming acceptance of Plate Tectonics is surprising. The anomalies that do not fit the mould will, if the scientific method works ideally, stimulate new and better theories of the earth-as-a-whole.

CAROLINA BAYS, ORIENTED LAKES, ENIGMATIC DEPRESSIONS

The Carolina Bays are the best known of the several sets of shallow depressions described in this section. Thousands of these elliptical lakes pockmark the southeastern U.S. coastal plain. From the air, they impress the observer by their sheer numbers and common orientation. The Carolina Bays, however, represent just one member in this class. Almost as well-known are the Alaskan oriented lakes. Similar lake systems are now beginning to be recognized in other parts of the world.

The question of origin dominates the literature on these bays and lakes. An immense meteor swarm is favored as the excavating agent for the Carolina Bays, while the Alaskan lakes may have been formed by thawing permafrost. Wind-and-water erosion, underground seepage, and several other hypotheses are still in contention.

Somewhat smaller than the above bays and lakes are the systems of craterlets apparently blasted out by erupting gases and fluids. Some of these occur where severe earthquakes have shaken the region. Others have been discovered recently in shallow off-shore waters and are attributed to escaping natural gases.

• The Carolina Bays and Their Kin

SOME NOTES ON DARLINGTON (S.C.), 'BAYS'

Glenn, L. C.; *Science*, 2:472-475, 1895.

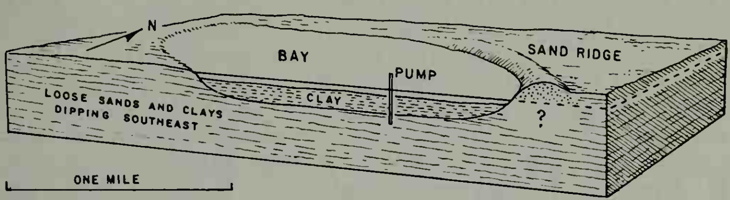
Having noted on a surveyor's map of my school district of Darlington, S.C., several lake-like expanses usually represented as being at the head of some very small stream, I began inquiries concerning them and followed this up by visiting several of the largest.

Parenthetically, I may say that Darlington is well out on the loose sands and clays of the coastal plain and while the main streams have cut down 30 to 40 feet beneath the general level of the country, yet their side streamlets are small, and much of the inter-stream surface is poorly dissected and but slightly changed from the condition in which it was uplifted from sea bottom. This inter-stream surface is very level, the slope being about one foot per mile; the streamlets are weak; and extensive systems of ditches are necessary to keep the upland drained for cultivation.

To the lake-like expanses the term 'bay' is usually applied, and by it is meant a perfectly flat, clayey area with a surface some two to four feet below the general level of the country and varying from a few acres in size to stretches a mile or two long and a half mile or more in width; the smaller ones being much more numerous and having usually an area of 20 to 30 acres. They are in some cases approximately round in shape, though they are usually ovoid or elliptical, and are covered with vegetation-stained water from a few inches to a foot or two deep, according to the season. Growing in this water, where the 'bay' is uncleared, are cypress, juniper or black-gum trees with a moderately thick swamp undergrowth.

Except when overflowed in a rainy season, there is often in the smaller 'bays' no permanent drainage. In the larger ones a small streamlet usually rises. When cleared for cultivation, the first requisite is to dig a ditch to the nearest stream or main ditch sufficiently deep for thorough drainage.

A sand ridge borders each 'bay' on the east and southeast and sometimes extends fairly well round toward the south, but is never found, so far as I could ascertain, on the west or north. The size of this sand ridge varies with the size of the 'bay,' rising in some well-pronounced cases 5 or 6 feet above the general level in the highest part and thinning out near both ends. In the usual case, however, it rises only some 2 or 3 feet above the general surface level. The width of the ridge varies from a rod to three or four rods. The transverse surface curvature is most often uniform, or if more precipitous on one side than on the other no law could be found governing such variation.



Section through a typical Carolina Bay.

A gentleman owning large tracts of land containing 'bays,' and having been a close observer of them, gave me much information and went a number of times to visit them with me. He called my attention to the fact that on first attempting to drain them for cultivation he had tried cutting ditches through this sand ridge, but found that the sand caved so easily (being, in a few cases, very quick) that it was very difficult to dig and keep such ditches open. The sand I thus found extended down below the surface of the adjacent sands and clays. How deep I could not find by direct test, probably not deeper at farthest than 15 to 25 feet, if nearly as deep as that, which I doubt. It is a rounded sand and, though used in Darlington for mortar, is very poor for building purposes. No fossils could be found in it so far as I searched. No stratification was visible. It is agriculturally extremely poor, and from its characteristic whiteness may be detected in a field that has been tilled for years. It seems to be a beach sand.

The basin when drained shows a dark fertile, compact clay, impervious to water and with no fossils so far as a rough search could detect. This clay extends down some 15 to 25 feet, as is proved by driven wells that have been forced down through it. No water is gotten until the pipe reaches the underlying sand, when the water at once rises to the general water level, within 6 or 8 ft. of the surface.

Other duties prevented my mapping the large number of 'bays' that occur, to see what relationship, if any, could be discovered from their position. They seem to be scattered irregularly over the flat surface, some nearer the present coast than others. Whether they arrange themselves along certain lines I cannot say.

By some the sand ridges are attributed to wind action. This, however, would require a region free of vegetation, and we do not know that this one ever was so over any broad area. Besides, the wind would pile the dunes on <u>other sides</u> of the 'bays' than the east and southeast, unless it blew always from the east or southeast---a supposition of which no proof can be given. Finally, wind action is insufficient to account for the bases of the sand ridges extending beneath the general surface of the adjacent sands and clays.

From an examination of the Coast Survey charts of the Albemarle and Pamlico Sound region, I was at first led to conclude that I had in the 'bays' the results of numerous repetitions on a smaller scale of what is now going on in these sounds---the difference in the <u>size</u> of the bodies compared being great, but their agreement in <u>process</u> being strong. Each sound is a drowned valley with a bottom 15 to 25 feet deep at most and, being cut off from the ocean by the sand bar thrown across its mouth, they are slowly silting up with the very fine material brought down by the sluggish streams that empty into them. If present conditions continue long enough they will be filled with a fine, compact clay, and are already skirted on the southwest and east by a sand dune. There is an apparent analogy. The former sea where Darlington now stands---though deep shortly before this from the thick beds of fuller's earth which must have been very gently deposited far from shore sands---was shallow, as is shown by the marl deposits near the surface and by the sands over all the region showing false or cross bedding and containing in some places moderate sized quartz pebbles. The shore line must have been low. Streams were probably numerous and small, no large drainage basins having been formed. Allow time enough for a little cutting of their channels by these newly-born streams, then a very small downward oscillation of the land, let the headlands be beaten off and bars thrown across the mouth of the drowned streams while the enclosed basin slowly fills with fine sediment, and finally let the whole region gradually rise as it has done in fact, and we have a theory of their origin.

This theory, however, is open to certain objections. No remains of an old stream channel entering this 'bay' is found. The existence of old beaten-off headlands on either side has been asked about. If these exist they are too faint to have made themselves noticeable when not looked for. They may exist in the case of the larger ones. The irregular distribution toward the present shore is another difficulty. The prevailing rounded or elliptical shape is not explained.

That the sea, when this part of the coastal plain rose above it, left numerous inequalities somewhat similar to the ripple-made pittings seen in the sand in the bottom of a gutter after a rain has suggested itself to me. If so, these basin-like pittings---separated from each other by sand ridges highest above the general shore slope on their east side---might have formed the basins for these 'bays.'

Fuller observation and study is needed before anything but a tentative conclusion may be reached. Any additional observations or suggestions will be gladly welcomed.

CAROLINA BAYS AND THEIR ORIGIN

Prouty, W. F.; *Geological Society of America, Bulletin,* 63:167-224, 1952.

Abstract. The Carolina Bays have a known distribution along the Atlantic Coastal Plain from northeast Florida to southeast New Jersey. Estimates based on actual counts in limited regions indicate a conservative figure of half a million bays in the entire area. Local areas show over 50 per cent coverage by bays.

Statistical studies of orientation show a greater divergence of smaller bays from the mean than of larger bays. Smaller bays also show greater variation in ellipticity than do larger bays. Both facts are most satisfactorily explained by the meteoritic theory of origin. Multiple and "heart-shaped" bays overlap in patterns explained most logically by the impact of tandem meteorites, some likely explosive in nature. The probable mechanics of such phenomena is illustrated. Study of near-coast bays indicate that the bays are younger than the youngest Pleistocene terrace and some of the Coastal Plain drainage and older than at least one of the more recent marine transgressions.

Magnetometer studies of 26 different bays all indicate associated spot highs, with no definite highs observed that are not readily associated with some bay.

Laboratory experiments with projectiles involving simulated Coastal Plain conditions duplicate remarkably the cross-section and rim characteristics of the Carolina Bays and strengthen the meteoritic theory.

Although the meteoritic theory in general is indicated by all critical analyses of the bays, a modified meteoritic theory (air-shock wave) is offered to better explain additional data.

Introduction. The terms "bay" and "pocosin" as generally used in the Atlantic Coastal Plain refer to an area usually overgrown with swamp vegetation and underlain by peat deposits. In some areas shallow lakes, with peat-filled border swamps, are also classified as bays.

A large percentage of these bays are nearly elliptical, have approximately the same elongation direction in any given area, are depressed below the general level of the ground, and have well defined sand-rims which rise above the general level of the area. Such elliptical, sand-rimmed bays are now generally spoken of as the Carolina Bays because of their greater abundance in the two Carolinas, although there is a very sparse and irregular occurrence in the extreme distribution areas, as far south as northeast Florida and as far north as New Jersey.

In this Coastal Plain area occur hundreds of thousands of these elliptical, sand-rimmed, and oriented depressions. The Carolina Bays have attracted world-wide attention during the past decade or so. Many articles, both scientific and popular, have been written about them, and there is still a great difference of opinion regarding their origin. In the northeastern area of their occurrence, the few bays found have their axial elongation a little to the east of southeast. Southwestwardly, the direction of axial elongation turns gradually clockwise through southeast to a little east of south in central Georgia. There is great variation in the size of the bays---from a few hundred feet to about 7 miles---and also a slight local variation in the direction of elongation of the bays and in their ellipticity. The sand rims are usually best developed along the southeast side. The bays appear to be of about the same age and, seemingly, are independent of topography and rock character.

Michael Toumey (1848), the first State Geologist of South Carolina, was apparently the first scientist to call attention in scientific writing to these peculiar rimmed depressions. The first scientific description was by Dr. L. C. Glenn (1895). Two small depressions of Carolina Bay type, near Darlington, South Carolina, were described and their possible origin suggested. No further published scientific notice was taken of these peculiar land forms until aerial photographs of the Myrtle Beach Estate were studied by Dr. F. A. Melton of the University of Oklahoma. An article by Melton and Schriever (1933), claiming a meteoritic origin of the bays, aroused world wide attention and started intensive investigation which has resulted in varying conclusions as to the probable origin of the bays.

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More Important Facts Concerning Carolina Bays. Following are the more obvious facts concerning the Carolina Bays:

1. Bays are geographically restricted to the coastal plain area between southern New Jersey and northeastern Florida, with most of the bays in the two Carolinas and northeastern Georgia.

2. Bays are very irregular in their distribution and size.

3. Bays have no relationship to geological formations, geological age (older or younger terraces), or topography. Some bays are on interstream flatlands, others on valley slopes or older stream terraces, and a few on the older portion of the present flood plain of streams.

4. Toward the northeast and southwest extremities of their occurrence, the bay groups are less numerous and smaller, but as variable in their distribution and size as they are never the center of the area.

5. No bays have been found outside of the sand-covered coastal plain or its erosional remnants, and none should be expected there according to the air-shock wave meteoritic theory. Large rimmed depressions would not have been formed as readily in the clay soil of the Piedmont as in the sandy Coastal Plain and such rimmed depressions in clay soil would be more readily destroyed by both erosion and sedimentation. On the other hand, buried meteorites would be better preserved in the clay soil than in the previous, sandy soil. The area to the northwest of the known bay country has yielded more meteorites than any other equal area in the United States.

6. An estimate of the probable number of bays, large and small, in the Atlantic Coastal Plain area is about half a million.

7. The direction of elongation of the bays is controlled, seemingly, by a force which varies slightly and more or less regularly between the two extremities (northeast-southwest) of the occurrence area.

8. An area of unusually large bays and elliptical lake basins, which includes parts of Cumberland and Bladen counties, North Carolina, is elongated in a direction about parallel to the direction of elongation of the

individual bays. This pattern is repeated elsewhere.

9. Bays have sand rims which stand above the general level of the land and are best developed generally at the southeast end of the bay, especially the eastern portion of the southeastern end. The poorest development, as a rule, is along the west and northwest sides, although even there some bays have fairly well developed rims.

10. Rimmed depressions of similar ellipticity can readily be formed by the air-shock waves created by a rifle bullet shot at an angle into a light powder, such as plaster of paris powder, resting on plastic clay. The rimmed shock-wave depression made in the powder is many times the diameter of the hole made in the plastic clay by the projectile. The ellipticity of the depression depends upon the angle of penetration.

11. The larger bays generally have larger rims, but local conditions modify the size. Rims are better developed where a bay is located in a high and dry sandy area rather than in a low and wet sandy area.

12. The deepest part of the bay is usually toward the southeast end and a little west of the axial line.

13. The similarity of development and the condition of preservation of bays in all parts of the "bay country" seems to indicate that they are all of about the same age.

14. Similarity of rock character, climatic conditions, groundwater, and topography seem to be as favorable for the formation of bays in bordering areas as in the areas of known occurrence.

15. Elliptical sand-rimmed bays are not being formed anywhere in the world at the present time as far as known.

16. There are no well developed bays or beach ridges for a distance of 7 miles northwest from Myrtle Beach, South Carolina. This area was either covered by the ocean at the time of the formation of the bays, or else the ocean returned to cover and destroy the bays formed in the area. In many low, near-coast areas, the bays have apparently been considerably effaced by marine or lagoonal sedimentation and erosion.

17. Most bays are associated with other bays of slightly different age. These associated bays frequently overlap. The overlapping younger bay completely obliterates that portion of the older bay overlapped. Occasionally a small bay is contained wholly within the area of the larger bay. The rim of the smaller bay usually rises above the level of the swamp or lake of the larger bay. Some unusually elongated or unusually broad bays are found to have been formed by a number of associated and overlapping bays. The overlap direction of twin or multiple bays in North Carolina is generally more to the northwest than to the west, thus creating some unusually elongated multiple bays in that area. Toward the southwest in the South Carolina-Georgia area, such overlap direction is frequently more toward the west, so that the multiple bays in that area are broadened rather than lengthened. Some oval or heart-shaped bays appear to derive their shape from two or more overlapping bays which have a slight convergence of their long axial directions toward the southeast; in such cases, the bay unit on the west has the smaller azimuth (counter-clockwise rotation) of orientation.

18. Many bays have more than one rim usually along the southeast and east sides. In some cases where rims are broad and high, these successive rims are the result of multiple bay formation. In these bays, each newer overlapping bay is formed slightly more to the west or, in other cases, to the northwest or north of its predecessor. In many cases

of overlap, the only portion of the older bay not concealed by the overlap is a small crescent portion of one side. Where the inner rims are comparatively small and appear more or less symmetrically placed in respect to the plane of symmetry of the bay and with development limited to the southeastern two thirds of the bay, the origin of the rims may be associated with the forces forming the larger and outer rims.

19. In a number of cases, a later-formed bay has cut across earlier-formed outer and inner rims of a single bay, thus indicating that the two types of rims were closely associated in time of formation, if the meteoritic theory of origin is assumed.

20. In soluble rock areas, many of the bays are being modified by solution and some can now be classified as sinks---"bay sinks," Sand rims are being lowered in some regions by groundwater moving from the bay underneath the rim to a stream which is "heading up" toward the bay and at a lower level than the water table in the bay.

21. A very small proportion of bays drained by streams are drained from the southeast end, but more often from the southwest, west, northwest, or east sides, indicating drainage by normal headward erosion of tributary streams.

22. Many bays have been partially filled by stream deltas, more often entering from the northwest, north, or northeast sides.

23. Many bays have been partially filled by windblown sand from the southwest, west, and northwest. In such cases the sand is usually finer-textured than that of the average rim.

24. Sand dune areas in many cases extend northeastwardly from the east and northeast sides of the bay.

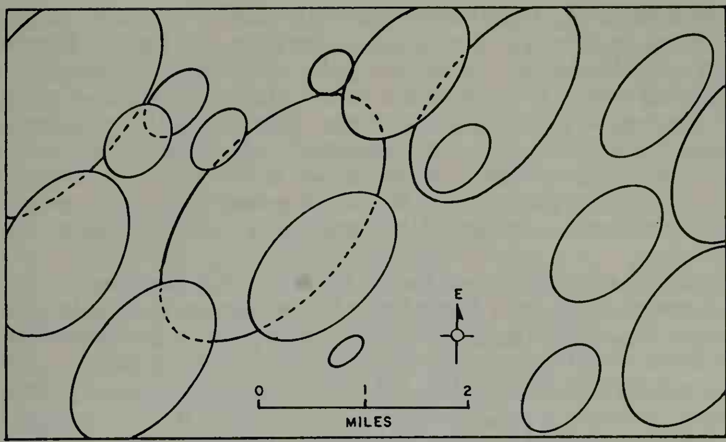
25. Samples taken from one medium-sized bay just beneath the thick peat deposits show a gradation from medium-coarse sand near the sides of the bay to silt in the central portion of the bay.

26. Near Myrtle Beach, South Carolina, the inland waterway cuts through the north-central portion of two small contiguous bays to a depth of about 25 feet. The two continuous shell beds found elsewhere along the canal are absent in the central portion of the section through each of these two bays. These shell beds must have been removed by either chemical or physical means. Nowhere else along the canal beneath the peat deposits, former swamp areas but not bays, have the shell beds been removed.

27. In Bladen and bordering counties, North Carolina, where large bays and bay lakes are numerous, it is not unusual to find large areas with more than 50 per cent of the surface covered by bays, and in much of this area the bays will also have an overlap of 10-25 per cent or more.

28. Practically every bay, large or small, surveyed by magnetometer has a well defined spot magnetic high or highs associated with it. If there is a single spot high, it usually occupies a position a little east of south from the southeast end of the bay at a distance about that of the short axis of the rim from the southeast end (the "Prouty Rule," so-called by Douglas Johnson, 1942). If there are two or more associated spot magnetic highs, the distance of each from the southeast end of the bay is considerably less than in the case of a single spot high. There is considerable variation in the direction of the spot highs from the bays as well as in the size of the spot highs in relation to the size of the associated bay. This variation seems logical from the variable conditions encountered.

29. In some parts of the coastal plain area, linear magnetic highs are



Concentration of bays in part of Bladen County, North Carolina. About 65% of this region is covered by bays, including overlap. Bays smaller than 1900 feet not shown.

present. These usually trend in a northeast-southwest direction and tend to swell and diminish along the strike, making it difficult to entirely eliminate their effects from the spot high magnetic readings.

30. Many of the bays have a slightly flattened elliptical border on the southwest side. In some cases this may be accounted for by eastward- or northeastward-drifting sand; in other cases, the reason is not clear but may have some connection with the development of the deeper part of the bay, which is toward the southeast end and to the west of the median line. Also, in multiple bays, the later-formed bay usually is responsible for the northwest portion of the bay rim and this later formed unit of the multiple bay has a slight counter clockwise orientation from that of the earlier formed unit of the bay responsible for the southern portion of the west rim. These conditions result in a somewhat flattened southwest rim.

31. The rim sand of bays is in general a little coarser than the average sand of the area. This is to be expected according to almost every theory, including the meteoritic air-shock wave theory. The coarseness is emphasized by the down wash of the finer material or by the very important action of ants which live on the dry sand rims. In building their nests, the fine grains are left below and the coarse ones are brought to the surface; also wind tends to move the fine sand grains from the rim. If air-shock waves are responsible for the rim formation, one would expect the fine sand particles to be carried farther from the depression than the coarse particles.

32. The sand in the rim shows little, if any, stratification. The formations beneath the rim appear to be undisturbed. There are no known deep sections across the bays at the critical points (deepest area in bay). A rumor of the presence of a "pipe" of disturbed ground beneath bays has not so far been verified.

33. Metallic iron, fragments of basement rock, or fused glass have not been found in association with any of the Carolina Bays. They should not be expected in view of the porous soil and climatic conditions.

34. All bays were formed on the superficially sandy Pleistocene terraces of the coastal plain and are younger than any of the well developed beach ridges with which they are associated, as shown by the fact that they cut across these ridges. An exception to this is found in some bays near the coast, where temporary marine flooding has both largely destroyed the sand rims and built faint beach ridges and swales across the bays.

35. In a few places there is direct evidence that the sea has encroached upon some of these bays since their formation and has again withdrawn, as in Blythe Bay, Wilmington, North Carolina, where peat deposits in the bay have been covered by sediments of probable marine origin. Later elevation and stream erosion has cut through the sediments and into the peat.

36. A few are known to have lake bottom springs. Most of these springs are near the southeast end of the bay.

37. Bays are generally largely filled with peat which apparently has a maximum thickness of from 15 to 30 feet. The peat filling reaches an elevation a little below the general level of the surrounding area. This elevation is governed by the height of the water table.

38. Bottom samples from the deeper part of some of the bays in Bladen County, North Carolina, taken from beneath the peat deposits, show a thickness of several feet of light-colored silt which, according to B. W. Wells (personal communication) is of wind blown character. The deposition of silt over the coarse bottom sand shows that the bays were formed suddenly and were soon filled with water, then followed sedimentation from a wind swept barren area. It is apparent that a slow sinking depression such as postulated by either solution or artesian springs could not yield the type of profile shown in these bays. According to Wells, the slow sinking postulated by either the solution or the artesian spring theory would yield deposits containing shallow-water or marsh-plant pollen. Instead of this there is a silt deposit without marsh-plant pollen made in deep water. The silt grades at top into aquatic peat containing pollen from water lillies and from trees of boreal or cold climate type.

Distribution, Coverage, Number, and Grouping of Carolina Bays. The Carolina Bays are entirely confined in their occurrence to the Atlantic Coastal Plain and a few coastal plain outliers. The large percentage of these rimmed, elliptical depressions are found in South Carolina and southeastern North Carolina. The bays also occur in rather large numbers for some distance to the west of the Savannah River in Georgia. Scattered bays also occur in the south and north central parts of the Georgia Coastal Plain in groups and clusters, as they do in the north central part of the Coastal Plain of North Carolina. A very few scattered bays are to be found even in extreme northeastern Florida and in the Chesapeake Bay Region of Virginia and Maryland, and three or four questionable bays exist in New Jersey.

Concentration of large bays occurs in some localities as does the concentration of small bays in other localities, but in general there is a fairly uniform mingling of sizes in the distribution. In some parts of the bay area, a number of overlapping bays occur in a northwest-southeast line, giving elongated "multiple bays." In other parts of the area, several bays overlap, making broad, more or less pear-shaped or heart-shaped "multiple bays." Roughly speaking, the large bays occur in greater porportion in two large districts, one in the southeastern North Carolina-northeastern South Carolina district and the other in the southwestern South Carolina-northeastern Georgia district. The North Carolina district includes the large Lake Waccamaw bay which has a length of over 6 miles, a sand rim at the southeast end about 23 feet above the lake level, and a width of over 2000 feet. At several localities in the Carolinas, small bays are found within a few hundred yards of the inner edge of the coastal plain. In a few localities in Georgia, "ghost" or remnant bays are found on coastal plain outliers a little distance into the Piedmont from the unbroken coastal plain line. These outliers were formerly part of the Coastal Plain before streams removed much of the sand cover from the underlying Piedmont rocks.

Some bays were without doubt formed in the lowlands, in many cases river bottoms, as well as in the interstream areas and valley slopes. Skeleton bays can be seen in a few places in the floodplain of the Cape Fear River and partially destroyed bays can be seen along the present river banks. Some bays project across waterways or are partly concealed by river swamps. There are no bays to be seen in the more recently formed portions of the Coastal Plain and for 7 miles inland from the coast town of Myrtle Beach, South Carolina. Going inland and north toward Conway, South Carolina, the first bays to be seen show signs of having been partially destroyed by wave action. It is logical to conclude that the bays were either formed in shallow water along the sea coast of that time and were partially destroyed before the ocean retreated to its present position, or that the ocean raised after the formation of the bays and migrated back to the position of the partially destroyed bays before retreating to its present position. Partial destruction of bay rims is to be seen in a number of places along the coastal areas and in places several miles back from the present shore. Study of plant remains in the sediments of the present coastal swamps and beach ridges by Professor Wells (personal communication) confirms the theory that there has been a relatively recent sea advance and retreat along a considerable portion of the coast line of the Carolinas. In the Wilmington, North Carolina, area, as pointed out also by Wells, peat deposits in Blythe Bay which have been covered by several feet of marine sediments are now exposed by stream erosion. This seems to show a marine invasion and retreat some time after the formation of the peat in the bay.

As far as known the Carolina Bays were formed under both geographical and time limitations, later than the formation of most of the Pamlico Terrace.

The area of distribution of the bays is about 83,000 square miles. Of this area, perhaps 43,000 square miles have very few or no bays. The bays cover, including overlap, roughly about 10 per cent of the surface. Where bays are large and thickly distributed, they may cover more than 50 per cent of the surface. Two large areas in Bladen County, North Carolina, were measured. In one of these, 7 miles long by 4 miles wide, the area covered by bays was found to be a little over 50 per cent. Another section of Bladen County, 5 miles by 4 miles, had a bay area of 67-1/2 per cent. In places, 20 bays to the square mile, each longer than 500 feet, have been counted. Some of the large bays cover several square miles. These, in some cases, may be made up of several overlapping bays. Many bays are concealed in heavily wooded, swampy, or river-bottom lands.

A conservative estimate of 3.5 bays to the square mile, each longer than 500 feet, gives an estimate of 140,000 bays of moderate and large size. It is almost impossible to estimate the number of small bays. One might be justified in roughly guessing that the total number of bays, large and small, is about half a million.

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THE ORIGIN OF THE CAROLINA BAYS AND THE ORIENTED LAKES OF ALASKA

Kelly, Allan O.; *Popular Astronomy*, 59:199-205, 1951.

[Allan O. Kelly has long belonged to the school that claims that many topological features of the earth were caused by the impact of large meteorites. Thus, it is surprising to find him advocating a radically different origin for the Carolina Bays and the oriented Alaskan Lakes.]

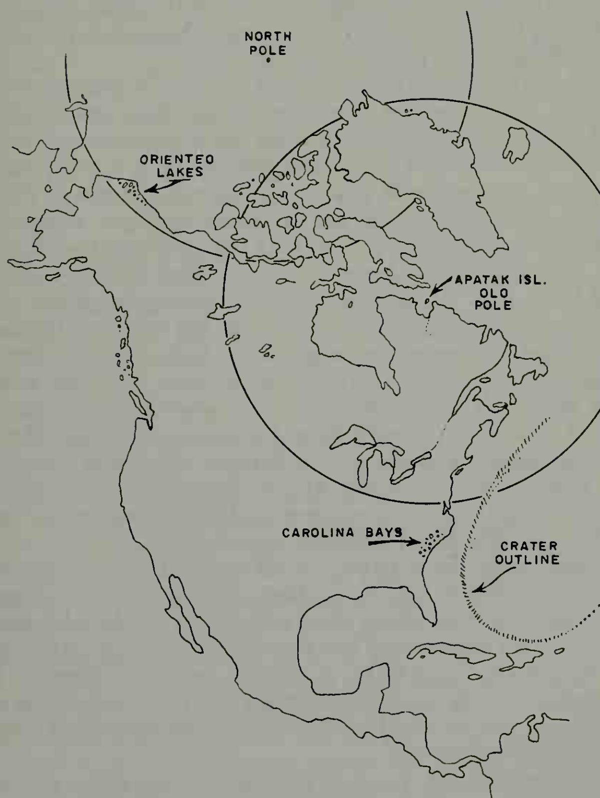
The origin of the Carolina Bays and the Oriented Lakes of Northern Alaska is a problem that has long intrigued the scientific world. Probably the great interest in this scientific puzzle arises from the fact that Melton and Schriever, geologists from the University of Oklahoma, who first discovered the Carolina Bays, attributed them to a gigantic shower of meteorites. This interpretation was made in 1933. Such a spectacular theory immediately aroused the interest of the Press and several articles appeared in popular magazines describing the fearful holocaust that must have occurred. Following this introduction to the public, the scientific world began to investigate. Many different hypotheses were proposed but none seemed to fulfill all the requirements. Dr. Douglas Johnson, geologist of Columbia University, said of these bays or depressions: "They are without doubt one of the most remarkable geomorphic features on the surface of the earth. They share with submarine canyons the distinction of being among the most difficult of earth forms to explain." Johnson was unaware of the Oriented Lakes of Alaska.

The Oriented Lakes of Northern Alaska were first investigated by R. F. Black and W. L. Barksdale of the United States Geological Survey. They published a rather complete article about these lakes in the Journal of Geology in March of 1949. They did not propose a complete theory of origin but they did give a table of comparisons between the Carolina Bays and these lakes. It was shown that out of 17 items of comparison, the two groups were similar in all but five. Among other things they concluded that "The Carolina Bays and the Oriented Lakes of Alaska are so strikingly similar that it is believed that the conditions operating to produce them must have been, at least in part, similar." No one else, so far as we know, has made any investigation or any proposal as to the origin of these lakes.

It is not our purpose in this short article to criticize other theories of origin but rather to advance one which we believe answers all of the requirements, so far as we know them.

This theory is based on cosmic collision as the motivating energy that produced these bays or lakes, and, in fact, the force that has produced most of the physical features of the earth. Such collisions and the oceanic floods that must have followed, can explain every unexplained problem of modern geology, including submarine canyons. Many thousands of these collisions have occurred in the earth's long history and the last major one caused the Biblical Flood which is also recorded by many other races of people. The physical evidences of this last great flood are found all around the world, in tremendous gravel deposits in unusual locations; in old shore lines high above the present levels of inland lakes such as Great Salt Lake and the Dead Sea; in recent glaciation and evident change of climate; in prehistoric animals found frozen in the Arctic, and a vast array of other physical evidence that cannot be mentioned here.

The Carolina Bays and Oriented Lakes of Alaska are only a small part of this great array of collision evidence, but they are the immediate concern of this article and one more step in proving the collision theory. Our reasoning is as follows: Before this last great catastrophe, the North Pole was located near Apatak Island in Hudson Strait. This fact is proved by



The present Arctic Circle is intersected by a postulated older Arctic Circle centered on Apatak Island. The meteor crater associated with the pole movement is purportedly off the U.S. southeastern coast.

drawing an arctic circle around this point, which is then found to contain all the glaciated area of North America, including Greenland and Iceland. These two islands were in practically the same relative position to the old arctic circle as they are today, so that their ice conditions have not changed.

It will be seen, then, that a considerable part of the North Atlantic was well within this old arctic circle and so must have contained large quantities of sea ice and glacial ice. On the other side of the circle, the Arctic Ocean also was in a position suitable to the production of ice.

The meteorite or asteroid, which caused this last cataclysm, struck the earth at a point which was then just outside the arctic circle but now off our South Atlantic Coast. It formed a great under-sea crater whose outlines can be traced for hundreds of miles as a nearly perpendicular wall. When this collision occurred it moved the surface of the earth in relation to the rays of the sun and at the same time changed the axis of the earth to its present location. A new alignment would certainly follow if the striking body penetrated the crust of the earth and added its weight to one side of the earth flywheel. On the other hand, if it only struck a glancing blow, the earth would probably wobble a little like a spinning top and soon regain its former axis. All the evidence seems to indicate that this object did penetrate the crust of the earth.

Such a collision would, of course, cause a terrific earth shock felt all over the world. The polar ice cap would have been shattered and the oceanic flood that followed would have floated vast quantities of ice far away from its source. Geologists have estimated the ice over Hudson Bay to have been over two miles thick. This ice and the ice in the Great Lakes apparently melted in place but the old polar cap was elevated and the ice moved off the land in all directions as the grooves in the rocks so plainly indicate. The glacial ice and sea ice that was floated by this flood must have rushed back with these waters to fill the impact point. This ice would have melted quickly in such an inferno but some of the sea ice far away near the coast of Greenland might have trailed far behind and missed this hot water bath. This ice could have been stranded like a great fleet of ships, for wind and tide grounded on the coastal plain, the seaward end of each berg or cake of ice would float more easily. Thus the bergs were grounded or anchored like ships in a harbor and would swing with the tide, all pointing in the same direction as the outgoing tide. As the tides receded, there came a time when the bergs failed to float on the incoming tide and so remained in this fixed position until melted.

Once the stranded bergs were firmly fixed on the bottom, the tides began to shape the land surfaces between. Since ice floats with about nine-tenths of its mass below the surface, this grounding would take place while the tidal floods were still quite deep for these cakes of ice might have been several hundred feet thick, judging by Antarctic sea ice. The ice in the Carolina Bay region probably remained for a year or so after the tides had returned to normal but in Alaska, they may have remained hundreds of years before melting completely.

The length of time that might have passed before the tides returned to normal would be difficult to determine by geological observation but the Biblical account of the Deluge tells us that the waters were "Going and returning continually for one hundred and fifty days." This seems like a reasonable estimate of the time that might have been required.

Major Chapman Grant, of San Diego, California, who visited the Carolina Bays in 1948, describes the area as not really a flat plain but a region in which low gravel hills are interspersed with Bays of a little lower elevation and with stream channels a little lower than the Bays. He also pointed out that seldom, if ever, does a stream flow from one bay to the next as is the case in all other lake country, but always around the Bays. In like manner the gravel hills do not encroach upon the bays nor do the so-called beach ridges. Johnson and others were at a loss to explain why these old surf lines or beach ridges, as they called them, did not cross the bays for the ridges are no higher than the bay rims. All these questions are easily answered if we imagine a cake of ice in each bay and tidal waters flowing in and out among these obstructions.

At first, when the tides were deep and strong, the gravel hills were deposited in the larger open areas between bergs. At the same time, channels were eroded out where the bergs were closer together and the current stronger. This kept the gravel hills from approaching too close to the bergs and produced the "kettle holes" or basins around each berg. Big bergs usually produced the dominant current and so the bays formed by little bergs close by seldom overlap the rims of bays made by bigger bergs. There are exceptions to this overlapping of rims, but, in general, the rule holds good. There are, in fact, exceptions to every general feature of uniformity in the Carolina Bays but all of these exceptions can be explained by the varying shape of the bergs, by distance of separation, and by the varying current of water flowing between them. Aerial photographs show this flow pattern around fixed objects so plainly that one wonders why this explanation was not forthcoming long ago.

Another characteristic feature of the Bays is the occurrence of rows or chains of Bays. Many chains of three or more are found nearly touching one another and with stream channels on either side. Usually these chains are made up of bays of nearly equal size and may have resulted from a large berg breaking up after grounding. In any event, such a chain would force the water to flow parallel to the sides of such group and the current would tend to arrange them in better alignment. These chains occur so frequently in the Carolina Bay region that they became a stumbling block to the advocates of the meteoritic theory, for it seemed beyond the realm of chance that meteorites should fall in many rows.

Since the ice probably remained long after the tides receded, the final melting took place without any passing current. Thus the final melt-water overflowed the bowl in which each berg was sitting and produced the delicate sand rims, even improving upon the symmetry that the tidal current had produced. Later, small channels were cut in the rim of each bay, allowing the greater part of each lake to drain into the stream channels.

The Oriented Lakes of Alaska show greatest deviation from the Carolina Bays in that the water drains from one lake to the next. This may be explained by the fact that Alaska was moved from a north temperate climate into the arctic; that the ice bergs stranded there did not melt for many hundreds of years; and that the streams and vegetation built up the land around them so that when the bergs did finally disappear, the streams were forced to flow from one lake to the next.

The Alaskan Lakes cover an area somewhat larger in size than the Carolina Bays, being about 450 miles east and west and extending from Point Barrow south about 100 miles. As in the Carolina region, the biggest lakes are found near the coast for the largest bergs grounded first. Farther inland the lakes become more scattered, less elongated, and more erratic in orientation. A few scattered lakes of smaller size are also found near the coast, but on higher ridges and plateaus, apparently because smaller bergs were thrown to greater heights by the first great tides and were less well oriented because of the shallower tidal currents following.

In outline, the Alaska Lakes are more rectangular than the Carolina Bays. This was probably due to a different fracture pattern and to the different orientation relative to the sun. The Carolina Bays are oriented in a northwest-southeast direction and therefore the northeast and east side of most bergs received more sunlight and melted faster. This difference in exposure to the sun produced the curious ovoid shape with the straighter side on the shady side. Where bergs were close together so that one might shade the other, the curvature on the shady side fits the theory. Another point bearing this out, is the fact that in large bays with multiple rims, the outer older rim is always a more perfect oval, showing that as the berg melted faster on the sunny side the new formed rims changed in shape with the berg. No other theory has ever been able to account for these multiple rims or the ovoid shape.

In Alaska the lakes are pointed more nearly north and south, the average trend being 12 degrees west of north. Being well above the Arctic Circle (most of them above 70 degrees north) the summer sun shone on all sides of the bergs with little favoritism, so that a more even rectangular shape was achieved.

Another possible reason for the uniformity in outline of these bays and lakes would be that the shock waves from the collision, through the water and through the earth, produced a uniform pattern in cracking the ice. This same collision shock pattern may be seen in the grid-like pattern of the mountains on the moon, especially in the mountain rim around Mare Imbrium. Shock waves traveling outwardly and upwardly might fracture ice floating on a sphere, in boat-shaped forms. In Alaska, which was much more distant from the point of collision than the Atlantic ice, the shock might have cracked the ice in a more rectangular pattern. Such a shattering of ice would almost surely produce a uniformity of some shape but there would be many minor variations. Such is the case, in both Alaska and Carolina, and, as the old proverb goes, "The exception proves the rule."

Conclusion. We believe that the Carolina Bays and the Oriented Lakes of Alaska were formed by strong tidal currents flowing around fixed objects that have since disappeared, that cakes of sea ice are, so far as we know, the only large objects in nature that could have fulfilled all the requirements, and that cosmic collision flood is the only possible force that could have moved them into place. We therefore rest our case and await the onslaught of our critics.

ON THE ORIGIN OF THE CAROLINA BAYS

Schriever, William; *American Geophysical Union, Transactions,* 32:87-95, 1951.

Abstract. A critical reconsideration of all important theories concerning the origin of the Carolina Bays led to a modified meteorite theory of origin, and to the conclusions: (1) Johnson's theory of "complex origin"

is quite untenable; (2) a modified meteorite theory of origin can meet all of Johnson's 29 requirements; (3) such a meteorite theory of origin has not yet been shown to be untenable; and (4) the modified meteorite theory of origin is the least unsatisfactory of all the theories which have been published thus far.

Introduction. It has now been 17 yr since the publication by the writer and his colleague, Melton (and Schriever, 1933) of their paper which brought to the attention of the scientific world the problem concerning the origin of the Carolina Bays. Johnson (1942) concluded his book with these statements: "The Carolina Bays are without doubt one of the most remarkable geomorphic features on the surface of the Earth. They share with submarine canyons the distinction of being among the most difficult of earth forms to explain. They are literally innumerable, and one investigator can see relatively few of them. A large field of study thus remains open, and new and pertinent facts doubtless remain to be discovered."

During these 17 yr numerous investigators have studied these bays and numerous papers concerning them have appeared in scientific journals. Johnson's book reviews all the pertinent information published prior to 1942 concerning the Carolina Bays. In addition it sets forth in great detail his "hypothesis of complex origin." In it Johnson also discusses in great detail the meteorite theory of origin of the bays, which was proposed by Melton and Schriever (1933), together with certain other theories of origin proposed by other. As a result of his valuable studies, Johnson concludes that all theories of origin, except that of "complex origin," seem quite incapable of accounting for the vast array of facts which must be explained by any acceptable hypothesis."

....

Objections to the meteorite hypothesis of origin---In Chapters 5 and 8 inclusive of his book, Johnson has given a most detailed discussion of the Meteorite hypothesis of origin of the Carolina Bays; he devoted 100 pages ---nearly one-third of his book---to this discussion. His objections to the meteorite hypothesis merit consideration here.

In his first objection (page 35) to the meteorite theory of origin he contends that, "There seems to be no escape from the conclusion that had oval basins and sandy rims existed in the Myrtle Beach area prior to construction of the beach ridges, the oval forms would not merely have been slightly modified or partially obscured, they would have been annihilated" (while coming out of the sea and passing through the shore building processes). Whether or not this would be the case would depend on how fast the relative sea level changed.

For the sake of argument, let us suppose that the sand rims were "annihilated" as Johnson assumes. As has already been explained in this paper, after the obliterated craters emerged from the sea they could well have formed lakes. Then the same winds and waves that might build rims in Johnson's "Hypothesis of complex origin," would build rims for the meteorite scars.

On page 56 Johnson states, "We must conclude that the beach ridges, the parallel depressions between pairs of beach ridges, and the irregular depressions between different areas of beach ridges are fairly early features of this old shore zone; and that the ovals, developing later, were influenced by pre-existing forms or structures of the region." It is proper to point out that it is just as logical to conclude that the bays were there first and that the locations of the beach ridges were influenced by the preexisting bays with their rims. In fact, on page 54 Johnson states, "While the vague and confused assemblage of imperfect ridges and swales and equally imperfect basins and rims are reasonably open to the interpretation given by Melton and Schriever (that the ovals and rims were formed first and later obscured by the process of beach ridge building), they are equally open to the opposite interpretation." In the writer's opinion, Johnson has presented no evidence which would compel one to conclude that the craters were formed later than the beach ridges.

On pages 64-69, Johnson concludes that the elliptical form of the craters cannot be due to the impact of large meteorites at oblique angles. He states, "If the angle of impact be sufficiently high for the mass to enter the ground, even a large meteorite does not produce a prominent crater but a pit with diameter not notably greater than that of the meteorite itself." He next argues that such large meteorites when striking our Earth with high velocities would explode and therefore produce round craters, and not elliptical ones. Let us examine the largest confirmed meteorite crater, namely Meteor Crater near Winslow, Arizona. This crater is over 4000 ft in diameter; it is slightly elliptical, the major axis being 250 ft longer than the minor axis. This crater was described in detail by Jakosky, Wilson, and Daly [1932]. In their work these authors examined Meteor Crater, Arizona, very carefully by both geological and geophysical methods, the latter including both magnetic and electrical methods of prospecting. Their paper shows sectional views of the crater along both the major and the minor axes of the ellipse. The section along the major axis shows that the meteorite struck at an angle and that its remains are now located inside the rim well beyond the center of the crater on the major axis.

Jakosky [1932], further reported the results of drilling in Meteor Crater. He states, "The electrical survey located the meteorite in the southwestern part of the crater, and indicated it to consist of a shallow fragmentized zone, surrounding a more concentrated main mass occurring at an effective depth of 700 ft below the present crater floor." This was confirmed by the magnetic survey.

He continues, "The first hole, placed in the center of the favorable area indicated by the geophysical survey, ran into the zone containing meteoric fragments at a depth of 414 ft. At 675 ft further progress was halted as the drill became lodged in the upper part of the more concentrated meteoric zone. The existence of the meteoric material was further proved by analyses which showed the presence of nickel. The second drill hole, as far as it has been carried out, revealed similar conditions to the first."

It seems reasonable that a huge meteorite, perhaps even hundreds of feet in diameter, when it struck the Earth, would make a "splash" in the Earth similar in appearance to the splash made by a pebble when it is dropped into thin mud. That such a meteorite would "explode" is certainly contrary to the facts found at Meteor Crater, Arizona, by geological methods, geophysical methods, and drilling. That steam, produced by the heat of impact, blew out some material is entirely possible, but the meteorite, as such, did not explode. These findings also indicate that the diameter of this meteorite was very much less than the diameter of the crater which it produced.

Thus Johnson's statements concerning impacts of meteorites are contrary to the facts found in connection with the Meteor Crater, Arizona. This meteorite produced an elliptical crater; it did not explode; and its diameter was much smaller than the diameter of the crater which it produced.

....

Summary---The writer has re-examined all important reports concerning the origin of the Carolina Bays to see if he could show the possibility or impossibility of an explanation based on a modified meteorite theory of origin which he has suggested. Johnson (1942), has presented a most valuable, complete and critical review of all reports bearing on the subject published before 1942, and has also added much new information, including a detailed discussion of his "Hypothesis of complex origin." Johnson lists 29 "Requirements of a satisfactory hypothesis" and shows that his theory meets these tests.

The writer has applied these 29 tests to a meteorite theory of origin and has found that not a single one of the tests ruled out such a theory.

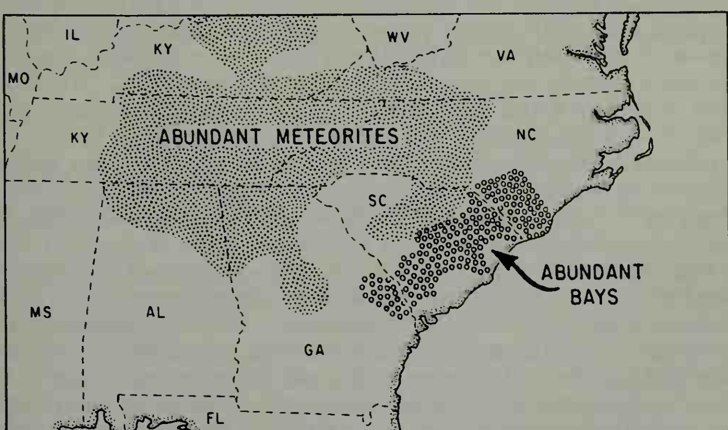
The writer has shown that Johnson's theory of complex origin is untenable because certain of his assumed and absolutely necessary geologic conditions do not exist, and because his theory violates the principle of the conservation of energy.

The writer has found no important evidence, or logical interpretation of evidence, which makes a meteorite theory of origin of the Carolina Bays untenable.

Conclusions---At the present time it appears to be impossible to set up a sufficiently critical set of specifications which a satisfactory theory of origin of the Carolina Bays must meet.

A completely satisfactory theory for the origin of the Carolina Bays has not yet been presented.

At the present time a meteorite theory of origin of the Carolina Bays appears to be the least unsatisfactory of all theories that have been pub-



Map showing areas of abundant Carolina Bays and frequent meteorite finds.

lished.

One is forced to the conclusion that subsurface investigations over a number of typical Carolina Bays must be made before a satisfactory explanation of their origin can be written.

THE PANS OF THE SOUTHERN KALAHARI, BOTSWANA

Lancaster, I. N.; *Geographical Journal,* 144:81, 1978.

The southern Kalahari in Botswana is an extensive, gently undulating sand plain at an altitude of some 1100 to 1200 m, covered by shrub and bush savanna. The climate of the region is semi-arid, with a very variable annual rainfall of 250 to 400 mm, which falls mostly in the hot summer months of October to April. The region forms a broad watershed between the Okwa and Mmone dry river systems, which are directed towards the Makgadikgadi Depression, and the Nosop and Molopo rivers which form the southern border of Botswana. It corresponds approximately with the area called the Bakalahari Schwelle by Passarge.

The principal geomorphic feature of the Southern Kalahari are the thousand or so pans which break the monotony of this otherwise almost featureless sand plain. Most of the pans, or small dry or ephemeral lakes, are contained in isolated sub-circular to sub-elliptical depressions, 5 to 20 m deep and 0.5 to 4 km across, excavated in the red-brown Kalahari sands which mantle the region. On the southern side of most of the pans lies an area of fixed, arcuate sand dunes, which rise to heights of up to 30 m above the depression floor. This paper aims to describe the main features of the pans and to put forward hypotheses to explain their origins. It is based upon field work undertaken in Botswana in 1972 and 1973, together with subsequent analysis of data.

. . . .

Conclusions. The origins and development of the pans: Although the morphological and sedimentary evidence suggests that the sequence of development of each pan has followed slightly different lines, three main phases in their origins and development can be recognized. These are illustrated in Figure 6 and consist of two periods of dune formation, the first of which was more active and prolonged, represented by the outer and inner dunes. Between these was a period in which the pan depressions were occupied by shallow alkaline and saline lakes, in which clays and sandy clays were deposited. The available evidence indicates that the pans are situated in deflation depressions excavated in the surface Kalahari sands. The depressions originated by the enlargement of blowouts at sites of seasonal water accumulations and seepage from groundwater bodies. The deflated material accumulated downwind of the depressions to form the outer dunes. The inner dunes represent the accumulation of sandy sediments deflated from the floors of the pan depressions. Where this was most effective, the upper sandy phase of pan deposits was completely removed, resulting in a bare clay pan surface. Elsewhere, part of the sandy phase remained, so forming partly grassed or grassed pans. In the interval between the formation of the inner and outer dunes, the pan depressions were occupied by shallow alkaline and saline lakes, in which calcareous clays and sandy clays were laid down. The sequence of pan deposits indicates that permanent lakes in conditions of moderate runoff were succeeded by seasonal lakes in low runoff conditions. Gradual desiccation of the pans is confirmed by the calcification and secondary silicification of marginal pan deposits.

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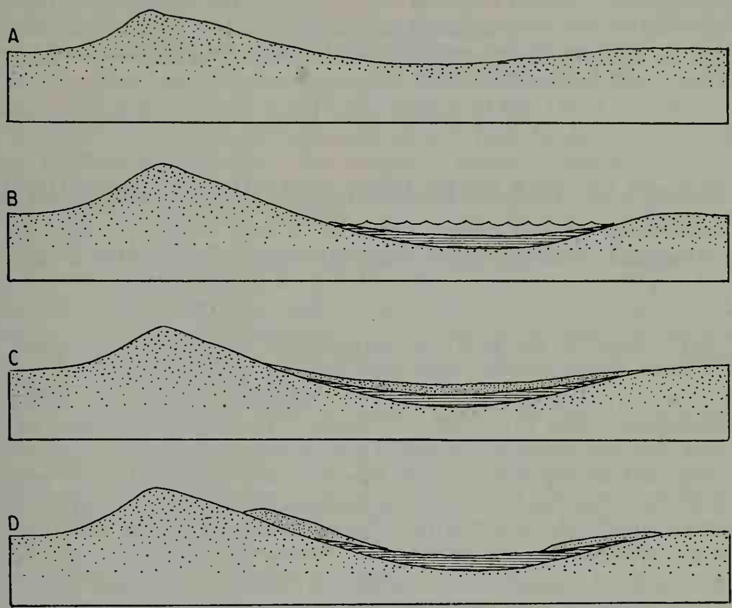

Possible steps in the formation of the Kalahari pans: (a) deflation to form outer dune; (b) deposition of clays; (c) deposition of sands; and (d) deflation to form inner dune.

BAYS IN HOLLAND

Hoffleit, Dorrit; *Sky and Telescope,* 12:8, 1952.

The origin of the Carolina Bays has been a controversial subject ever since they were first photographically mapped by Melton and Schreiner in 1933. The meteoritic theory, much as it has captivated the imagination, seems to be losing favor. These formations were recalled at meetings of the International Society of Photogrammetry which were held in Washington in September. Colonel C. A. J. von Freitag Drabbe, of the Netherlands Topographic Service, presented a monograph, Aerial Photograph and Photo Interpretation, in which he showed that closely similar formations abound in the Netherlands. There, however, their discovery is difficult because of the overlying civilization, whereas the Carolina Bays are in practically virgin condition.

Von Drabbe thinks both groups of oval depressions are glacial phenomena produced by the melting of glacial ice. Some of the ovals may have been formed when already buried glacial ice (ice fossils) melted and the overlying layers of sediment collapsed. Bringing together many geological factors, he presents very convincing evidence in support of his theory. In particular, he calls attention to rocks in the vicinity of the Dutch craters. No natural rock formations of the sort exist in the Netherlands, but similar boulders are found strewn along the Baltic. The origin of such boulders seems to be in the mountains of Finland and Scandinavia, whence glaciers carried them southward.

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DEPRESSIONS OF THE NORTHERN PORTION OF THE SOUTHERN HIGH PLAINS....

Judson, Sheldon; *Geological Society of America, Bulletin,* 61:253-273, 1950.

Abstract. Study of the shallow depressions of the Southern High Plains of eastern New Mexico shows that they are the result of alternate periods of leaching and wind deflation and not of collapse into the underground or local subsidence in the Pliocene sediments. During wet periods of the Pleistocene the calcareous cement of the Ogallala formation was destroyed. During succeeding dry periods these locally leached areas suffered wind deflation. The depressions are located along broad shallow troughs which involve the "cap rock" of the Plains in a manner not yet clearly understood. Evidence suggests that the "Pliocene cap rock" may not have the value as a stratigraphic horizon that is usually attributed to it. The Cuneva depression, a true collapse depression active within historic times, is described.

• Oriented Lakes

ORIENTED LAKES OF NORTHERN ALASKA

Black, Robert F., and Barksdale, William L.; *Journal of Geology,* 57:105-118, 1949.

Abstract. The oriented lakes of northern Alaska occur in an area of more than 25,000 square miles in the Arctic Coastal Plain Province. The topography, drainage, vegetation, climate, geology, and permafrost of the area are briefly described. The average range of orientation of the lakes is 12°---from N. 9° W. to N. 21° W. In any locality the deviation from the average is commonly less than 3° and rarely over 5°. The lakes range in size from small ponds, a few tens of feet in length, to large

lakes more than 9 miles long and 3 miles wide. The shapes may be described as elliptical, cigar-shaped, rectangular, ovoid, triangular, irregular, or compound. One group of lakes has a shallow shelf or underwater bench surrounding a deeper central portion. The rest are shallow throughout, and the underwater profile is commonly concave. The major outline of the lakes is smoothly curved, but in detail it is cuspate or jagged. No lacustrine beach ridges were recognized. Former lake basins, now drained, and extensions of the present lakes are evidenced by shore features, lacustrine deposits, the character of polygonal ground, and vegetation. The effect of wind, vegetation, and permafrost are briefly described. The lakes are compared with the Carolina Bays and with rectangular lakes in eastern U.S.S.R. Many of the lakes are believed to be the result of thawing of permafrost; others may be produced by the segmentation of uplifted lagoons. The origin of some is not known.

General Statement. The oriented lakes of northern Alaska occur in a remote and sparsely inhabited area of more than 25,000 square miles adjacent to the Arctic Ocean. The origin of the thousands of lakes has aroused the curiosity of most men traveling on the Arctic slope; however, few systematic data have been collected regarding their origin or their remarkable parallelism. The areal extent and orientation of the lakes probably has been recognized only since observations could be made by air or from aerial photographs.

Method of Investigation. The oriented lakes first came to the attention of the senior author, R. F. Black, during the summer of 1945. In the summer of 1946, in connection with the permafrost investigations of the United States Geological Survey, W. L. Barksdale visited numerous lakes along the Meade River and in vicinity of Barrow, R. F. Black, assisted by Donald R. Loftus, visited many lakes along the Arctic coast southwest and southeast of Barrow, in the vicinity of Barrow, and in the Cape Simpson area. Several trips were made by air from Barrow south and east over the lake country. Trimetrogon photographs, taken in 1942, 1943, and 1945 of most of northern Alaska, were used as a base for delimiting the areal extent of the lakes and for providing data in places not visited. Planimetric maps, on the scale of 1/48,000, made by the Geological Survey from these aerial photographs, provide coverage for most of the entire area.

The authors have not had an opportunity to study in detail the many aspects of the oriented lakes; however, in the light of the increasing interest in Alaska it seems desirable to present the available information at this time. The Geological Survey anticipates further studies of the oriented lakes and associated permafrost phenomena.

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Topography. The area occupied by the oriented lakes of northern Alaska covers almost completely the physiographic province known as the Arctic Coastal Plain. The Coastal Plain is the northernmost physiographic province in Alaska and is bordered on the south by the Arctic Plateaus Province. The boundary between the Coastal Plain and the Plateaus has been arbitrarily chosen on the basis of topography and of distribution of Quaternary sediments. In general, that boundary is between 400 and 600 feet in altitude, although Leffingwell reports that on the Okpilak River, 40 miles from the coast, the boundary is about 1,200 feet. East of the Sadlerochit River (outside the area of the oriented lakes and not shown on fig. 1) the Coastal Plain widens abruptly to about 50 miles and narrows where the British Mountains approach the ocean at the international boundary line. (Figs. omitted.)

In some places the Coastal Plain grades imperceptibly into the northern front of the Arctic Plateaus. In the Canning River area the northern front of the Arctic Plateaus rises with a slope of 15°-20° from the flat Coastal Plain and may be as much as 300 feet higher.

To the north the profile of the Coastal Plain is broken only slightly by the Arctic Ocean. In many places the plain is only 1-10 feet above the sea. The average height of coastal bluffs is only 15 feet, and the highest rise 25-50 feet above sea level. The shoreline is characterized by many offshore bars of silt and sand, mud flats, and spits. Lagoons, in places as much as 5 miles wide and many tens of miles long, are generally less than 10 feet deep.

Except for minor features, the Coastal Plain extends with monotonous flatness from horizon to horizon. Broad low ridges and valleys have a very low relief of about 30 feet. Locally steeper slopes of former wave-cut benches or wave-built benches or beaches occur. Small earth and ice mounds, commonly 1-4 feet high, occur over most of the plain. Shallow troughs, commonly less than 2 feet deep and in many places underlain by vertical wedges of ice, form a network (polygonal ground) over most of the surface.

Drainage. All runoff is on the surface, as permafrost underlies the entire Coastal Plain at a depth of a few inches. All but the largest rivers, such as the Colville River, freeze solidly to permafrost every winter. It is estimated that possibly 50-75 per cent of the Coastal Plain is covered with lakes and marshy ponds. Many are without external drainage except in spring, when high waters overflow their banks. Certain localities are partially dissected, and some lakes are draining through recent gullies.

Only one large river, the Inaru, lies entirely within the limits of the Arctic Coastal Plain Province. However, most rivers that head in the Arctic Plateaus Province or on the north flanks of the Brooks Range cross the Coastal Plain on their way to the Arctic Ocean.

Vegetation. The entire Coastal Plain is a treeless, prairie-like tundra region characteristic of the arctic and subarctic zones. It is covered with a thick mat of vegetation composed of a mixture of lichens, mosses, grasses, sedges, shrubs, and other plants. Small prostrate shrubs are rare along the coast but are more abundant inland. Willows are particularly common along the protected banks of the larger streams, though they rarely grow as high as 10 feet. Evergreen or large deciduous trees are absent.

Climate. The climate on the Arctic slope is cloudy, cold, arid, and windy. The only weather station on the northern Coastal Plain of Alaska is at Barrow, but data collected there since 1912 by the United States Weather Bureau are probably applicable to the entire coastal area. Monthly and annual climatic data are given in table 1. [deleted]

The annual mean temperature at Barrow is 10° F.; the annual mean maximum temperature is 16° F.; and the annual mean minimum temperature is 4° F. The monthly mean maximum and mean minimum temperatures are shown in figure 2. The absolute maximum temperature is 78° F. and the absolute minimum temperature is -56° F. The monthly and annual number of days with freezing temperatures are shown in table 1.

During a period of 27-30 years the most frequent wind direction was northeast during every month except July, when it was southwest. The prevailing direction and relative velocity of the wind at Barrow are shown in figure 3. The average monthly and annual wind velocities are shown in table 1.

Geology. The Arctic Coastal Plain is underlain by several thousand feet of relatively impervious sandstones, shales, and some interbedded conglomerates, coals, limestones, and bentonites of Upper Createceous and early Tertiary age. These rocks are essentially flat-lying, although gentle folding has produced large low domes and anticlines and broad, shallow basins and synclines. Dips are commonly less than 5^{o}.

The Upper Cretaceous and early Tertiary rocks are mantled uniformly throughout much of the Coastal Plain by unconsolidated clays, silts, sand, gravel, and peat, as much as .150 feet thick, of late Tertiary-Quaternary age. The unconsolidated sediments are of interfingering marine and fluvial origin, and different deposits vary widely in areal distribution, thickness, and composition. The detailed geologic history and relations of these deposits are known for only a few areas.

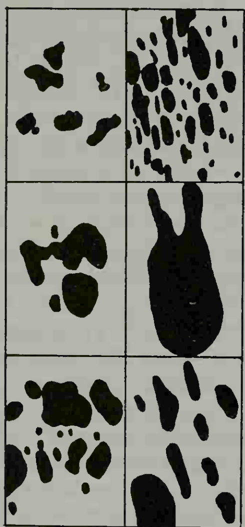
Permafrost. All surficial deposits and the bedrock to a depth of several hundred feet under the Arctic slope are permanently frozen. The surficial deposits, in particular, contain large quantities of ice in the form of nearly vertical ice wedges, horizontal ice sheets, irregular ice masses, and small grains, crystals, stringers, irregular particles, and films of ice as a cement. Shallow thawed zones probably occur under the larger streams and below some of the deeper lakes. Summer thaw penetrates from 6 inches to a maximum of about 30 inches. The average summer thaw is about 8-20 inches.

Description of the Oriented Lakes Distribution. The oriented lakes occupy almost completely the Arctic Coastal Plain Province of northern Alaska and, as far as is now known, are limited to that province. The northern limit of the lakes is the Arctic Ocean. The southern limit coincides approximately with the boundary between the Coastal Plain and the Plateaus Province, from the Arctic Ocean near Cape Beaufort, about 450 miles eastward, to the Arctic Ocean near the Kalakturuk River. Although the Arctic Coastal Plain Province continues east of the Sadlerochit River to the international boundary, the lakes in that area are apparently not oriented. The maximum width of the oriented-lake area, from Barrow southward, is more than 100 miles. The average width is between 50 and 80 miles.

Oriented lakes occur chiefly in lowland areas and less commonly on the sides or tops of low ridges. Many are in basins cut directly into broad, featureless plains. Others are present in lowland areas along coasts, on tops of high bluffs, and less commonly in river floodplains.

Concentration. The oriented lakes are concentrated in elongated belts or zones, which apparently represent former stages in the uplift of the Coastal Plain. It is estimated that locally the lakes or drained lake basins comprise from less than 25 per cent to as much as 90 per cent of the surface of the land, although in most places the lakes probably comprise between 50 and 75 per cent of the surface. Most of the oriented lakes are concentrated in a large area north of latitude 70^{o} and between the Kuk River on the west and the Itkillik River on the east. The number of oriented lakes is markedly less along the southern boundary of the area, and particularly so in two areas of slightly higher relief and coarser-grained surficial deposits, one of which lies between the Itkillik and Kuparuk rivers and the other between the Sagavanirktok and Shaviovik rivers, where only remnants of former oriented lakes remain. In certain areas adjacent to the coast, along many of the larger rivers, and wherever slopes are moderate, gullies have intersected and largely drained the oriented lakes without, however, completely destroying the lake basins themselves.

Orientation. The remarkable parallelism exhibited by the thousands of elongated lakes in the Arctic Coastal Plain Province in northern Alaska is a rare phenomenon and, so far as is known, is duplicated in such a marked degree only by the Carolina "Bays" of the Atlantic Coastal Plain Province of the United States. The uniformity of alignment of the lakes is so perfect in many parts of the Arctic Coastal Plain that their orientation has been used as an aid in air navigation.



Representative outlines of Alaskan oriented lakes. The rectangles are about 4 miles wide, and north is up.

In order to determine accurately the regional orientation of the lakes, the long axes of five to twenty lakes in a particular locality were determined by bisecting the outlines of the lakes as shown on Geological Survey planimetric maps; the trend of the axes was measured; and the average trend determined arithmetically. The number of lakes measured was increased as the variability of orientation increased. Of the well-developed lakes oriented in a northerly direction, the total range in orientation is only 30°---from north to N. 30° W. The average range for seventeen localities, as shown by the arrows on figure 2, is only 12°---from N. 9° W. to N. 21° W. In any one locality the deviation from the average is commonly less than 3° and rarely over 5°. The lakes in the southeastern part of the Coastal Plain in the vicinity of the Colville River at latitude 70° 00' trend more nearly west than do the lakes in the rest of the Coastal Plain. Most lakes in the central portion of the Coastal Plain north of latitude 70° 00' and between the Kuk River on the west and the Ikpikpuk River on the east trend N. 13° W. to N. 15° W.

Not all lakes on the Coastal Plain are oriented, nor are all oriented lakes aligned in the same direction. The north-northwest trend is uniformly developed throughout the region. An easterly trend is shown by a few lakes in scattered localities but is nowhere so pronounced as is the north-northwest trend. Rarely, individual lakes along the coast or in the floodplains of some of the major rivers are oriented in other directions, but no other pronounced trends were noted.

Lakes which are not oriented occur in the area along the southern limits of the Coastal Plain, in the areas of higher topographic relief between the Itkillik and Kuparuk rivers and the Sagavanirktok and Kadleroshilik rivers, in certain relatively high sections along major streams, and on the floodplains of many streams.

The oriented lakes in some places form groups or chains that are aligned along the axis or at an angle to the axis of individual lakes composing the chain.

Character of the Oriented Lakes. Size. The oriented lakes range in size from small ponds a few tens of feet in length to large lakes more than 9 miles long and 3 miles wide. Lakes of all sizes occur in any locality, although large lakes are more numerous in a broad zone adjacent to the coast from Barrow eastward and as far south as latitude 70° 30'. Many of these lakes are 4-6 miles long and 1/2 - 1 mile wide. Lakes are conspicuously less numerous and smaller east of the Itkillik River than west of that river, and they are, in general, less numerous and smaller toward the southern boundary of the Coastal Plain.

Lake Teshekpuk, about 80 miles southeast of Barrow, is an unusually large and irregular lake more than 21 miles wide and 29 miles long.

Shape. The shapes of the lakes of the Coastal Plain may be described as elliptical, cigar-shaped, rectangular, ovoid or egg-shaped, triangular, irregular, or compound, having any combination of these shapes. All the lakes are somewhat irregular, and few are so smooth or so perfectly formed as to fit clearly into any one type. Any one or more types may predominate in a particular locality, although in most areas all types are at least represented.

....

Comparison of the Oriented Lakes of Northern Alaska with the Carolina Bays and Other Oriented Lakes. As far as is known, this paper contains the first description of a group of oriented lakes which compare in number and in extent of orientation with the Carolina Bays of the eastern United States. Up to the present time the Carolina Bays have been unique, for nowhere else had such a large area containing such well-oriented lakes been known.

The Carolina Bays have been discussed at great length by Douglas Johnson, and it is from his book that data are derived for the comparison with the oriented lakes in table 2.

Obruchev reported that rectangular lakes oriented in a rectangular pattern occur on the Recent Arctic Coastal Plain to the southwest of the Iamskaia beach of the Okhotsk Sea, in the valley of the Penzhina River near the village of Penzhino, and in the valley of the Anadyr River. These lakes are reported to vary in diameter from several hundred meters to as much as 5 km. Those on the plain surrounding the Okhotsk Sea are parallel to the coast. Obruchev believes that the origin of the lakes in the

Table 2. Comparison of the Oriented Lakes of Northern Alaska with the Carolina Bays

	Oriented Lakes of Northern Alaska	Carolina Bays
Distribution	Total area of more than 25,000 sq. mi.; limited to the Arctic Coastal Plain	Total area of at least 25,000 sq. mi.; limited to the Atlantic Coastal Plain
Abundance	Probably tens of thousands of lakes or lake basins	Probably tens of thousands of bays and possibly hundreds of thousands
Orientation	Most trend from N. 9^{o} W. to N. 21^{o} W.; average trend is N. 12^{o} W.	Majority trend from N. 10^{o} W. to N. 55^{o} W.; average trend varies according to locality
Size	A few tens of feet in greatest diameter to 9 miles long and 3 or more miles wide; many average between 1 mile and 3 mi long by 1/2 mile wide	A few hundred feet in greatest diameter to 4 miles long by 2 or more miles wide
Shape	Elliptical Cigar-shaped Rectangular Ovoid or egg-shaped Irregular Triangular Compound	Elliptical, many with one side more strongly curved than the other Ovoid or egg-shaped Irregular
Ratio of length to width	From almost 1:1 to 5:1; many are 2:1 to 3:1	From almost 1:1 to 3-1/2:1
Depth.	Exclusive of filling, from less than 10 feet to 60 or 70 feet below surrounding plain	Exclusive of filling, from 1 or 2 feet to 30 or 40 feet below surrounding plain
Shorelines.	Major outline of many lakes is smoothly curved; in detail, most lake shores are jagged or rough	Shorelines are smoothly curved
Sand rims	Conspicuously absent	Conspicuous, partial, or complete rim or rims of white or pale buff sand around most, but not all, bays
Drainage	No present subsurface drainage; surface drainage absent from many	Subsurface drainage for all; surface drainage absent from many
Relationship to one another	Lakes parallel, intersect or overlap one another	Bays parallel, intersect, or overlap one another
Relationship to beach ridges	Clusters of lakes lie between what are interpreted as beach ridges	Clusters of bays lie between what are interpreted as beach ridges

	Oriented Lakes of Northern Alaska	Carolina Bays
Linear arrangement of lakes	Rows of lakes are present in a few localities	Rows of bays are present in a few localities
Material in Coastal Plain	Permanently frozen gravel, sand, silt, or muck	Sands, sandy loams or marls, limestones, and arkosic sand
Present wind direction in relation to axial trend	Average wind is from northeast, normal to orientation of lakes	Winds highly variable and cannot be correlated with trends of bays
Climate at time of origin	Presumably arctic climate similar to that of today	Cold accompanying maximum Wisconsin glaciation
Age	Probably Pleistocene to Recent	Pleistocene

valley of the Penzhina and Andyr rivers is connected with the origin of the polygonal ground which occurs in the area, but he does not explain further. He believes that many of the lakes less than 2 meters in depth are the result of the thawing of permafrost. Some lakes deeper than 2 meters are fed by fresh-water springs and others by mineralized waters from taliks, or thawed zones within the permafrost. Seasonal and biennial mounds are reported to rise from the bottoms and from the shores of some of the lakes. It is not known how well the lakes are oriented or how large an area they cover. They are presumed to be Quaternary in age.

Johnson briefly discusses oriented lakes of undetermined origin in Florida, Georgia, and Texas and comes to the conclusion that they are similar to, but not identical with, the Carolina Bays.

Theories of Origin of the Oriented Lakes. The data on the oriented lakes of northern Alaska are too few to permit any definite analogy with the Carolina Bays or with other groups of oriented lakes. However, the Carolina Bays and the oriented lakes of northern Alaska are so strikingly similar that it is believed that the conditions under which they were formed and the physical processes operating to produce them must have been, at least in part, similar. An analogy may be drawn also between the oriented lakes of northern Alaska and the rectangular lakes of eastern U. S. S. R., although data for this comparison are much less satisfactory.

Many conflicting and widely divergent hypotheses are advanced by various authors to explain the many perplexing problems involved in the origin of the Carolina Bays. Johnson gives complete references to the numerous papers and discusses all hypotheses. Three of the most outstanding hypotheses are: (1) meteoritic origin, by F. A. Melton, William Schriever, et al.; (2) segmented lagoons and crescent-shaped keys, by C. Wythe Cooke; (3) artesian-solution-lacustrine-aeolian hypothesis, by Douglas Johnson.

Of these, the meteoritic hypothesis caused the greatest excitement in the scientific world, but, with certain exceptions, it is not now so widely believed as before. The fact that the oriented lakes are limited only to the Arctic Coastal Plain and almost completely cover that plain, that magnetometer and geophysical surveys do not indicate any deposits of meteorites, and that the shapes of the lakes and absence of "rims" do not conform to such a theory points to the conclusion that the meteoritic hypothesis does not explain the origin of the oriented lakes of northern Alaska.

With some modifications, Obruchev's "cave-in" hypothesis, Cooke's segmented-lagoon hypothesis, and Johnson's complex hypothesis probably will explain some of the problems connected with the origin of the oriented lakes of northern Alaska.

The writers believe that many lakes of northern Alaska, some oriented and others unoriented, are the result of thawing of perennially frozen ground and are true "cave-in" lakes. These lakes may or may not occupy parts of the basins of oriented lakes now drained, and they are possibly of more than one generation. "Caving" in itself, however, cannot produce regional orientation.

In the vicinity of Peard Bay and Harrison Bay and at other localities on the Coastal Plain of northern Alaska, clusters of lakes lie between what have been interpreted as beach ridges and are aligned in rows that may have any orientation relative to the axial trend of the lakes. As in the Myrtle Beach area in South Carolina, described by Cooke, such lakes are believed to be the result of uplift and segmentation of lagoons, although the actual processes involved in such segmentation are not clearly understood.

Prevailing winds in the direction of the long axis of the Alaskan lakes are believed to be the chief factor that controlled their orientation. What climatic changes would have to be made to produce a northwesterly (or southeasterly) wind are not known, but presumably they were connected with the major climatic changes during the Pleistocene period and possibly with the most recent uplift of the Brooks Range to the south.

Johnson's hypothesis of the origin of the Carolina Bays "supposes that artesian springs, rising through moving ground water and operating in part by solution, produced broad shallow basins occupied by lakes, about the margins of which beach ridges were formed by wave action and dune ridges by wind action." Such an origin for the oriented lakes of northern Alaska presupposes that the ground was thawed to a considerable depth during the time that the lakes were forming. Whether during one of the warmer interglacial periods known to have occurred in Alaska the ground was thawed sufficiently to permit circulation of ground waters or artesian waters is not known. Evidence for such phenomena should be looked for particularly in the deeper lakes in the southern part of the Coastal Plain. During such a period of thaw, solution might have taken place in Cretaceous limestone beds, some as much as 6 feet thick and totaling about 100 feet in thickness, which are believed to underlie the area. However, the presence of frozen and well-preserved plant and animal remains dating back into the Pleistocene indicates that there has been no long period of thaw since that time.

Whatever the origin, the lakes present an intriguing problem that deserves considerable attention.

ORIENTED LAKES AND LINEAMENTS OF NORTHEASTERN BOLIVIA

Plafker, George; *Geological Society of America, Bulletin,* 75:503-522, 1964.

Abstract. Strongly oriented lineaments, defined by lake shores and stream and vegetation alignments, are distributed throughout more than 45,000 square miles of the Beni basin in northeastern Bolivia. The area in which these features occur is a flat, poorly drained, lake-studded plain. It is underlain by flatlying, poorly consolidated, continental clastic sediments of Late Cenozoic age which, in turn, overlie crystalline basement. To the west the basin sediments abut abruptly against the folded and faulted Andean foothills and to the east they gradually overlap gently rolling crystalline outcrops of the Brazilian Shield.

The main lineaments within the basin show preferred orientations perpendicular to each other in northwest-southeast and northeast-southwest directions. These two preferred directions of lineament orientation occur in sediments that extend from the margin of the Brazilian Shield westward 200 miles to where the basin sediments are 10,000 feet thick. Two poorly developed sets of lineaments that trend roughly north-south and east-west are also present within the basin.

Most lakes are strongly rectilinear in outline with shores that commonly trend northwest-southeast and northeast-southwest. They range in size from about 1000 feet square to 5.4 by 12.4 miles. Only a few lakes have streams draining into or out of them. Those that have been studied on the ground are shallow with relatively flat bottoms and abrupt steep sides. The water surfaces are almost level with the surrounding flat terrain.

The two major northwest-southeast and northeast-southwest trends are probably controlled by a regionally oriented system of longitudinal and cross fractures in the crystalline basement; the poorly developed north-south and east-west sets of lineaments may reflect basement "shear" fractures. The oriented lakes and many of the major northwest-southeast and northeast-southwest-trending lineaments occupy shallow surficial subsidences that appear to form by progressive downfaulting of basement blocks or differential compaction of unconsolidated deposits over basement blocks. The minor north-south and east-west sets and some of the northwest-southeast and northeast-southwest-trending stream and vegetation lineaments may reflect individual fractures in the underlying basement rather than areal subsidence over basement blocks. The youthful appearance of some oriented features indicates that they are probably forming at the present.

Because of the unique environment of the Beni basin, where alluvial deposits are accumulating over a relatively stable shield margin in an area of flat terrain and high water table, many of the subtle surficial depressions are clearly visible as lakes with orthogonally oriented shore lines. Lakes of comparable size, shape, and degree of orientation are known to occur elsewhere only in the Old Crow Plain area of Canada.

It is postulated that prelithification fractures, such as those in the Beni basin, must play a significant role during compaction, jointing, faulting, and folding of sedimentary sequences. Criteria are needed to distinguish between fracture trends that are inherited from basement rocks, and those formed by postdepositional deformation.

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Oriented Lakes. Density and distribution. Oriented lakes occur over an area of roughly 45,000 square miles in the Beni basin where water table is at or near the surface. They extend from the margin of the Brazilian Shield outcrop, westward to within 20 miles of the Sub-Andean zone. In the area of detailed study there are 104 oriented lakes and dry lakes more than 1 km in length, and almost an equal number of lakes less than 1 km in maximum dimension. Lakes constitute 3 per cent of the total area with roughly one lake more than 1 km long per 40 square miles.

In general, lake distribution is similar to that of the lineaments, except that the lakes are restricted to flat terrains with high water tables. As with the lineaments, they are concentrated along the more recently alluviated areas such as the west side of Rio Mamore and the abandoned courses of the Rio Beni and the Rio Grande. In one exceptional instance, a large lake, Lago Rogagua, clearly cuts across an abandoned channel of the ancestral Rio Beni.

Orientation and physical characteristics. Most of the lakes in the Beni basin have axes or long straight segments of shore line that trend within 10^{o} of N. 45^{o} E. or N. 45^{o} W. Lake shore lines in the mapped area either are oriented in one or both of these two directions or are completely unoriented.

The lakes range from about 1000 feet square to 12.4 miles long by 5.4 miles wide. The larger lakes are concentrated between the Rio Grande and Rio Ibare, in the vicinity of Rio Apere, and along the abandoned course of the Rio Beni. One large, unoriented lake (Lago Rogaguado) is partly included along the northernmost edge of the map area. Where known from seismic work, the shorter dimension of individual lakes is at least as long as the depth to crystalline basement. Rarely, however, is this dimension as little as half the depth to basement.

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SOME OBSERVATIONS ON THE SO-CALLED "LAKES" OF THE LLANO ESTACADO OF TEXAS

Patton, Leroy T.; *Geological Society of America, Proceedings, 1934*, p. 451.

Abstract. The depressions on the surface of the Llano Estacado, loosely termed "lakes," belong to three general classes: (1) Circular or elliptical depressions 10 to 50 feet deep, one eighth to one half mile in diameter; (2) Linear shaped and linear arranged depressions 100 feet or more in depth, one to three miles long; (3) Alkali lakes.

Original irregularities, differential compaction, and slumping due to solution of underlying Permian salt and gypsum strata, may account in part for these depressions, but no one of these causes seems sufficient to account for all of them. An important cause is thought to be the solution of the material immediately underlying the surface such as the "caliche." Evidence in support of this is found in the numerous, very small depressions forming in the bottom of the lakes at present.

Concentration of the annual rainfall to the summer season favors the development of broad, flat, shallow, steep-sided valleys characteristic of such climatic conditions. Erosion under these climatic conditions is relatively feeble and the development of such valleys is easily interrupted.

The interruption of the development of such valleys by wind work, piracy, the development of sinks, or a combination of these causes is believed to be the explanation of the origin of the lakes of the second class.

Lakes of the third class are sinks developed in the bottoms of the valleys, and derive their supply of brine from water under artesian pressure from the underlying salt and gypsum beds of the Permian.

• Pockmarks and Craterlets

CRATERLETS IN EAST-CENTRAL ARKANSAS PROBABLY DUE TO THE NEW MADRID EARTHQUAKE

Thomas, E. T.; *Science,* 56:20-21, 1922.

The following brief description of six craterlets occurring on and about the border between the southeast quarter of Sec. 31 and the northeast quarter of Sec. 32, T. 8 N., R. 7 E., is of interest because it apparently extends the sphere of destructive violence of the New Madrid earthquake from that illustrated in Bulletin 494, United States Geological Survey, to within about 20 miles northwest of Memphis. These are also of interest because few, if any, larger than these have been described.

Occurrence: Five of the craterlets occur on the upper surface of one of the low ridges of the Mississippi flood plain. The sixth is a double craterlet, occurring on the slope of the ridge. They apparently bear no relationship to each other except as regards origin and age. With the exception of the double craterlet, they are saucer-shaped, with diameters ranging from 10 to 40 feet, and depths ranging from 2 to 6 feet. One part of the double craterlet is about 15 feet by 10 feet along the diameters of its elliptical outline. The smaller craterlet is about 10 by 8 feet along similar directions. They are separated by a ridge about three feet high. The bottoms of both craterlets lie about 4 to 5 feet below the surrounding surface. These craterlets are all located within a radius of 800 feet.

Origin: The ridge on which these craterlets occur has long been cultivated, and between cultivation and sporadic attempts to fill them up, any evidences of rims that may have surrounded the craters have disappeared. However, the material about the craterlets is made up of the characteristic fine sand and clay that appears in all the dredgings in this vicinity, together with rocks that range in size from 1 inch through to 11x4x5 inches. These rocks very clearly are not indigenous to the flood plain materials that form the ridge. The supposition is that they were forced up from below by gaseous and water pressure that gave rise to the craterlets.

Age: No evidences as to age was obtained by the writer. However, as similar craters are found farther to the north and are there shown to have been formed at the time of the New Madrid earthquake, it is logical to assume that these were formed during the same disturbances.

SMALL SAND CRATERS OF SEISMIC ORIGIN

Sheppard, George; *Nature,* 132:1006, 1933.

In connexion with the earthquake of October 2, which was felt throughout the coastal zone of Ecuador, I was fortunate in being able to photograph several examples of unusual structures which were formed directly after the seismic disturbance. The craters were found in a dry lagoon close to the seashore and were associated with pronounced fissures in the alluvium, these being oriented from north-east to north-west. The fractures occur near a major fault which separates the Eocene and Oligocene formations, and thus it appears that there was movement along this fault at the time of the earthquake.

According to the version of the inhabitants, the cracks in the ground appeared immediately after the first tremor, and at the same time numbers of jets of fresh water, two feet or more in height, were observed issuing out of the fissures. Large quantities of sand were brought up by the water and this material was precipitated in the form of the small craters which are illustrated in Fig. 1. The cones were occasionally fused into groups, whilst in other examples the structures were elongated along the apertures of the respective fissures. The largest craters measured about four feet in diameter and varied from six to twelve inches in height. After a short interval of time, which probably corresponded to the duration of the initial tremors, the activity of the springs ceased, and the water, which had temporarily inundated the area disappeared underground through the open fissures. (Figs. omitted.)

It is evident from the above, therefore, that the land surface in the vicinity of the faulted zone in the Tertiary rocks subsided at first, and this movement caused the ejection of the fresh water, which resulted in the crater-like structures of loose sand. After the earthquake, however, the surface of the ground was restored to its original level.

Apart from the geological interest which is attached to these recent seismic phenomena, they probably help in the elucidation of the cause of certain sandstone dykes which are found in the Tertiary formations of south-western Ecuador. In many shale sections of the coast near Chanduy, high angle joints are seen to be filled with sand, many up to a foot in thickness, and they invariably assume the nature and appearance of typical sandstone dykes.

As there is little possibility of the sand being derived either from the shale or from above, it is conceivable that they may have been injected from below during a seismic disturbance, probably very similar to the recent example which forms the subject of this note.

EXPLAINING THE NORTH SEA'S LUNAR FLOOR

McQuillin, Robert, and Fannin, Nigel; *New Scientist,* 83:90-92, 1979.

The topography of the seafloor around Britain, like that of its land area, has formed over many thousands of years and results from many well understood geological processes. So it is surprising that recent studies have discovered a wide expanse of seabed in the middle of the North Sea---between 15000 and 20000 square kilometers in area---which appears on sonar pictures to have a topography much like a miniature lunar landscape. Geologists by no means fully understand the origin of the principal features---small craters called "pockmarks"---and are currently hotly debating the subject.

This tract of seafloor, just north of the Forties oilfield, is about 150 metres below sea level. On the broad scale the seabed is flat or gently sloping, but there are many thousands of the shallow crater-like features distributed across it. These pockmarks are defined as cone-shaped depressions normally without a rim, which occur in unconsolidated sediments at seabed level. They were first recognised off Canada where investigators---using echo-sounders, side-scanning sonar and submersibles---found craters that were typically 15-45 m across and 5-10 m deep.

In the North Sea, the Institute of Geological Sciences, supported by the Department of Energy, is marking a detailed study of pockmarks in an area of about 80 sq km where about 2500 depressions have been identified; individual pockmarks are between 10 m and 100 m across, and from 2-8 m deep. Thus the larger of them are shallow craters about the size of a football pitch the sides of which generally slope between 5° and 10° inwards, though in some of the smaller pockmarks the slopes are up to 17°.

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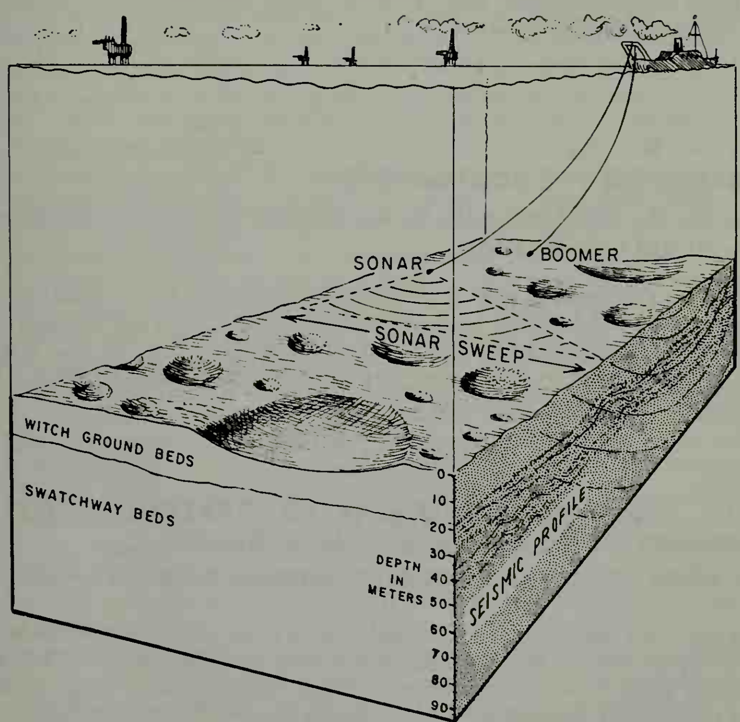

System of craterlets or pockmarks detected by sonar on the floor of the North Sea.

In water depths of about 150 m in the North Sea, which is where the main pockmarks in the UK sector are (see above), geologists investigating the nature of the seabed, or the structures of underlying sediment layers, have to rely heavily on geophysical profiling methods. Scientists from the IGS have studied pockmarks in the North Sea over a number of years using both sidescan sonar and seismic profiling techniques. By plotting the results of sonar surveys (part of an original record is shown in the next page) we prepared a seabed map of pockmark distribution covering the institute's 4 km by 20 km study area. (Record omitted.)

Using large-scale maps we then digitised pockmark shapes and locations so that we could do a statistical study of shapes and distribution. We found that in this particular area there are approximately 31 pockmarks per sq km. They are generally elliptical and the ratio of length to breadth varies from 1 (circular) to 2.12 with a mean of about 1.4. The most common direction of elongation, NNE-SSW (the mean was 21°), is the same in general as that of tidal currents in the area. About 7.5 per cent of the seabed occupied by pockmarks and the average pockmark takes up an area of approximately 2000 sq m. We also made tests to see if pockmarks tend to line up (have "significant lineations") along any particular direction or direction. The lineations we found were not very well defined but they can be detected and have a mean direction of 10° from North. This is similar to, but does not coorespond exactly with, the overall direction of the long axis of the elliptical pockmarks.

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POCKMARKS ON THE SCOTIAN SHELF

King, Lewis H., and MacLean, Brian; *Geological Society of America, Bulletin,* 81:3141-3148, 1970.

Abstract. Pockmarks are cone-shaped depressions that occur in large numbers across the LaHave clay of the Scotian Shelf. They normally range in diameter from 15 to 45 m and in depth from 5 to 10 m. They were possibly formed by ascending gas or subsurface water leakage from underlying coastal plain sediments.

MODERN BIOGENIC GAS-GENERATED CRATERS (SEA-FLOOR "POCKMARKS") ON THE BERING SHELF, ALASKA

Nelson, Hans, et al; *GSA News & Information,* 1:190-191, 1979.

Abstract. As many as 1,340 small craters per square kilometre cover the sea floor of Norton Sound in the northeastern Bering Sea. The craters are circular pits, 1 to 10 m in diameter and less than 1 m deep, observed on sonographs over 20,000 km^2 of northern Norton Sound sea floor. Craters typically are associated with acoustic anomalies, near-surface peaty mud, and gas-charged sediment.

The peaty mud is a thick (>1.5 m), nonmarine pre-Holocene deposit that is now covered by a 1- to 3-m-thick layer of Holocene marine mud in

the area of the craters. The peaty mud (2% to 8% organic carbon) contains abundant biogenic methane [$C_1/(C_2 + C_3) = 256$ to 7,669] with carbon isotope (δ ^{13}C) values of -69% to -75%. Decomposition of organic debris in the peaty mud apparently charges the mud with gas. The peaty and gassy zones attenuate sound waves and cause acoustic anomalies on high-resolution seismic profiles in the area with craters.

The craters are forming now, as shown by the disruption of modern ice gouges by the craters. In the absence of storms, the gas apparently is trapped in the peaty mud in a saturated state by the cover of Holocene mud. Periodically, possibly during storms, the gas escapes through the thin Holocene cover and forms craters.

ON CERTAIN NATURAL PITS IN THE NEIGHBORHOOD OF RIPON

Tute, J. S.; *Geological Magazine,* 1:5:178-179, 1868.

Near the city of Ripon, on both sides the river Ure, but more particularly on the eastern side, there are a great number of natural pits, probably fifty or sixty, the origin of which appears to be very obscure.

They chiefly occur in groups of two, three, or four, in the lowest beds of the New Red Sandstone, and the overlying drift-gravel; but there are some also in the Magnesian Limestone. Their general form is crater-like, with a diameter of 40 to 100 feet, the sides having a slope of about 30°. But, in one instance (marked c on the plan), the pit consists of a perpendicular shaft about 30 feet in width and 60 in depth, cut through the New Red Sandstone. Here the gravel bed is very thin. In another, close to this one, the crater-like hollow terminates in a sandstone shaft, which is nearly filled with water. In a third, a, the sides of the pit, which occurs in the Magnesian Limestone, are perpendicular on the one side, but slope gradually down to the bottom on the other. The limestone is thinly-bedded, and in small slabs, dipping evenly to the east about 5°.

The crater-like form of these pits is evidently due to the falling in of the sides when a pit has occurred beneath the gravel; though in what manner the pits themselves have been formed is very difficult to understand. That they are due in some way to the action of water is probable, as they seldom, if ever occur more than half a mile from the river; and several of them now contain water. The Magnesian Limestone in the neighbourhood is full of cracks, and swallow-holes, and subterranean passages. If any of the overlying rock gave way, this would produce rather irregular subsidences, than such regularly formed pits as these are. The structure of the New Red Sandstone will be understood best from the following copy of a well-sinker's report of a well sunk 28-1/2 yards deep, very near to the pit marked d:---

"After cutting through the soil, which is not very thick, a soft sandy red rock, 10 feet thick, was penetrated, and then a layer of soft marly clay, about 10 inches thick. These clay layers occur about every 10 feet of rock. The rock was much harder as the shaft descended, and alternated red and white. The rock is not laid in horizontal layers, but is what well-sinkers call Eddy-Rock; and not all inclining one way, but crossing one another with great irregularity, and at various angles of descent."

Three of these pits have been formed in the memory of persons now living. The one marked a fell in about six or seven years ago. A clergyman, who happened to be near at the time, told me that he was standing by the river side with some boys watching two men, who were fishing, when they heard a noise like thunder; and looking round in the direction of the noise, they saw a mass of earth and stones rising into the air, and then falling down again. One of the men went near, and found that the rock had fallen in, and a pit had been formed about 30 feet in depth, at the bottom of which there was a quantity of water in a state of ebullition. The water continued in this agitated state during the following day, and afterwards gradually sunk. At present the pit is dry, and partially filled up by the falling in of one side.

Another pit, b, fell in about twenty-two years ago with a considerable noise, alarming the inmates of a neighbouring house, from which it is only separated by a road, but otherwise doing no harm. It is crater-like, having occurred beneath the gravel, and is now planted as an orchard. The pit marked c, mentioned above, fell in about forty years ago. It contains water, but in dry seasons this is nearly all drained away, and the rock is laid bare at the bottom.

These pits are also of frequent occurrence in the parish of Hutton Conyers; there are several in Sharrow, and one in Bishop Monkton, three miles south of Ripon, which was formed between thirty and forty years ago, near the Old Hall. Some men had been engaged in making a stack, and had left it for some purpose, when suddenly the ground gave way beneath the stack, and it disappeared. The place still exists, a receptacle for rubbish.

Perhaps some of the readers of the Geological Magazine will be able to throw a little light upon the manner in which these singular pits have been probably formed.

THAT WILTSHIRE CRATER

Moore, Patrick; *New Scientist,* 19:304, 1963.

Considerable interest has been aroused by the now-famous crater in a potato field, at a farm at Charlton, Wiltshire (near Shaftesbury). Various theories have been advanced to account for it; some are rational, while some are, perhaps, less rational. Since I have been to the site myself, and since I have been quoted as well as misquoted, it may be worth my making a few comments.

When I arrived at the site, on 25 July, the form of the original crater could be judged only with great difficulty and uncertainty. The bomb disposal team had been at work, and there had been a great many visitors to the field; it was said, indeed, that the visitors had been responsible for more damage to the potatoes than would have been caused by a dozen craters. However, I talked with Mr. Blanchard, the owner of the farm, who had seen the crater before it became notorious. Mr. Blanchard said that it took the form of an 8-foot depression, with a deeper 2-inch hole in the middle. Radiating from it were four "spurs", from which vegetation had been removed; three of these "spurs" lay to one side, while the longest spur was more or less opposite. (I saw the remains of these spurs, somewhat trampled.) He also said that the general impression was that some object had landed and then taken off again.

In the adjoining wheatfields were other features, taking the form of circular or elliptical areas in which the wheat had been flattened. I saw these myself; they had not been much visited, and were certainly peculiar. One, very well-defined, was an oval, 15 yards long by 4-1/2 broad. There was evidence of "spiral flattening", and in one case there was a circular area in the centre in which the wheat had not been flattened. In no case was there any evidence of an actual depression in the ground.

The bomb disposal team had excavated to a depth of about 8 feet, and it had been previously stated that the crater was due to an old bomb which had exploded for some reason or other. This did not seem very probable, and by the time I arrived the idea had been more or less given up. I have done some bomb disposal myself (though a very long time ago), and I was therefore able to appreciate what had been going on. The only interesting feature was one particular piece of material, found in the crater, which was suspected to be meteoritic. I examined it; and though I make no pretence of being an expert, I said that in my view the object was emphatically not a meteorite, and was similar to the other material in the area. In the television news that evening, it was said that I had expressed the view that the object <u>was</u> a meteorite, What I had actually said was that the crater could be of meteoric origin, and quite probably was. It may be added that the Museum authorities in London eventually found that the object itself was not a meteorite of any kind.

The bomb disposal authorities were subsequently satisfied that no bomb was involved, and so their interest in the crater understandably vanished. By the time that this letter appears in print, peace will have descended once more upon the potato field; but it is worth pausing to see just what the crater really was.

It could have been caused by natural subsidence, but it did not give that impression, and in any case there are the areas of flattened wheat to be taken into account; it would be a remarkable coincidence if these areas were not associated with the crater. Since the areas of flattened wheat "led" to the crater, it looks very much as though they, and the crater, were caused by something which came from the sky. In this case, the wheat would have been flattened by violent air-currents produced by the falling body.

The body itself---assuming that it existed---could have been a piece of an artificial satellite, but this appears improbable. It cannot have been a piece of an aircraft, as this would have been traceable, and no machines were reported either lost or in trouble. We can, of course, invoke secret aircraft or even flying saucers from Uranus, Saturn, alpha-Centauri or some other world. But on the whole, the most likely explanation is surely that some meteoritic body was involved.

The radiating spurs are certainly odd, but this, remember, was a potato field, and had been dug in various set directions, so that an impact might have opened up old furrows. A body of small size could have caused an 8-foot crater, and even produced air-currents sufficient to produce the areas of flattened wheat. On the other hand, I was quite unable to find any trace of meteoritic material; and there is certainly no definite evidence of a meteoric impact.

The suggestion of a hoax has been made, but seems, to me, to be wildly improbable.

When public interest has died down, it might well be worth carrying out an investigation to see whether any evidence of a meteoric fall can be found. Meanwhile, there is little more than I can add to this somewhat odd episode.

A PECULIAR HOLE NEAR TIFFIN, IOWA

Wylie, C. C.; *Popular Astronomy*, 46:221-222, 1938.

In Contributions of the University of Iowa Observatory, Number 8, page 265, Popular Astronomy, 45, 445, we published a description of a peculiar hole found in the bottom lands of Clear Creek, near Tiffin, Iowa. A countour map of the hole, and a map showing the location with respect to the creek, were published. Tradition calls this hole a "buffalo wallow," but in the opinion of university men most familiar with the buffalo, or American bison, the hole was not made by that animal. Experts in hydraulic engineering, who personally examined the hole, said that it was not produced by the ordinary processes of stream flow and erosion. Experts in geology also examined the hole, but could offer no explanation of its origin.

The possibility that it might be a sinkhole was considered. However, bedrock is more than 100 feet below the bottom of this hole. If the underlying rock did crack it appears that the channelling of the waters would be from the creek bed and not from comparatively high land on the flood plain. The possibility that a jam of driftwood had caused it was considered. However, a jam of driftwood in the stream occurred while we were investigating the hole. It caused some change in the channel, but a year later there was no noticeable depression. The silt had filled in around the driftwood leaving the flood plain level.

The possibility of an artificial origin was considered, but the hole does not have that appearance, and there is no reason for excavating such a hole in the bottom land near a stream. Certainly it would be of no value as a reservoir of water, since it is dry except when filled by flood water, and the nearby creek is never dry.

The possibility of a meteoric origin was considered. The elliptical shape, with a rim to the south, is similar to known meteoric craters. Soil borings from the rim of the hole contained reddish layers with plenty of iron oxide. Borings in the flood plain surrounding the hole showed no such layers of concentrated iron oxide. This is in agreement with the meteoric theory. Probings showed that the gravel under the hole is at about the same level as the gravel in the bottom of Clear Creek. This is against the meteoric theory.

Since the publication of the preceding article, tests of the soil borings for iron and nickel have been made by Professor Louis J. Waldbauer of our Chemistry Department. The tests showed plenty of iron, even in the borings from the flood plain a considerable distance from the hole; but they showed no nickel. The absence of nickel is against the meteoric theory. If a meteoric hole were very old, the nickel might be dissolved, but from the erosion, we believe the age is less than one hundred years.

Settlements within ten miles of this hole were established between 1835 and 1840, and a newspaper has been published since 1840. If the hole had been formed by an explosion, meteoric or others, windows would have been broken ten miles away. Since we have no record of such an explosion, we know that such a meteor did not fall later than 1840. The appearance of the hole makes it pretty certain that it was not formed as long ago as 1840. Hence, the hole can hardly have been made by a meteor.

Following the publication of this article, Messrs. J. D. Boon and C. C. Albritton, Jr., of Southern Methodist University, referred us to "Torrential Flood Erosion in the Connecticut Valley in 1936," published in the American Journal of Science, 34, 293, October, 1937, by R. F. Collins and M. Schalk. This article by Collins and Schalk appeared in the same month as our article on the Tiffin hole. It describes a number of "swirl-pits" excavated in the bottom lands of the Connecticut River at the time of a powerful flood. Some of the larger swirl-pits are very similar to the Tiffin hole in size, in shape, and in location with respect to the stream. Messrs. Boon and Albritton suggested, and we agreed, that the swirl-pit theory for the origin of the Tiffin hole appeared better than anything previously suggested.

In favor of the swirl-pit theory is the size and general appearance of the hole, the location with respect to the stream, and the fact that Clear Creek overflows the bottom land rather frequently. It does not account for the reddish layers in the rim of the hole, but there is plenty of iron oxide in the bottom lands. The only obvious objection is the fact that there is a noticeable rim on three sides of the Tiffin hole. The Connecticut swirl-pits showed no such rim. But the flood plain near the Tiffin hole is now covered with underbrush. In such a case it seems possible that soil thrown out by a swirl might be caught by the underbrush, and a rim formed in that way.

Summary. On the basis of the present information, it appears highly improbable that the Tiffin hole is a "buffalo wallow," an old oxbow loop, a sinkhole, a pit from driftwood, a man-made hole, or a meteoric crater.

The "swirl-pit" theory fits the observed facts fairly well. The hole probably was made at the time of some powerful flood of Clear Creek fifty or sixty years ago.

CRATERS, ASTROBLEMES, GEOBLEMES

Fifty years ago, geologists recognized only a handful of small meteor craters on earth. Meteor Crater in Arizona was the biggest, although some still thought vulcanism was more likely than an astronomical encounter. During the 1960s and 1970s, close-up spacecraft pictures of the moon, Mars, and Mercury revealed heavily cratered surfaces. Obviously, the earth could hardly have escaped this bombardment that raked the inner solar system. With this change in outlook, geologists soon found dozens of new terrestrial craters---some many miles in diameter---by looking for evidence of impacts (breccia, cohesite, etc.) rather than obvious craters. Satellites, too, aided the search by photographing large ring-shaped structures that could not be discerned from the ground. Instead of doubting mile-wide craters, scientists now published papers describing ring structures hundreds of miles across.

In this section, only impact structures larger than 10 miles in diameter will be presented. (Smaller ones are too mundane) Some are not sharply incised craters but rather astroblemes (star wounds), where erosion has left only shattered rocks, cone-in-cone structures, cohesite (a mineral created under high pressures), and evidence of melting.

Now that the earth's ancient bombardment is accepted as dogma, it is crucial to call attention to observations that conflict with this theory. Thus, the word "geobleme" (earth wound) occurs in the section title, indicating that some large circular structures may have been engraved by purely terrestrial forces.

• 10-99 Miles in Diameter

THE SPACE SCARS OF EARTH

Millman, Peter M.; *Nature, 232:161-164, 1971.*

The two planetary bodies whose surfaces can be seen best from Earth and from spacecraft are the Moon and Mars. A dominant characteristic of both surfaces is a complex of circular craters of widely varying size and there is now considerable evidence that most of these craters resulted from the infall of the smaller, and less massive, bodies of the solar system---asteroids, meteoroids and possibly comets. We see the primary and secondary impact scars of these collisions with material from interplanetary space. It can be argued that the Earth should have suffered a similar celestial bombardment, and evidence of this is now growing rapidly, but because the Earth's surface is subject to many changes initiated by the atmosphere and oceans, the impact craters often have to be untangled from a maze of other features that may hide them from all but the persistent investigator.

Increasing Attention. It is rather surprising that in the past the detection of impact scars on Earth attracted little attention from most geologists. This situation is now changing rapidly and new information is becoming available in such profusion that any review of the subject rapidly becomes out of date.

Near the end of the last century there were tentative suggestions that the formation of certain depressions on Earth might have a connexion with meteoritic impact. G. K. Gilbert, for example, discussed this possible origin for the crater in Arizona---then known as Coon Butte---and for Lonar Lake in India. He discarded the hypothesis, chiefly because of a lack of understanding of the tremendous explosive force inherent in an impact at typical interplanetary collision speeds (15 to 25 km s^{-1}).

The scientific study of terrestrial impact features can properly be dated from the presentation of two papers before the Academy of Natural Sciences in Philadelphia on December 5, 1905. Both Barringer and Tilghman put forward in detail numerous reasons why Coon Butte should be considered a meteoritic crater and not the result of volcanic action or a steam explosion. In the face of considerable opposition to his theory, Barringer followed up his original paper with a continuing study of the Arizona crater until his death in 1929; in recognition of his pioneering work this feature is now officially named the Barringer Crater. (Barrington also has a crater on the Moon named after him.)

It was not until 1926 that the crater at Odessa, Texas, was suspected to be of meteoritic origin and in the next few years impact features were recognized in a number of other sites. Spencer reviews accounts of twenty-eight craters in seven locations, all of which are now considered to be meteoritic in origin and to contain associated meteoritic material. Spencer also mentioned the Tunguska event in Siberia on June 30, 1908, but this is not generally considered to have produced recognizable impact craters on the Earth's surface.

Cryptovolcanism. The second phase in the study of terrestrial impact scars commenced with a series of papers by J. D. Boon and C. C. Albritton who gave reasons why certain geological structures, previously called cryptovolcanic, should be considered of impact origin. In this case the argument was not as direct as for the craters listed by Spencer. The ages of the cryptovolcanic features were measured in hundreds of millions of years so that little remained of the original form, and any meteoritic material that might have been scattered in the area had long since disappeared. A common characteristic of these generally circular structures is the evidence of strong explosive action at a period that did not coincide with the age of the rocks involved. A wide acceptance of the views of Boon and Albritton came only after recent advances in the knowledge of highly shocked minerals. Eight of the nine structures listed by these authors as possibly meteoritic are now generally accepted as impact scars.

Canadian Studies. The third phase in the study of meteoritic craters did not start until 1950 when V. B. Meen of the Royal Ontario Museum led an expedition to Northern Ungava, Quebec, to investigate a circular lake that seemed to be a geological anomaly in the peninsula. This feature, now named the New Quebec Crater, was pronounced meteoritic by Meen. Other discoveries among the ancient rocks of Canada were made soon afterwards, many as a result of a systematic search of air photographs organized by C. S. Beals at the Dominion Observatory, Ottawa. Beals also introduced a new technique in the study of these ancient structures; various geophysical measurements were carried out systematically in a coordinated programme and then combined to give an overall picture. A good example is the investigation of the Brent Crater, which included aerial photography, topographical survey, surface geology, deep core drilling, and surveys by magnetic, seismic and gravity techniques. Brent has been used as a type example for comparing and assessing data secured in various ways. About twenty Canadian features are now being studied by these comprehensive geophysical methods.

The latest developments in the study of meteoritic impact features have arisen from the recognition of several definitive characteristics, both microscopic, of highly shocked materials. As early as 1946 Dietz pointed out the value of shatter cones as shock indicators and since 1960 further knowledge of shock metamorphosis has accumulated rapidly as a result of X-ray analysis and work with the microscope and the electron microprobe. The application of these new techniques to samples recovered from suspected impact sites has made it much easier to distinguish between structures that have only a superficial resemblance to impact craters and those that are genuine impact scars.

Geophysicists, geologists and astronomers now have at their disposal a wide variety of criteria for deciding the origin of a possible terrestrial impact feature. Some of the more important of these are shown in Table 1 but the list is by no means exhaustive. The overall picture of any site and the possibilities of origins other than impact must be considered carefully in coming to a conclusion in any given case.

Energy Release. The shape of a newly formed impact crater is caused by the sudden release of the kinetic energy of the impacting mass within a small volume somewhat below the original impacted surface. Matter will be ejected approximately equally in all directions and the impacting meteoroid will be broken up, pulverized and partially vaporized in the process. The result is a bowl shaped depression with a raised rim and, in some cases, a central uplift. Typical energies range from 10^{20} erg for a crater of diameter about 1 km to $\sim 10^{30}$ erg for a diameter of 50-100 km.

The form of relatively recent terrestrial impact craters corresponds closely with the youngest craters on the Moon and craters produced by artificial explosions on the Earth. The best example of a comparatively fresh impact scar is the Barringer Crater which has been preserved by the arid climate of Arizona from excessive erosion and sedimentation during the 30,000 or more years since it was formed. The outward tilting of the normally horizontal rock strata is very evidence, even to the casual observer, and one-sixth of more of its original depth has probably been filled up. In the case of the much older Canadian craters in the same size range, the original depression has often been completely filled by sediments tens or hundreds of millions of years old. Geophysical methods introduced in the 1950s make it possible to outline the original crater depth and the brecciated volume beneath the crater floor in these instances. The old craters of a category in which the original diameter was more than several kilometres normally show a central uplift. In many cases, the original crater has been filled and the rim eroded, but the central uplift is the one dominant feature which remains clearly visible. Some details of the central uplift in terrestrial craters are not yet completely understood but, in broad terms, the uplift may be ascribed to a combination of post-impact slumping of the crater walls, isostatic adjustments, and elastic rebound in the subsurface rock layers. The mechanisms of central uplift will have a greater effect in the larger craters, since here the energy of impact is in a higher ratio to the energy required to deform the geological strata. One of the large Canadian impact scars, Manicouagan, demonstrates well the peripheral trough which is often the most comspicuous structural feature in deeply eroded ancient craters.

Meteoritic Evidence. The presence of meteoritic material was once considered essential for the positive identification of an impact crater, and meteorites have been associated with all the smaller and younger impact features. Nickel-iron spherules of several types in the millimetre size range were first found in 1946 by Nininger at the Barringer Crater,

Table 1. Identification Criteria for Impact Craters

Form and structure	General circular form, depression with raised rim, radial fracturing and rim strata uplift, central uplift.
Meteoritic material	Presence of meteorites, nickel-iron spherules, iron shale of meteoritic origin.
Rock breccia	Impact produced breccia---on surface with fragments approaching metre sizes or larger, in drill cores with fragments of centimetre sizes, in rock samples as micro-breccia or suevite.
Shatter cones	Cone shaped formations found in a variety of rock types.
Mineralogical shock evidence	Numerous small scale and microscopic characteristics ranging from planar features and deformation discontinuities to fused glassy fragments with vesicles and streaks, forming a pumice-like material with lechatelierite.
Impact melts	Igneous materials---rocks, lavas, glasses, formed by impact melting.

and have been found more recently at a number of sites where meteorites have not yet been located. The manner of formation of these spherules is still a matter for discussion but there is no doubt that they are a product of the original meteoroid. In the case of the very old impact features identifiable meteoritic material has not often been found. Calculations of the diameters of the meteoroids producing these craters have varied from 1/20 to 1/30 of the crater diameter for a stony meteoroid, so the meteoroid volume would have been much less than 10^{-4} times the volume of terrestrial rock involved. Surface meteoritic material would not have remained in situ for millions of years, and probably only the nickel-iron portion of this material would be identified in the drill core sampling. Only a very small fraction of the total volume is studied in drill core methods and it is not surprising that there is little direct evidence of the original meteoroid.

Evidence of the shattering force of space impact may be seen in the broken rock fragments commonly associated with space scars. Barringer called early attention to the large-scale debris scattered around the crater that now bears his name. Drill cores, such as those from the Holleford Crater, illustrate vividly the type of rock breccia that is found below the crater floors. Breccias of an even finer grain size can be identified with a microscope.

The work of R. S. Dietz on shatter cones has already been mentioned and he has recently reviewed their occurrence at terrestrial impact sites. These cone-shaped structures are formed by shock in a variety of rock types at pressures from 20 to 100 kbar, much greater than the pressures usually ascribed to terrestrial volcanic mechanisms.

Other mineralogical shock evidence is relevant to even higher pressures and at shock pressures between 100 and 300 kbar planar features (closely spaced fine parallel lines) develop in quartz, plagioclase and other minerals. Apart from the planar features there is other evidence of deformation, for example, slip bands, kink bands and deformation lamellae. At pressures from 300 to 500 kbar there are still planar features and also the highly shocked phases of SiO_2, coesite and stishovite. In this pressure range undisturbed mineral crystals begin to change to the disordered or amorphous phases and at 500 to 650 kbar glasses containing vesicles and streaks are formed and most of the original texture of the crystalline rocks is destroyed. At pressures approaching 1,000 kbar and temperatures of 5,000 K complete melting occurs.

High temperatures are developed in an impact event, particularly the larger terrestrial features. The surface rocks melt and leave igneous materials in the form of glass in mixed breccias, layers of rock melt, and intrusions into basement rocks below the crater. Dence has noted these melts at about forty impact sites.

POPIGAY DEPRESSION: A SIBERIAN ASTROBLEME?

Anonymous; *Sky and Telescope,* 43:93, 1972.

About five degrees north of the Arctic Circle, near longitude 110° east in the Khatanga river basin, there is a round depression about 45 miles in diameter. The Popigay and other lesser rivers flow through the depression, which has usually been regarded as the result of a collapse some 100 million years ago in the Cretaceous period. But Soviet scientists who explored this feature during the summer of 1970 believe it was formed by the impact of a large extraterrestrial object about 30 million years ago.

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SUDBURY STRUCTURE AS AN ASTROBLEME

Dietz, Robert S.; *Journal of Geology,* 72:412-434, 1964.

Abstract. The Sudbury structure is interpreted as a 1.7-billion-year-old asteroid impact structure or "astrobleme" created by a 3 x 10^{29} erg event. If traveling at 15 km/sec, the asteroid was about 4 km. in diameter. A crater was formed 30 miles across and 2 miles deep. Along with melted country rock, the bolide, possibly a copper-rich nickel-iron meteorite, is still partially preserved, although converted to sulfides, as a marginal sheet along the crater wall and as injections into radial tension cracks. Shock brecciation and rock were heaved up, forming the crater wall. The collar is still easily recognized along the southern periphery of the Sudbury structure, but it can only be permissibly assumed in the massive granitic rocks around the northern periphery. Because of its great magnitude, the Sudbury event triggered magmatism by offloading the lower crust and mantle and by adding shock heat. Partial fusion of already critically warm rock resulted. A saucer-shaped pool of magma, an extrusive lopolith, formed and differentiated in the crater bottom, also

laying down a thick capping of welded tuffs (Onaping tuffs). A body of water subsequently occupied the basin, in which the Whitewater sediments were deposited. Rebound, isostasy, tectonism (especially the Grenville thrust from the southeast making the lopolith oval), and finally erosion have modified the structure.

The writer considers that lunar maria may also be created by impact-triggered magmatism to form extrusive lopoliths. Hence, while other astroblemes so far known may be the terrestrial equivalents of lunar craters, the Sudbury structure may be the equivalent of a small lunar mare.

INVESTIGATION OF THE MANICOUAGAN IMPACT CRATER

Phinney, W. C., et al; *Journal of Geophysical Research,* 83:2729-2735, no. B6, 1978.

Abstract. A heavily cratered surface is a feature common to the early evolution of all the terrestrial planetary bodies. However, because the multiple impact history and inaccessibility of other bodies provide such poor geologic control, it is considered that the integrated effects of these impacts are best detailed and constrained through the intensive study of terrestrial impact structures. A survey of terrestrial structures indicates that the 65-km-diameter Manicouagan ring structure in Quebec, Canada, has by virtue of its size, exposure, and relatively well known geologic and geophysical characteristics the potential to provide details of impact processes, in particular those concerned with impact melting. This paper serves as an introduction to several detailed companion papers that resulted from a recent multi-disciplinary study of Manicouagan. The major conclusions are as follows: The structure is 214 m.y. old. The melt rocks are texturally inhomogeneous but chemically homogeneous, can be modeled as a mixture of target lithologies, and have a $^{87}Sr/^{86}Sr$ ratio compatible with the melting of crustal rocks. Grain size and inclusion content of melt rocks vary inversely, grain size increasing upward. The melt had a two-stage cooling history with clast-melt interactions indicative of mixing superheated silicate liquid with cold clasts. Extensive digestion and reaction of clasts in the melt during the first stage of cooling resulted in a more refractory clast population than would be provided directly from the target rocks. However, a stronger bias toward refractory clasts in the interior zones of the sheet suggests a higher equilibration temperature and a lower initial content of clasts in these zones. Thermal equilibration of clasts and melt during the first stage of cooling required tens of seconds to a few minutes, whereas completion of crystallization during the second stage required about 1600 more years. Geophysical data suggest the presence of uplifted mafic rocks in the center of the structure and are compatible with an initial transient cavity with a radius of 15 to 22 km and a modeled depth of 6 to 9 km.

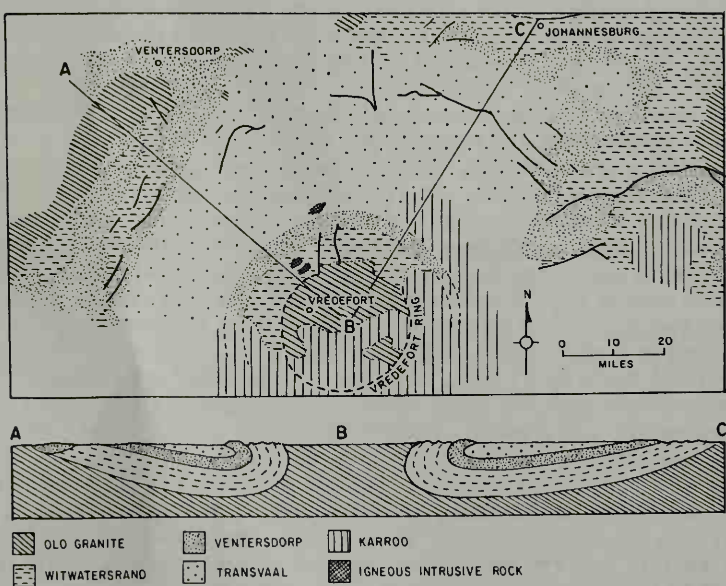
VREDEFORT RING STRUCTURE: METEORITE IMPACT SCAR?

Dietz, Robert S.; *Journal of Geology*, 69:499-516, 1961.

Abstract. The peerless Vredefort Ring structure of South Africa defies rational interpretation by tectonic, volcanic, or magmatic forces. Following the heretical opinion of Boon, Albritton, and Daly, it is suggested to be a meteorite impact structure or "astrobleme." Using an impact velocity of 20 km/sec, it was found that an asteroid 2.3 km. in diameter would provide the 6 x 10^{28} ergs (1.4 million megatons TNT-equivalent) needed to create the original crater 40 km. across and roughly 16 km. deep.

An impact event adequately explains: (1) the apparent impulse direction which was radially outward from the center; (2) the shatter cones as shock-induced; (3) the bilateral symmetry as owing to an oblique impact; (4) the upturned and overtilted 16-km. thick collar as the effect of radial forces spreading out from the explosion focus; (5) the pressure and thermal metamorphism of the sedimentary collar as shock wave-induced; (6) the intensive fracturing and microshearing of rock with little relative displacement as shock wave-induced; (7) the pseudotachylite as a "shock impactite" produced by overpressures in excess of 10^5 bars; and (8) the granophyre dikes as injected crater-lining "impactite."

The uplifted granite plug now filling the original crater was caused by a combination of elastic rebound and isostatic forces. It would seem that, at Vredefort, an impact event transpired equivalent to the formation of Copernicus or Tycho on the moon.



The Vredefort Ring in South Africa. The center is a plug of granite surrounded by a collar of up- and overturned strata. Recent sediments cover part of the structure. (Adapted from Scientific American, *205:56-57, August 1961.)*

METEORITE CRATERS AND ASTROBLEMES.....

Dietz, Robert S., and McHone, John; *EOS*, 55:336, 1974.

Abstract. Based upon ERTS imagery and map analysis, following are some impact structures which may be added to the recent list compiled by Dence. (1) Circular Lake Rossignol, 20 km across in central Nova Scotia, may be an astrobleme etched out by glacial erosion as with many of the other Canadian examples. There is some suggestion that Manicougan may be a double astrobleme, as a tangent ring of equivalent size appears to lie to the NNW. (2) In India, ERTS imagery supports the view that Ramgahr in Rajastan is a probable, considerably eroded meteorite crater, as noted by Crawford. (3) In the USSR, as already noted as possible examples by Dence from Zotkin and Tsvetkov, El Gygytgyn seems a probable example of a meteorite crater on the style of New Quebec, only much larger. Labynkyr is a probable astrobleme 60 km across of the depressed outer ring type (e.g., Manicougan). The Konder dome is possibly an astrobleme, but more likely is endogenic. (4) In Brazil the 40-km Araguianka ring in Mato Grasso is a definite astrobleme based upon its damped wave tectonic style, shatter coning, impact melt rock, and shock metamorphism. The 20-km Serra da Cangalha ring in Coiaz, also of damped wave style, is a probable example.

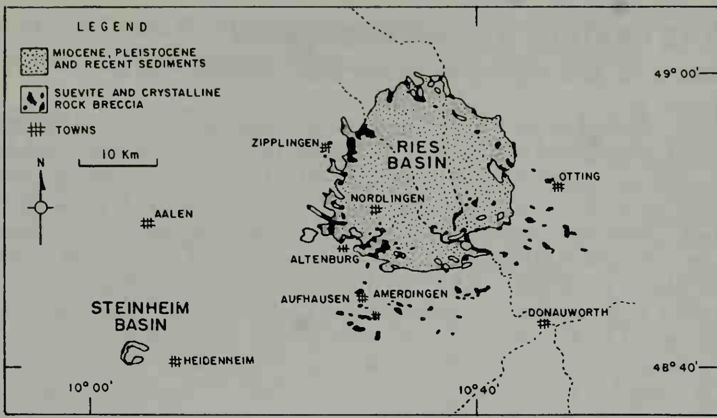
CRYPTOEXPLOSION STRUCTURES CAUSED FROM WITHOUT OR FROM WITHIN THE EARTH? ("ASTROBLEMES" OR "GEOBLEMES?")

Bucher, Walter H.; *American Journal of Science*, 261:597-649, 1963.

Abstract. Roughly circular structures with elevated centers consisting of materials forced up from below in disordered fashion were called "cryptovolcanic" by Branco and Fraas in 1905. In the last decades it was realized that the impact of a giant meteorite may have caused the explosion. Dietz's term "cryptoexplosion structures" is useful; it leaves the cause unspecified. For the same reason, open craters surrounded by a low wall of ejected bedrock fragments should be called "explosion craters", not "meteor craters". The presence of shatter cones in most cryptoexplosion structures, and especially the discovery of coesite, a heavy phase of silica, in two cryptoexplosion and two explosion structures seemed to provide evidence of impact from above. Moreover, some puzzling aspects of cryptovolcanic structures are simply explained by meteorite impact.

If meteorites caused these structures, they must be distributed randomly, i.e., they must not bear a systematic relation to structures of terrestrial origin nor to magmatic activity. In this paper this test is applied to the largest cryptoexplosion structures in Europe, North America, and Africa. This impartial selection includes the most quoted examples of coesite occurrence and of shatter cones.

Maps and detailed descriptions show that the European and American examples lie on large anticlinal flexures and that they and so-called satellite structures are aligned along these flexures with structures of



The Ries Basin, Bavaria, Germany.

demonstrably deep-seated magmatic origin. The Ries Basin lies, in fact, at a unique point where a broad anticlinal axis joins the flexure. Moreover, they are essentially contemporaneous with the magmatic activity. The Vredefort Dome is one of a whole string of basic and ultrabasic intrusions, in a part of the continent where such intrusions are widely distributed.

These test cases are decidedly not randomly distributed, neither in space nor in time. The meteorite impact hypothesis is therefore rejected. The writer suggests the release of vast quantities of water vapor through sudden crystallization of supercooled molten rock near the base of the crust as source of energy, carried rapidly into porous rocks near the earth's surface under an impervious cover. Rapid arrival of the vapor results in an explosion crater, with coesite, but without shatter cones. The energy required to form coesite may have been kinetic, transmitted as the pulverized material was forced through narrow and crooked passages toward the surface.

The presence of shatter cones in cryptovolcanic structures suggests that the presence of vapor under high pressure in the pores of the rock favored their formation. The pressure of the intergranular water vapor would increase its brittleness. Typical shatter cones from brittle bituminous coal lend credibility to this suggestion. Simple experiments show that the direction in which a cone points can not be used to "prove" impact from above.

Finally two other "evidences" frequently mentioned to "prove" meteoritic origin are criticized: the presence of nickeliferous iron among the ejecta of explosion craters and the remoteness from centers of volcanic activity of cryptovolcanic structures. Nickeliferous iron is habitually associated with basic and ultrabasic rocks. It is not the presence, but the high percentage of nickel in the original mineral that is diagnostic of meteoritic origin. If it is the release of water vapor from sudden crystallization of supercooled magma near the base of the crust below stable continental platforms that causes the explosion, then it is not "volcanic" activity we must look for, but the evidence of transport to or near the land.

CRYPTOEXPLOSION STRUCTURES: A DISCUSSION

Dietz, Robert S.; *American Journal of Science,* 261:650-664, 1963.

Abstract. An attempt is made to reply to and discuss the objections raised by W. H. Bucher in the preceding paper against the concept that cryptoexplosion structures of the Steinheim (Germany) and Wells Creek (Tennessee) type are astroblemes (meteorite impact structures).

The writer considers that the Barringer Crater (Meteor Crater) is unquestionably of meteoritic origin and that criteria for astroblemes may validly be extrapolated from it. The Wells Creek and Steinheim cryptoexplosion structures are not necessarily genetically related to the larger geologic structures around them. The Vredefort Ring may well be really related to the Bushveld complex and the Great Dike of Rhodesia, but an impact rationale can be suggested for the entire group. Perhaps great lopolithic bodies can be created by impact; for example, the Sudbury lopolith. All seem to agree that shatter cones and coesite validly indicate intense shock; the writer believes such shock can only be created by meteoritic impact.

The writer agrees with Bucher that there are many puzzling and unresolved aspects of cryptoexplosion structures and that we are still far from a definitive understanding of their true nature. These fascinating structures, which may be the terrestrial analogs of lunar craters, deserve careful scrutiny.

BIZARRE HYPOTHESIS

Hoffleit, Dorrit; *Sky and Telescope,* 2:15, 1943.

In a brief note, Popular Astronomy reports on an investigation on the "bizarre hypothesis" that the meteor responsible for Meteor Crater in Arizona may have had something to do with the felling of the trees in the petrified forests of northeastern Arizona. Richard Feldman finds a general common orientation for undisturbed tree trunks in each of the three petrified forests, Holbrook, Cameron, and Ganado. The intersections of the three directions for these areas form a triangle including Meteor Crater! Geologists consider his idea fantastic---but nevertheless there is food for thought.

• 100 Miles and More in Diameter

ASTRONS—THE EARTH'S OLDEST SCARS?

Norman, John, et al; *New Scientist*, 73:689-692, 1977.

[Satellite photos are revealing unsuspected systems of immense cracks in the earth's crust that seem to have been established well prior to the onset of continental drift (we assume the validity of this dogma). Norman and his colleagues ask why the continents did not split along these old fracture lines. Why should separation have occurred along west Africa's long arcuate coast rather than the deep inland fractures seen in satellite photos?

Aircraft photos frequently show small arcuate structures, due presumably to salt domes and other intrusions, but the smaller-scale photos from the orbit show much larger curved structures similar to some seen on the moon, Venus, and Mars.]

We have recently also noted, on the much smaller-scale satellite images of the Earth, concentric arcuate fractures in geologically old areas having much larger diameters of tens or a few hundreds of kilometres and at first we could not explain their origin. One cannot conceivably justify scaling up such events as granite or salt intrusion to the required huge size, and we need to look for another explanation. However, it is possible to see apparently similar fractures around some Moon craters and herein lies the clue.

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The Earth, being larger than the Moon, Mars and Venus, must inevitably have suffered the same bombardment of meteorites but, because of its atmosphere, ancient surface features have disappeared as the result of erosion by wind, rain, rivers, etc. Some craters and events on Earth have already been attributed to meteoritic impact. For example, the Diablo Canyon in America is a geologically recent crater measuring 1.5 km in diameter. Somewhat larger, more ancient, structures have been detected (et that at Sudbury, Canada) although their origin is still debated. Nothing approaching the size of the Moon's maria has been reported. But we cannot escape the conclusion that, in the past, the Earth must have endured many tens of thousands of impacts from meteorites, and that nearly all of these events involved high expenditure of energy.

What is the maximum impact shock that the Earth can absorb without disintegration? Obviously the Moon has been able to absorb the energy which has resulted in the larger maria. If we take Mare Imbrium and scale it up to the Earth's dimension, we obtain a comparative diameter for a terrestrial feature of the order of 3500 km. One should not, of course, take simple linear relationships between the size of Moon and Earth structures. But, we may certainly anticipate Earth structures resulting from impacts which could approach diameters of 3000 km. By scaling up the dimensions of Jones' experimental results, it follows that a structure of 3000 km diameter would require an energy of 10^{35} ergs (equivalent to the detonation of a billion-megaton nuclear device). Such energy would be generated by the Earth, moving at its normal speed (approximately 30 km/s) around the Sun colliding with a "stationary" stony meteorite of the size of some of the larger asteroids (diameter 300 km).

[The authors define an "astron" as a large disc of plastically welded rock bounded by a circumferential fracture zone. An astron is much larger than the more familiar astrobleme ("star wound") although due possibly to the same sort of impact process. The graben (fault troughs) surrounding an astron would dominate subsequent geographical changes and be visible from space.]

For example, we suggest that the almost circular bulge of the West African coast marks the graben-defined boundary of one of the Earth's major astrons. Work with satellite images has shown us that a large arcuate graben full of sediments continues this circle along the line of the Benue River, and that further sedimentary basins align themselves with the circle through Chad, Libya, Mauretania and Morocco. There are interruptions in this circle, but that is not surprising when you bear in mind the complex pattern of overlapping craters seen on the Moon. We suggest that when the processes of plate tectonics opened up the Atlantic Ocean the fractures of the graben, which formed a curved zone of existing weakness, were exploited and so determined the present coast line of the West African bulge.

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It is suggested that an astron showing this effect is the curve of the Peruvian part of the Andes, where South America has a coastal outline reminiscent of West Africa. In eastern Brazil a curved zone of geological features lies on the circle which is defined by the arcuate portion of the Andes. The downward inclination of the over-ridden ocean-floor crustal material beneath this curved portion of the Andes may have been initially influenced by the eastward-dipping fractures of the outer part of the astron's graben; or it may be controlled by the downward curving rim of the astron. In either case, the surface curvature of this inclined zone immediately leads one to suggest that island arcs such as the Aleutians now need examination in the light of their being the outer expression of an astron.

We have noted horizontal displacement along some of the arcuate failures, indicating that astrons may be able to rotate in certain situations (eg during oblique impact with a plate). Nor is it only the faults of the circumferential graben which may undergo renewed movement, for the radiating faults provide extensive planes of weakness which may subsequently be utilised. In this context the Pacific is of interest. For example "transform faults" mapped on the Pacific Ocean floor, tend to radiate from an area north-east of Australia, where the world's largest positive gravity anomaly has been recorded. Correlation of this phenomenon with the "mascons" (mass-concentrations), which occur in several of the maria of the Moon, is tempting.

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There appears to be a fascinating geological task ahead in trying to solve a mainly concealed jig-saw puzzle consisting of incomplete pieces of different ages. However, we suggest that any large-scale crustal feature which exhibits an arcuate outline is deserving of special scrutiny---for example, the curve of the coast of China, the curved mountainous coast of eastern Australia, and the magnificent sweep of the Himalayas bordering northern India. Smaller-scale versions exist bordering the southern parts of the Caspian and Black Seas, and eastern Korea. We must also think of examining concave arcuate coasts such as the Gulf of Mexico or the Great Australian Bight. These and other possible astrons are indicated in Figure 6.

[Since fast-moving meteorites would probably completely vaporize upon collision with the earth, slow stony bodies are proposed as the cause of astrons. Such projectiles would penetrate deeply into the earth's mantle, like the lunar mascons are supposed to have done. Although most astrons were likely created 3 billion years or so ago when the major lunar craters were formed, some may be as recent as 100 million years old. The possible terrestrial consequences of such a colossal impact include: biological extinctions, climate modification, magnetic field changes, and, if the impact were oceanic, waves as high as 3 km.]

Locations of possible astrons inferred from topographic maps.

SOVIETS FIND METEOR CRATER

Anonymous; *Astronomy*, 5:60, February 1977.

Based on recent studies, Soviet scientists have indicated the discovery of what appears to be a large and ancient impact crater, 6 miles deep and 400 miles wide. This discovery gives evidence that the bombardment of Earth by large meteors did not end in our planet's earlier years.

The Soviet discovery was described by Dr. Frank Dachille of Pennsylvania State University at the annual meeting of the Meteoritical Society (an international association) in October 1976, at Lehigh University in Gethlehem, Pa.

The area in northern Kazakastan in the Soviet Union is now heavily eroded and filled in. The enormous crater would cover northeastern

United States from Boston to Baltimore. It appears to have been formed four billion years after Earth's formation, or around 425 million years ago. According to Dachille, such impacts occur about once every 100 million years.

Dachille used estimated timetables of crater producing impacts on the moon, plus the recent discovery and dating of several large crater remnants on Earth, to approximate the relative frequencies of large and small impacts on this planet.

Older craters have been identified through the discovery that the explosive impacts in which they were formed left telltale rock transformations. Included in this are tiny diamonds, greatly compressed forms of quartz (coesite and stishovite), shatter cones, and minerals known as impactites.

Soviet scientists have suggested that the impact ruptured Earth's crust deep enough to release volcanic outpourings and generate ore deposits such as occurred in the Sudbury Basin of Ontario, Canada (the source of much of the world's nickel).

The huge area in Kazakastan---centered on salty Lake Tengiz, and now referred to as the Ishim Impact Structure---has been attributed to impact because of the seemingly shock-altered quartz formations there.

CIRCULAR STRUCTURES OF LARGE SCALE AND GREAT AGE ON THE EARTH'S SURFACE

Saul, John M.; *Nature,* 271:345-349, 1978.

The Earth's surface exhibits faint circular patterns which have not been described before. These circles are characterised by near perfection of outline, by the presence of topographic highs (rims) along parts of their circumferences, by their generally large scale (diameters of from under 7 km up to approximately 700 km in the areas examined), and by their definition in various geological environments, in many rock types, and in rocks of all ages. Many of the circles are intermittent in places along their rims but about 55% of the approximately 1,170 definite circles observed to date can be visually traced around an entire 360^{o} of arc. The circles are further characterised by the presence of fracturing and brecciation along parts of their rims and by the extraordinary control they place on regional geology in general and on ore mineralisation in particular.

To date, circles of this nature have been observed clearly in several areas with ancient continental crust at depth: the western United States, northernmost Mexico, the Appalachians, Alaska and the Yukon. Their existence is also strongly indicated in Madagascar and Corsica. No other areas have been examined. The circles are visible on displays which were produced from commercially available raised plastic relief maps with a 1:250,000 scale and a two- or threefold vertical exaggeration. These were illuminated at a low angle by a parallel light source and photographed individually. Photographs of adjacent maps were joined to give regional coverage.

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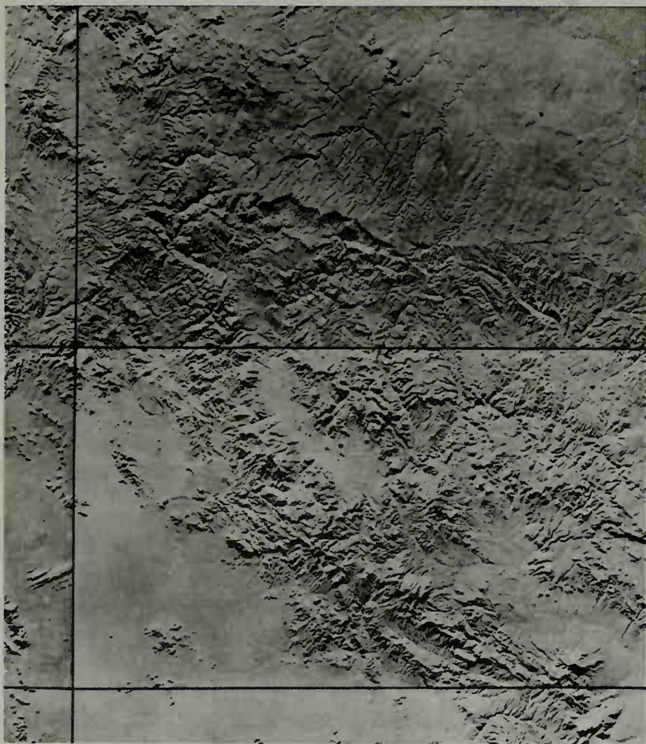
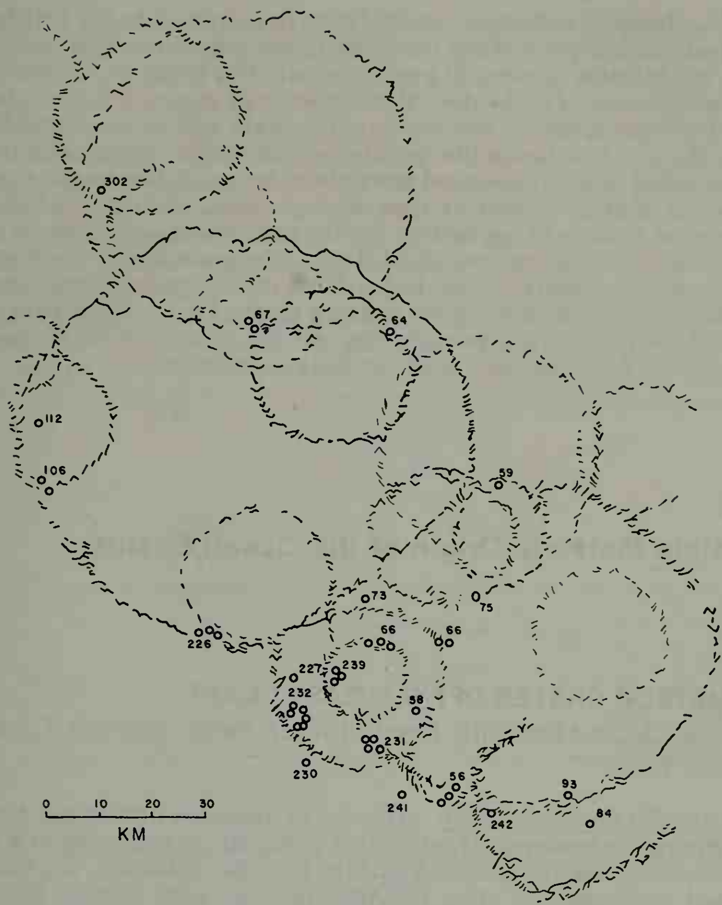
Individual circles exhibit different degrees of visibility. In general, a circle that is readily visible along one portion of its circumference will



A 70-km circular structure on a relief map of Arizona. This ring is the large central ring in the accompanying sketch. (John M. Saul)

be readily visible over the whole circumference, and a faint circle will be uniformly faint. The great majority of circles are indeed indistinct, and there is a real problem in reproducing the same circles in different viewings of the photomaps. Larger circles are easier to see than the smaller circles and a positive correlation between circle size and presence of mineralisation is suggested. This may have an upper limit, however. In this study no major mines were noted on circles larger than 150 km in diameter. Much larger circles may also exist. A circular feature of generally similar appearance and a 2,200-km diameter seems to encircle the southern end of Africa, passing through the watershed area of central Angola, the Limpopo Valley region, the offshore edges of the Mozambique and Agulhas Plateaus, various seamounts and the Walvis Ridge.

Intersections of two circles seem to have a somewhat enhanced chance of being mineralised and thus the identification of the fainter circles may prove important after all. In a few cases, the most notable of which is the Bingham copper mine in Utah, mineralisation was found at the inter-



Large-scale mineral rings in Arizona, as inferred from relief maps.

section of a circle and an obvious linear feature.

The centres of the circles seem to fall in a northwesterly trending pattern in Arizona and in a northeasterly trending pattern in the Appalachians, in both cases forming elongated clusters parallel or nearly parallel to the regional geological trends. Circles are much more abundant in mountainous areas than in the adjacent plains in many regions.

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The circles can be interpreted as having been formed by the impacts of meteorites during the most recent major bombardment of the Earth. At the time of this bombardment, which by analogy with the moon, was a discrete episode approximately 4,000 Myr ago, the Earth already had a brittle crust. Estimates of the thickness of that crust vary greatly. The Earth today is brittle down to a depth of at least 2.5–4 km; below this it is ductile. Impacts can cause major fracturing through to the brittle/ductile transition depth and the resulting scars may never heal completely due to a combination of several mechanisms. For instance, as the impact site is eroded away, the ductile subbasement will rise and become brittle with decreasing pressure, and the circular scars will be propagated downwards to the new brittle-ductile boundary. Similarly, movements in the fractured zones can be generated upwards to bequeath the circular patterns to overlying sediments or igneous sequences. A history of this nature seems capable of accounting for the preservation of some of the circular scars throughout geological time. The present-day fracture patterns may thus be inheritors or descendants of the original impact craters rather than direct remnants of the craters themselves. The circles differ from previously described astroblemes and the usual criteria of shock metamorphism have not been used for their recognition.

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• Possible Meteoric Origin of the Ocean Basins

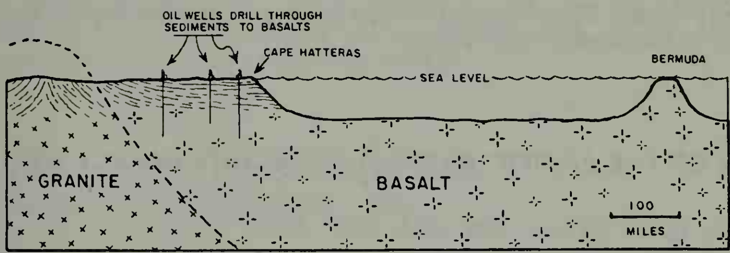
HUGE METEOR CRATER OFF U.S. EAST COAST

Kelly, Allan O., and Dachille, Frank; *Target: Earth,* Authors, Carlsbad, California, 1953.

Collision Off Carolina Coast. This great undersea crater has a rim that stretches for hundreds of miles in a great circle beginning at a point north and east of Puerto Rico and curving past the Bahamas, the Carolina Coast, and north and east along the Atlantic Coast until it loses itself in the deep ocean off the New England Coast. There is a very sudden break, almost a cliff, where the continental shelf (crater rim) breaks off into the deep ocean. The Bahama Islands form the south wall of this crater. They rise only a few feet above sea level but they form an undersea cliff that is nearly 700 miles long. Between the Great Bahama Bank and the islands of Cuba and Haiti, there is a secondary channel that is nearly half as deep as the main crater basin. The islands of Cuba, Haiti, and Puerto Rico are the mountains that form the remains of the outer crater rim, and the Brownson and Bartlett Deeps are the down-warped troughs that are common to many of the other great collision points that we shall mention later.

The floor of this great impact crater is also consistent with what might be expected. It slopes in every direction from the central peak (Bermuda) gradually growing deeper toward the rim although it averages deeper on the south and southwest than it does on the north. It is somewhat ovoid in shape being longer from northeast to southwest; the distance from Bermuda to Cape Hatteras being about 600 miles and from Bermuda to the Bahamas about 750 miles. On the east, the crater floor is about on a level with the rest of the deep ocean, probably because this part of the crater was made in deep ocean. In this respect it resembles Mare

Imbrium, having a mountain wall on one side and little or none on the other. The Bermuda central peak is surrounded on all sides by deep ocean, reaching a depth of 2,500 fathoms within a few miles from shore. From this point it gradually deepens outwardly in all directions for about 300 miles where it levels off and continues at about the same depth until it meets the sudden rise of the crater wall. This wall averages nearly 17,000 feet and in places more than 18,000 feet and this in a distance of no more than 15 or 20 miles. If one could remove the water and stand on the bottom of this crater he would look up at a mountain wall almost three times as high as the Grand Canyon is deep and almost as steep. The deepest part of the crater lies at the end of the Bahama chain and athwart the Mona Passage between Haiti and Puerto Rico. This is the Brownson Deep which is 4,780 fathoms or 28,680 feet. It is a comparatively narrow trench, as are most of the ocean deeps, and probably indicates a downwarping of the crust or an infalling of molten magma at the time of the collision.



Profile off the Carolina coast indicating the hypothetical meteor crater of Kelly and Dachille.

The National Geographic Society-Woods Hole expedition brought to light several new facts that fit in with the collision theory. They found that the greater part of the deep ocean was comparatively free from sediments and that the undersea mountains had only a few inches of sediments covering heavy crystalline rocks. Before this expedition it had been thought that the under sea mountains and ocean bottom might be so "deeply snowed under" with sediments that their rocks could not be raised by dredges to tell the story. The absence of deep sediments bear out the collision theory that oceanic floods carried away all such deposits and deposited them in distant localities. There is some evidence that in the lee of some of these undersea mountains deep drifts of sediments have collected. It is likely that the very fine sediments would remain in suspension for a long time after such a collision and some of this might have been returned to the deep sea and deposited there, but the heavier material would be carried long distances never to return. The fact that only 8 inches of Globigerina ooze was found on the ocean floor indicated that not many thousands of years have passed since these tiny marine organisms, called foraminifera, began dropping their shells to form this ooze.

Still another clue pointing to collision was the fact that several different kinds of rocks were hauled up in one dredge load, indicating that flood waters gathered rock from several localities and dumped it all in one spot. This is seen on our land surfaces but geologists always attribute this mixing of rock to stream action. However, the deep ocean waters are not supposed to move rocks of this size several hundreds or a thousand miles from land.

The curvature of the Appalachian mountains around this collision point and the folding and fracturing that has taken place in this area also points to this undersea crater as the point of impact. As might be expected, the mountains are violently folded and broken on the side next to the crater but gradually smooth out into nearly level strata on the westerly side of the mountains.

The great Charleston Earthquake of 1886 showed lines of equal intensity following this same curvature around the crater and indicate that some adjustment is still going on in the area surrounding this impact point. Other signs of a minor nature such as sulphur springs in Florida and volcanoes like Mt. Pelee on the island of Martinique show a surrounding activity. The Lesser Antilles, however, are probably the rim of a still older crater whose volcanic vents were re-activated by the later collision to the north. (pp. 35-36)

ORIGIN OF THE PACIFIC BASIN: A METEORITE IMPACT HYPOTHESIS

Harrison, E. R.; *Nature,* 188:1064-1067, 1960.

Very little is known about the processes that have fashioned the major features of the Earth's surface. Of the many problems unsolved, perhaps one of the most intriguing of all is that of the origin of the Pacific Basin.

It is known that the lighter crustal layers, which form the continental land masses to a depth of 20-40 km., are relatively thin on the ocean floors and in the particular case of the Pacific Basin are almost entirely absent. The Pacific Ocean itself has a mean depth of 5 km. and occupies almost half the Earth's surface; the greater density of its underlying rocks is consistent with the absence in the gravitational potential of any first harmonic terms about the axis of rotation. It was pointed out by Suess in 1888 that an outstanding characteristic of the Pacific is that it is surrounded by a variety of features which lie parallel to its coastlines. Among these features are the island festoons and the multiple arcs of deep-focus earthquakes, gravity anomalies, and ocean deeps. A further impressive characteristic is the seismic passivity of the Pacific Basin itself, which is in direct contrast with the continual tectonic activity in the surrounding regions where dissimilar crustal structures are in close contact and the land masses are folded as if by thrust against the denser and stronger mass of the Pacific Basin.

To explain such major surface characteristics it is proposed that the Pacific Basin was the seat of an immense explosion in the primitive Earth, and that the explosion was possibly due to a collision with a planetesimal or a satellite of approximately 100 km. radius. An attempt will be made to show that the explosion excavated a large crater of several thousand kilometres in radius and some hundreds of kilometres in depth. The great masses of material that were swept back and dropped at the rim of the crater formed the discontinuities of crustal structure and composition which survive to the present day and are responsible for the peripheral features of the Pacific Basin. Following the recovery of hydrostatic equilibrium there remained a shallow and permanent crater depression (because of the absence of the lighter surface layers) which is the present Pacific Basin.

....

[Harrison goes on to examine various theories that might account for the above facts. The calculations of Fisher and Darwin relative to the tidal tearing away of the moon from the region of the Pacific are reviewed. Detailed analysis by Jeffreys has brought disfavor on this theory, and it is difficult to understand why any crust torn from the earth would not fall back rather than go into orbit around the earth. The author next calculates that if the earth once had a second satellite with a radius of approximately 100 km, initially located less than about 7 earth radii away, it would have eventually approached the earth with enough energy to have blasted out the Pacific basin. (Interestingly enough, the now-dominant hypothesis of continental drift was not considered at all, being essentially totally rejected by earth scientists in 1960.)]

ORIGIN OF THE EARTH'S OCEAN BASINS

Frey, Herbert; *Icarus,* 32:235-250, 1977.

Abstract. The Earth's original ocean basins are proposed to be mare-type basins produced 4 billion y.a. by the flux of asteroid-sized objects responsible for the lunar mare basins. Sealing upward from the observed number of lunar basins for the greater capture cross-section and impact velocity of the Earth indicates that at least 50% of an original global crust would have been converted to basin topography. These basins were flooded by basaltic liquids in times short compared to the isostatic adjustment time for the basin. The modern crustal dichotomy (60% oceanic, 40% continental crust) was established early in the history of the Earth, making possible the later onset of plate tectonic processes. These later processes have subsequently reworked, in several cycles, principally the oceanic parts of the Earth's crust, changing the configuration of the continents in the process. Ocean basins (and oceans themselves) may be rare occurrences on planets in other star systems.

THE ORIGIN OF CONTINENTS

Salisbury, J. W., and Ronca, L. B.; *Nature,* 210:669-670, 1966.

The origin of continental nuclei has long been a puzzle. Theories advanced so far have generally failed to explain the first step in continent growth, or have been subject to serious objections. It is the purpose of this article to examine the possible role of the impact of large meteorites or asteroids in the production of continental nuclei.

Unfortunately, the geological evolution of the Earth's surface has had an obliterating effect on the original composition and structure of the continents to such an extent that further terrestrial investigations have small chance of arriving at an unambiguous answer to the question of continental origin. Paradoxically, clues to the origin and early history of the surface features of the Earth may be found on the Moon and planets, rather than on the Earth, because some of these bodies appear to have had a much less active geological history. As a result, relatively primitive surface features are preserved for study and analysis.

In the case of both the Moon and Mars, it is generally concluded from the appearance of their heavily cratered surfaces that they have been subjected to bombardment by large meteoroids during their geological history[1,2]. Likewise, it would appear a reasonable hypothesis that the Earth has also been subjected to meteoroid bombardment in the past, and that very large bodies struck the Earth early in its geological history.

The largest crater on the Moon listed by Baldwin[1] has a diameter of 285 km. However, if we accept the hypothesis of formation of some of the mare basins by impact, the maximum lunar impact crater diameter[1] is probably as large as 650 km. Based on a lunar analogy, one might expect several impact craters of at least 500 km diameter to have been formed on Earth. By applying Baldwin's[1] equation (7-1A), the depth of such a crater should be about 20 km. Baldwin admits that his equation gives excessive depths for large craters so that the actual depth should be somewhat smaller. Based on the measured depth of smaller lunar craters, a depth of 10 km is probably a conservative estimate for the depth of a 500 km impact crater. Baldwin's[1] equation (7-11A) gives the depth of the zone of brecciation for such a crater as about 75 km. The plasticity of the Earth's mantle at that depth makes it impossible to speak of "brecciation" in the usual sense. However, local stresses may be temporarily sustained at that depth, as shown by the existence of deep-focus earthquakes. Thus, short-term effects might be expected to a depth of more than 50 km in the mantle.

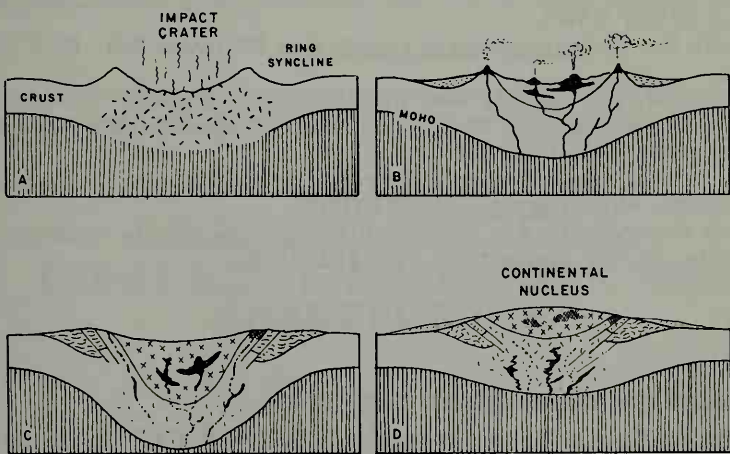
Even without knowing the precise effects, there is little doubt that the formation of a 500-km crater would be a major geological event. Numerous authors have considered the geological implications of such an event. Donn et al.[3] have, for example, called on the impact of continent-size bodies of sialic composition to form the original continents. Two major difficulties inherent in this concept are the lack of any known sialic meteorites, and the high probability that the energy of impact would result in a wide dissemination of sialic material, rather than its concentration at the point of impact[4].

Gilvarry[5], on the other hand, called on meteoroid impact to explain the production of ocean basins. The major difficulties with this model are that the morphology of most of the ocean basins is not consistent with impact, and that the origin and growth of continents is not adequately explained.

We agree with Donn et al.[3] that the impact of large meteorites or asteroids may have caused continent formation, but would rather think in terms of the localized addition of energy to the system, rather than in terms of the addition of actual sialic material.

The formation of a 10 km deep crater would result in a decrease in pressure of approximately 2,500 atm.[6] The effects of fracturing down to a depth of more than 50 km would strongly decrease the pressure locally at greater depths. It is impossible to speculate in detail on the sequence of events which followed the impact, but it is reasonable to assume that considerable volcanic action would result from the combination of sudden release of pressure and crustal fracturing[7]. Erosion of crater rim material and volcanism should then jointly fill the crater basin and circumferential syncline, which are typical features of large impacts, with low-density sediments and volcanics. As a result of this density differential, the entire complex would be isostatically uplifted to form a continental nucleus. It is of interest to note, in this regard, that the apparent age of the lunar maria (3.6 billion years[8]) is close to that of the oldest continental rocks[3].

Once the continental nucleus has been formed as suggested here, subsequent continental growth could occur in a number of ways. The temperature at a depth of 10 km early in the geological history of the Earth is not known, but 200° C is probably a very conservative estimate, considering the present-day extrapolated temperature at this depth of about 300° C. Before the formation of the continents, convection currents in the mantle were also probably distributed in some simple geometric pattern[9]. The impact would have caused the exposure at the surface of material originally at a temperature of at least 200° C. Even without volcanism, such a structure would be a powerful geothermal sink, conceivably able to modify the convection currents. The most logical modification would be the downflow of the cell immediately under the crater, with all the geosynclinal properties of such a phenomenon[9]. When sediments were sufficiently thick to result in a thermal blanket, the downflow would shift to the edge of the newly formed "protocontinent". From here on, the process would continue as described by Vening Meinesz[9]. Fig. 1 shows diagrammatically such a process.



Proposed mechanism for forming a continental nucleus: (A) immediately after meteorite impact; (B) shortly after a new Mohorovicic discontinuity has formed; (C) downflow causes sinking and compression; and (D) heat loss ends, downflow stops, and continental nucleus rises.

Kennedy's theory[10], in which the Mohorovicic discontinuity is held to be a phase change, also explains the process by which a geosyncline would sink and accumulate a great quantity of sediments, provided that a basin is present in the first place. Under this theory, the first effect of sediments deposited in the basin and ring syncline of the continental nucleus would be to increase the pressure under them, without any significant increase in temperature. This would cause the Mohorovicic discontinuity, which must have initially migrated downward in response to the reduced pressure attendant on crater formation, to move upward toward the surface. The resulting increase in density would cause the area to sink. As more sediments were added to the sinking trough, their low thermal conductivity would finally result in an increase in temperature, which would cause a downward migration of the Mohorovicic discontinuity. The resulting decrease in density would result in a general uplift of the area. The uplift would create a topographic gradient at the edge of the lifted area, where sediments would be again deposited, thus perpetuating the process.

Whatever the precise history of continental growth, it would appear that the localized additions of energy to the Earth's crust, which would result from the impact of large meteorites or asteroids, could produce continental nuclei through the formation of impact structures. Convection currents and/or the migration of a phase change boundary would assist in the formation of a nucleus, as well as in subsequent continental growth. Other mechanisms could, however, function just as well in continent formation, given the initial localized addition of energy resulting from an impact.

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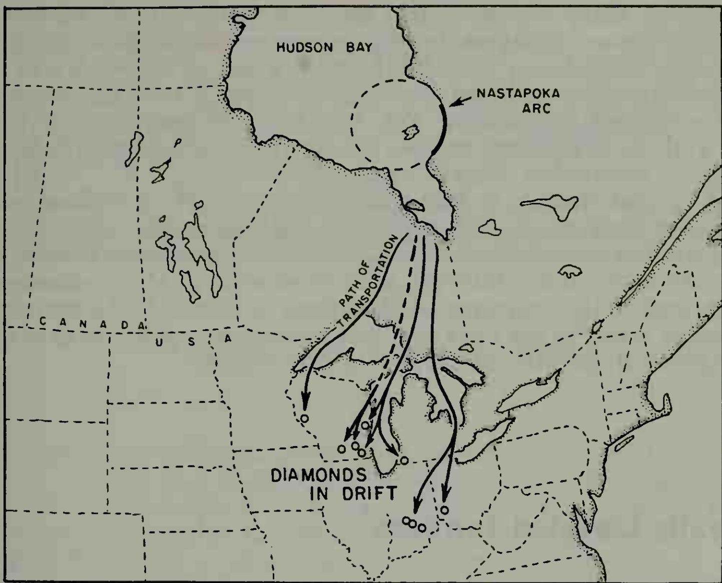
THE ORIGIN OF DIAMONDS IN THE DRIFT.....

Schwarcz, H. P.; *Journal of Geology,* 73:657-663, 1965.

Abstract. Diamonds found in Wisconsin drift in Ohio, Indiana, Michigan, and Wisconsin are proposed to have been carried south from an ancient meteorite crater at present outlined by the Nastapoka island arc in southeastern Hudson Bay.

Following meteorite impact, brecciation extended to a depth of about 150 km., and fragments of this mantle-rock breccia, enclosing diamonds, are inferred to have been brought to the surface in a central uplift similar to those found in lunar craters. Following the crater's formation, sediments filled it and were lithified, but these rocks are thought to have slid by gravity from the central part of the crater as it rose isostatically, permitting the diamond-bearing rocks to be re-exposed.



Occurrences of diamonds in the glacial drift seem to lead back to Hudson Bay. The dotted line extends the Nastapoka Arc into a complete circle.

LARGE-SCALE EMERGENCE AND SUBMERGENCE

Minor changes in sealevel have been recorded in historical times. Some Roman-built structures, for example, are now submerged, and some ancient Greek harbors lie high and dry. The continents and sea floors are restless in their ponderous fashion---rising, sinking, and drifting perhaps an inch or two per century. These miniscule movements are of no interest here. Instead, this section records extreme changes in sealevel: hundreds of feet in the last few thousand years to possibly miles in the case of the guyots drowned in recent geological times.

The principal topographic evidence of recent very high stands of the sea is seen in the worldwide occurrence of wave-cut benches and terraces at elevations up to about 1200 feet. Some of these terraces are located far inland, suggesting recent marine invasions. The frequent discovery of whale bones hundreds of miles from the ocean and old seawater on the bottoms of fresh-water lakes reinforces the hypothesis of enormous flooding.

At the other extreme, many guyots (flat-topped seamounts) now reside a mile or more below the waves that apparently planed their surfaces. Dead shallow-water corals on the guyots support the surmise that the guyots were once at sealevel. But did the guyots sink or sealevel rise? It is hard to believe that sealevel could have dropped a mile and more, leaving the continents high and dry. Yet, this situation would explain evaporites now well below sealevel and the submarine canyons that are deeply incised in the continental shelves and slopes.

If such radical changes in sealevel were due to the withdrawal and/or appearance of huge volumes of sea water, such planetary magic has not been explained in conventional terms. Some catastrophists have postulated extraterrestrial and internal sources of water. More conservative geologists look to less extreme combinations of vertical land movements, withdrawal of water to the ice caps, and mechanisms other than ocean waves to plane off guyots and carve inland terraces.

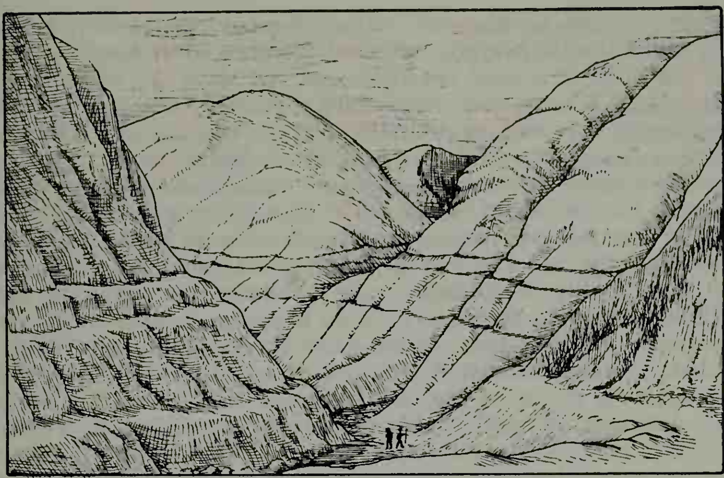
• Greatly Elevated Terraces

THE PARALLEL ROADS OF GLEN ROY

Anonymous; *Popular Science Monthly,* 10:309-313, 1877.

From a lecture recently delivered by Prof. Tyndall before the Royal Institution, we gather the following facts in regard to that natural wonder in Scotland, which for so long remained a puzzle to all investigators. There is an unusual interest centred around its history, from the time when the country-people explained it by their crude and half-mythical theories, to the time when it became a labor of love for the untiring efforts and acute observations of scientists.

The earliest published allusion to these roads was made in a work brought before the public a century ago, but no systematic description of them appeared before 1817. They are found in the district of Lochaber, Inverness-shire. On both sides of the steep, narrow glen through which the Roy runs, there are three perfectly horizontal and parallel roads, directly opposite on each side, those on one side corresponding exactly in elevation to those on the other. They are respectively 1,150, 1,070, and 860 feet above the sea, and are formed as shelves in the yielding drift which covers the sides of the mountains. They usually slope somewhat from the hill, and vary in width from one to twenty yards. The two high-



The parallel "roads" of Glen Roy, Scotland.

est stop abruptly at different points near the mouth of Glen Roy, although no barrier now remains to show any reason for it. At some points the grass on the shelves differs from that which is above and below, and, as the roads lie in the midst of heather-covered hills, the absence of the dark shrub from them adds greatly to their conspicuousness.

The terraces were originally supposed to have been made for the heroes whose deeds have been sung by Ossian. A less romantic view was that "they were designed for the chase, and were made after the spots were cleared in lines from wood, in order to tempt the animals into the open paths after they were roused, in order that they might come within the reach of the bowmen who might conceal themselves in the woods above and below." In 1816 Playfair believed them to be aqueducts for artificial irrigation. In 1817 Dr. MacCulloch discussed the probability of there having been lakes embosomed in Glen Roy at one time, and supposed that these roads were the margins of the lakes. It remained, however, for Sir Thomas Dick-Lander to bring forward the facts of the subject, and place them in a scientific light. Adjacent to Glen Roy is Glen Gluoy, along the sides of which there is a single terrace or road, having the same elevation on each side of the valley, and similar in all respects to the roads of Glen Roy. Wishing to see whether these two sides would be united at the head of the glen, and in what manner, he followed them into the mountains. As the valley gradually rose, he observed the shelves approaching each other more nearly; and finally, at the head of Glen Gluoy, he discovered a water-shed of exactly the same elevation as the road which swept around the glen. This height was found to be 1,170 feet, or 20 feet higher than the upper road of Glen Roy. From this watershed he passed through a lateral branch-valley to Glen Roy, descended to the highest road, and followed it up the glen as he had pursued the previous road. In the same manner he came upon a water-shed looking into Glen Spey, and of precisely the same elevation as the road. After this he dropped down to the lowest shelf, and followed it to the mouth of the glen. It did not end here, however, but doubled around the hills, and ran along the sides of the mountains which flank Glen Spean. Continuing eastward, he observed the Spean Valley gradually approaching the road until the two were on a level, when, as in the other cases, he discovered a water-shed.

From these facts, convinced that water alone could not have produced the terraces, he saw that if the mouth of Glen Gluoy were stopped by a barrier, the waters from the surrounding mountains would be collected in the valley until they had reached the water-shed, when any further rise would be prevented by the branch-valley, which would carry the additional water off to Glen Roy. As long, then, as the barrier remained, there would be a lake in Glen Gluoy, at the exact level of the road, which, by constant action upon the loose drift, would be sufficient to produce the road. Now, if the mouth of Glen Roy should also be barred at the same time by a sufficiently high barrier, the waters would be collected behind it, the surface of the lake would rise till it reached the water-shed dividing Glen Roy from Glen Spey, when the superabundant water would flow into the latter valley. In this way the highest shelf of Glen Roy would be formed. If its barrier were now to be partly removed, so as to establish a connection between it and the upper part of Glen Spean, while the lower part remained blocked up, upper Glen Spean and Glen Roy would then be occupied by a continuous lake, the level of which would be determined by the water-shed discovered in Glen Spean. The water in Glen Roy would take a level corresponding to its new place of escape, and the lowest parallel road would be formed. The conclusions thus drawn would be strictly logical, if proof could be offered as to the existence of the barriers.

In Glen Spean there is a large quantity of detritus, and Sir Thomas Dick-Lander supposed that this had at one time been heaped up by some unknown convulsion. As he could not account for the middle road of Glen Roy in the same manner, he assumed that at a certain point---the level of this road---the barrier which had been wasting away held its ground for a sufficiently long time to form the road. But, on the same principle, there would naturally have been a greater number of roads in this glen, and additional roads in the other glens. A weakness was thus admitted into the theory which was immediately attacked by Mr. Darwin. He believed that the whole region had once been covered by the sea, and that, in the upheaval of the earth, there were pauses during which these roads were formed. But this would not account for the sea being higher in one of the glens than in another, nor for the unequal number of terraces by which the mountains are belted. As soon as Mr. Darwin detected these fallible points, he abandoned his theory.

In 1847 the Dick-Lander hypothesis received new strength from a discovery made by Mr. Milne-Home. There is a lateral glen, called Glen Glaster, running eastward from Glen Roy, which had escaped the notice of Sir Thomas Dick-Lander. Mr. Milne-Home entered this glen, pursued a branch of it extending to the southeast, and came upon a water-shed exactly level with the second Glen Roy road. On the same theory as before, when the barrier should be properly removed, the water in Glen Roy would sink to the second road, and the surplus water would escape over the Glen Glaster water-shed into Glen Spean. But this mode of explanation could not yet be accepted, for there is scarcely a trace left of the immense quantity of detritus that would have been necessary to form the barriers. Nor could the detritus have been swept away by glaciers, for there have been no glaciers in these valleys since the retreat of the lakes.

At the time when Sir Thomas Dick-Lander was making his investigations, the action of ancient glaciers was not understood. The subject had been pursued in Switzerland, but it was not till 1840 that unmistakable marks of glacier-action were pointed out in Great Britain by Agassiz. He visited Glen Roy, and, having detected the traces of glaciers, pronounced these to have been the barriers blocking up the glens. This theory was afterward examined and confirmed by Mr. Jamieson. "It was their ascription to glacier-action," says Prof. Tyndall, "that first gave the parallel roads of Glen Roy an interest in my eyes; and in 1867, with a view to self-instruction, I made a solitary pilgrimage to the place, and explored pretty thoroughly the roads of the principal glen." At different places he found that the effects of the lapping of the water on the more friable portions of the rock are still perfectly distinct. Several months ago he again visited the place, prior to delivering a lecture upon the subject. The entire ground was thoroughly explored, and the principal hills were found to be intensely glaciated. The collecting-ground of these glaciers, which blocked up the valleys, were the mountains south and west of Glen Spean---among others, Ben Nevis. These lofty mountains encounter the southwestern Atlantic winds, and deprive them of their vapor. During the glacial epoch this vapor was precipitated as snow, which slid down the slopes, while every valley and recess kept up a constant supply of glaciers into Glen Spean, filling it to an ever-increasing height. There would of course be ice in Glen Spean, and water to the north of it, as the winds in passing north would be partly dried and warmed by the liberation of their latent heat. As long as the supply was in excess of the consumption, the dams closing the glens would increase in height. As the weather grew warmer, the opposite would be true. For a long time the conflict would continue, retarding indefinitely the disappearance of the barriers, but the ice in the end would have to give way. "The dam at the mouth of Glen Roy, which probably entered the glen sufficiently far to block up Glen Glaster, would gradually retreat. Glen Glaster and its water-shed being opened, the subsidence of the lake 80 feet, from the level of the highest to that of the second parallel road, would follow as a consequence." "In presence, then, of the fact that the barriers which stopped these glens to a height, it may be, of 1,500 feet above the bottom of Glen Spean, have dissolved, and left not a wreck behind; in presence of the fact insisted on by Prof. Geikie, that barriers of detritus would undoubtedly have been able to maintain themselves had they ever been there; in presence of the fact that great glaciers once most certainly filled these valleys---that the whole region, as proved by Mr. Jamieson, is filled with the traces of their action---the theory which ascribes the parallel roads to lakes dammed by barriers of ice has, in my opinion, an amount of probability on its side which amounts to a practical demonstration of its truth."

RISING OF THE LAND AROUND HUDSON BAY

Bell, Robert; *Smithsonian Institution Annual Report, 1897,* Government Printing Office, Washington, 1898, pp. 359-367.

In the Provinces of Ontario and Quebec it has been found from actual levelings by Gilbert, Spencer, and Upham that the old shore lines are not perfectly horizontal, but that they slope upward in a northeasterly direction at rates varying in different regions from a few inches to a foot and even 2 feet per miles. If this upward slope were continued in the same direction to the northeastern extremity of Labrador, 1,300 miles from Lake Huron, the increase in the elevation might there amount to 1,000 or 2,000 feet. It is scarcely probable that the differential elevation is constant and regular for such a great distance. Still, it is a fact that well-preserved shore lines are to be seen at great heights in the northern parts of Labrador. In my Geological Survey Report for 1884 I have mentioned ancient beaches at Nachvak, 140 miles south of Hudson Strait, which have an estimated altitude of 1,500 feet above the sea.

The two sides of Hudson Bay present very different physical characters. The eastern is formed mostly of crystalline rocks, and, as a rule, is more or less elevated, with a broken surface sloping somewhat rapidly westward or toward the bay; while the western side is mostly very low and much of it is underlaid by nearly horizontal Silurian and Devonian strata. These low shores are accompanied by shallow water extending far to seaward. The head of James Bay, which forms the southern prolongation of Hudson Bay, is extremely shallow, but the various rivers which flow into it have cut channels through the soft shallows, and by means of these the land may be approached with seagoing vessels. The whole of Hudson Bay may be said to be shallow in proportion to its great area, as the soundings show that it does not average more than 70 fathoms in depth.

The shores of the bay everywhere afford abundant evidence that there has been a comparatively rapid rise in the land and that the elevation is still going on. I have mentioned numerous proofs of this in my various official reports on the geology of these regions from 1875 to 1886, and I shall now recall a few of those and give fresh ones in addition, some of which came to my knowledge on a journey to the bay during the past summer. It is well known to those who have paid any attention to the subject that since the establishment of the posts of the Hudson Bay Company in the mouths of the rivers around the bay, two hundred years ago, there has been an ever-increasing difficulty in reaching these establishments from the sea.

On the eastern side the most striking evidence of the rising of the land is afforded by the numerous well-preserved and conspicuous terraces cut in the till and other deposits. Near the sea these may be seen at various heights, up to about 300 feet, but above this elevation the scarcity of soft material out of which terraces might be excavated renders this kind of evidence less apparent than it might otherwise be at higher levels.

On this side of the bay one of the best evidences that the elevation of the land is still going on is furnished by the long lines of driftwood which one sees in many places far above the reach of the highest tides.

The old beaches, on which this wood is plainly seen, occur at various levels up to about 30 feet above high tide, but the remains of rotten wood may be detected in some localities up to nearly 50 feet, above which it has disappeared from the ancient shores by long exposure to the weather. This driftwood consists principally of spruce, but a little white cedar and other kinds, which have been brought down by the rivers, are also mixed with it. The bark having been worn off by the action of the waves while the trunks were still fresh has tended to their preservation. Owing principally to the salt water and the cold climate, wood endures for an incredibly long time in exposed situations in this region wherever it has an opportunity of drying quickly after rain. Some of the wood which may still be seen upon the higher levels may be upward of six hundred years old.

It has been suggested that all this driftwood along hundreds of miles of coast may have been thrown up by some extraordinarily high tide. But there are many reasons why this is quite unlikely. It seems impossible that any modern tide could rise to such a great height and deposit so much wood at different levels all at once and in such even lines, following all the sinuosities of more than one of the raised beaches. The supposititious extraordinary tide would necessarily be of brief duration, and would be accompanied by a tremendous gale blowing upon the coast. This would have the effect of throwing the wood in confused heaps and only into situations favorable for catching it, such as angles of the shore. But instead of this we find it at different levels laid longitudinally all along, as if accumulated by slow degrees with moderate winds from every quarter. The fact that the wood is freshest along the lower lines and becomes progressively more decayed as we ascend, and that finally only traces remain on the higher levels, shows that it must have been stranded from time to time as the land was rising above the sea, and we are forced to adopt this obvious view of the case. (pp. 359-361)

POSTGLACIAL MARINE SUBMERGENCE IN CENTRAL ARCTIC CANADA

Bird, J. Brian; *Geological Society of America, Bulletin,* 65:457-464, 1954.

Abstract. In the Canadian Northwest Territories west of Hudson Bay, the postglacial marine transgression was more extensive than in any other part of North America. Although there are numerous isolated observations of strand lines and other raised marine features, there has been no systematic study of the maximum depth of this sea and the form of the subsequent emergence of the land.

Measurements made during 3 summer's field work in the area show that on the mainland the sea reached a depth of 360-400 feet. On the islands in the north of Hudson Bay the depth was 550-650 feet. The difference is explained by unequal waning of the ice sheet. In the western part of the Thelon and Dubawnt basins a large proglacial lake preceded the invasion of the sea. The lake fell by clearly defined stages. Subsequent emergence from the sea was continuous until the final 100 feet when there were two periods of temporary stability. There is widespread evidence that the land is still rising.

In the areas that were submerged, unconsolidated debris has been reworked by wave action into beaches, spits, bars, and other shoreline features. Along the shallower coasts these have completely changed the character of the landscape. The marine transgression did not last long enough to produce erosional features in consolidated rock.

AN 8,000-YR PALAEOCLIMATIC RECORD OF THE 'DOUBLE HALE' 45-YR SOLAR CYCLE

Fairbridge, Rhodes W., and Hillaire-Marcel, Claude; *Nature,* 268:413-416, 1977.

[This article is remarkable for two reasons: (1) its description of the curious sequence of 185 beach lines at Hudson Bay; and (2) their correlation with planetary configurations via the sunspot cycle. Note that the effect of planetary positions on solar activity is not only not understood but it is still ridiculed by many scientists.]

A continuous sequence of 185 Holocene, radiocarbon-dated raised beach lines on the eastern side of Hudson Bay, Canada, have a 45± 5-yr cyclicity that reflects storminess and high tide crescendos. The strandlines have been precisely measured by theodolite surveys and followed by helicopter and air photograph studies along the coast. They can be observed as far as Ungava Bay (Hillaire-Marcel). They have been known since the seventeenth century but have only now been surveyed. The beaches have been dated by radiocarbon analyses back from the present to 8,300 yr BP (sidereal) when the 'Tyrrel Sea' began to appear as a result of deglaciation during the Flandrian transgression. The relative uniformity of the 185 emerged beaches suggests a regular dynamic mechanism. Thus 8,300/185 = 44.86, conveniently rounded to 45. If the beach ages are plotted at 45-yr intervals, they are found to correspond closely to the radiocarbon dates.

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The 45-yr cycle of storminess. The normal climate of the Hudson Bay is continental arctic, commonly rather calm and mild in summer and frigid in winter. Westerly storm tracks usually pass to the south. When, however, they periodically reach the latitude of Hudson Bay considerable wave action leads to rapid longshore drift and beach-building. The beach ridges were first attributed to these storms by Captain L. Foxe in 1631.

Because of the steady isostatic uplift (over 1 cm yr^{-1}) it is unlikely that after a 45-yr interval a new cycle of storms will cause the younger beach accumulation to overwhelm the earlier one. Thus the 185 beach lines preserved seem to represent a true record of somewhat regularly spaced meteorologic events. These are modulated, with larger and smaller beaches, by the glacio-eustatic factor mentioned above. A comparable but non-uplifted sequence of beach ridges on the Alaskan Arctic coast is attributed to meteorologic pulses related chronologically to the sunspot cycle.

Such a regular succession of climatically related geomorphic phenomena cannot be easily explained away by any steady state or stochastic hypothesis and invite a search for an exogenetic (cosmic) cause. The solar cycle seems to be the most obvious candidate. In recent years, it has been demonstrated with a reasonable degree of certainty that the sunspots are in some way expressions of solar climate that is tidally induced by planetary alignments. If this is correct, two problems have to be considered: first, which of the planetary conjunctions or other configurations seem to have the leading role? And secondly, what is the mechanism of energy transfer from solar tidal behaviour to terrestrial climate?

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[Omitted here are sections dealing with solar tides and radiocarbon dating. The authors next launch into a discussion of terrestrial history as affected by the planets that has astrological overtones completely unexpected in a scientific journal. (Of course, the word astrology is never mentioned, but it is obvious from this article that our lives are ruled to some degree at least by the stars!!)]

The critical year AD 1433 was first brought to attention by Pettersson who believed that it correlated with catastrophic tides and flooding. In fact, the oceanic tidal effect of planetary conjunctions is quite minor, but the solar tidal response may have been quite different. This AD 1433 is the all-planetary conjunction, the so-called zero-check year. From Schove's long term Chinese sunspot evidence and other data, the year 1433 coincided by a remarkable high but short-lived period of sunspot activity, and after a brief but dramatic rise (to the >150 spot level) there was a second sunspot dearth (Maunder Minimum) at the same time attended by a major rise in ^{14}C flux. Historical climatic analyses show that 1433 initiated a time of great instability, culminating in the great medieval little ice age, with its attendant human suffering. It seems that the conjunction time coincided with a high sunspot state, which immediately followed by a low-spot condition indicates a minor glacial event.

[The paper concludes with an enumeration of the seven 1,134-year astronomical cycles observable in the beach lines, going back from the eventful year of 1433 AD, and corresponding to the times of planetary conjunction.]

SOME HIGH LEVEL TERRACES IN SOUTHEASTERN OHIO

Hubbard, George D.; *American Journal of Science,* 4:25:108-112, 1908.

About thirty years ago Professor J. J. Stevenson called attention to a considerable number of high level terraces or benches occurring in the upper Ohio river region, "almost absolutely level" and ranging in height from 1100 to 2580 feet above sea level. They were more widespread than the river terraces of outwash gravel, and consisted of rock benches well covered with mantle rock. The latter "contained little clay and no transported material but was mostly sand." Although always above all the outwash terraces, they descend nearly to the upper ones, but never merge with them. They seem to consist of a rock notch, and the removed material laid just below the notch. These high-level terraces are recent, having been made since the latest warpings of the region, and being very well preserved.

Professor Stevenson explained that they are due to wave work on the valley walls and hillsides when the region was deeply submerged subsequent to the retreat of the ice sheet. The upper one was formed when the region was depressed nearly 2600 feet below the present level, admitting the sea into a complex, branching system of valleys; and the lower terraces developed at successive halts as the land slowly emerged from the sea.

These terraces have probably never been causally connected with the

Cincinnati ice dam theory, but in 1890 Professor Chamberlin discussed them in connection with that theory, stating that the land on which the dam occurred is 440 feet above sea level and that the dam as described by other students, and as required to force the water over the cols to the southward, was probably 500-625 feet thick, placing its summit at 1000-1100 feet above sea level. He concludes that such an obstruction could scarcely make a series of terraces, ranging in altitude from 1100-2580 feet. He shows that some of the terraces are structural or gradational and perfectly related to the strata.

In 1903 W. G. Tight also discussed the high-level terraces especially from southeastern Ohio, and considers them to be wave-cut forms, and suggests lake conditions due "to obstructions to the drainage beyond the limits of the basin." He further states that they bear no relation to the ice dam of Wright. The author does not believe an ice dam was ever effective near Cincinnati nor that any of the phenomena up the valley require such a dam for explanation.

To sum up the previous literature on the subject. There have been described, slender, high-level horizontal terraces from the upper Ohio river region and from southeastern Ohio. They have been generally ascribed to wave work, but a few are due to structure and degradation or bear perfect relation to the strata. Sea invasion to an altitude of 2600 feet for those in the upper Ohio region, and lake conditions for the others, have been invoked to explain them. The ice dam theory has evidently been considered but has been discarded as insufficient.

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RAISED SHORE-LINES IN CAPE MAYSI, CUBA

Hershey, Oscar H.; *Science,* 8:179-180, 1898.

At the eastern end of the island of Cuba, on and in the vicinity of the promontory known as Cape Maysi, is the most magnificent example of raised shore-lines as seen from the ocean that I know of. They are in the form of huge wave-cut benches extending with perfect regularity and practical horizontality along the face of a long moderate slope and around several promontories. When a profile of the latter is seen from a passing ship the sharp-cut, step-like form readily attracts the attention even of the unscientific observer. The terraces are found one above another at somewhat irregular intervals, are of different degrees of development, possibly as much as a dozen in number, and seem to extend to an altitude of about 1,000 feet above the sea. Above the last terrace visible the land has a topography indicative of sub-aerial erosion. The view is backed by the high range of the Copper Mountains, whose crest along this portion of the island is smooth and even compared with most West Indian mountain ranges.

To the geologist the terraces of Cape Maysi are chiefly interesting because they demonstrate a recent uplift of this part of the island of Cuba. This is singular, because the island of Jamaica, but little more than 100 miles distant, is without evidence of such a very recent uplift. To a certain extent the two island have had a different geologic history.

The extreme recency, geologically speaking, of the uplift of Cape

Maysi is indicated by the perfection of the terraces. They have suffered practically no sub-aerial erosion. Although the land is a comparatively steep slope, constituting a very favorable situation for erosion, no gutters, ravines or valleys were seen from the ocean, with two exceptions. Even these exceptions tell of the newness of the land surface. They are two deep narrow canons formed by streams flowing down over the terraced slope. Where exposed on the precipitous face of one of the large raised sea-cliffs, the canons are just as narrow at the top as at the bottom.

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HIGH SHORE LINES ON THE ISLAND OF LANAI, HAWAII

Stearns, Harold T.; *Geological Society of America, Proceedings, 1936,* p. 105.

Abstract. The highest fossiliferous marine limestone yet found in Hawaii crops out 5 miles southeast of Lanai City, Lanai, at an altitude of 1,069 feet. This and the presence of 30 feet, or more, of soil above an altitude of about 1,250 feet, and its nearly complete absence below this altitude, suggest that the island has emerged about 1,250 feet. A prominent shore line at 560 feet altitude is shown by fossiliferous marine conglomerate, a pronounced wave-cut notch in the bed rock, and abundant shingle at this level. The presence of these marine sediments in some of the canyons indicates that the canyons had reached essentially their present form prior to this stand of the sea. The determination of the age of these deposits awaits identification of the fossils. Below the 560-foot shore line are prominent younger shore lines at the 25- and 100-foot levels. Several others, indicated by wave-cut notches and marine deposits, occur between 100 and 560 feet, but their precise altitudes have not yet been determined. Stripping of the soil and the presence of shingle indicate that Oahu, Molokai, and West Maui also have emerged about 1,250 feet, and probably, similar evidence will be found on the other high islands of Hawaii when their geology is studied in detail.

RAISED MARINE TERRACES IN NEW ZEALAND AND SOUTH AFRICA

Antevs, Ernst; *Geographical Review,* 20:516-517, 1930.

Between Wairau River and Banks Peninsula, New Zealand, a series of marine terraces has been distinguished by G. Jobberns (The Raised Beaches of the North East Coast of the South Island of New Zealand, Trans. and Proc. New Zealand Inst., Vol. 59, 1928, pp. 508-570). The terraces occur along the greater part of the coast mentioned but are lacking in small portions---a fact difficult to explain. The altitudes of the members of the series are respectively 40-60 feet, 120-150 feet, 230-250 feet, 330-380 feet, 500-525 feet, 650-700 feet, 800-900 feet, and 1000-1200 feet (estimated). The inner edges of the terraces, when traced over several miles, are not regular in height; the outer margin may occasionally be as much as 150 to 200 feet higher than the inner edge; and the surface cover may have a pronounced landward tilt.

The terraces cannot at present be correlated with pre-Quaternary and Quarternary stages distinguished in New Zealand: but their approximate agreement in altitude with terraces on the Mediterranean suggests, in Jobberns' mind, that they may be of the same age; that those up to 380 feet are Quarternary and those at higher levels are Pliocene. The New Zealand terraces are also correlated with the South American terraces as described by Charles Darwin.

Jobberns explains the terraces largely by differential movements between adjacent earth blocks, small compared with the widespread emergence. This emergence may have been due partly to an isostatic response to unloading on the melting of the Pleistocene glaciers and partly to regional deformation of the earth. The part played by changes of sea level, due to fluctuations in the relationship of water and ice, is difficult to estimate.

Jobberns' study is valuable because it includes a new area, New Zealand, among the parts of the globe in which Pliocene and Pleistocene terraces of about the same altitudes are recorded. Important regions, not mentioned by Jobberns, are the Atlantic and Gulf coasts of the United States. In the opinion of W. J. Sollas, Georges Dubois, and the reviewer (Ernst Antevs: Quaternary Marine Terraces in Non-glaciated Regions and Changes of Level of Sea and Land, Amer. Journ. of Sci., Ser. 5, Vol. 17, 1929, pp. 35-49) the four lower terraces on the Mediterranean and in North America date from the preglacial and the three Pleistocene interglacials. In the reviewer's opinion they suggest that the regions have risen different amounts and that, because of sinking of the ocean floor, the sea surface has undergone a progressive lowering besides eustatic fluctuations with the waxing and waning of the ice sheets.

That great caution has to be exercised in correlating raised terraces from different parts of the world becomes evident from A. V. Krige's study of the terraces on the coast of South Africa (An Examination of the Tertiary and Quaternary Changes of Sea-level in South Africa, with special stress on the Evidence in Favour of a Recent World-wide Sinking of Ocean-Level, Annals Univ. of Stellenbosch, Vol. 5, Section A, No. 1, 1927, pp. 1-81). In South Africa there are extensive terraces at altitudes of 4000, 2500, and 1000 to 800 feet and smaller terraces at roughly 550 to 450 and 250 to 150 feet. All five terraces are of Tertiary age, the last three being partly covered by a sheet of Mio-Pliocene sediments. They were formed during regression of the shore line, a regression continued below the present position, to at least the isobath of 300 to 330 feet and possibly much farther. Emergence was due mainly to upheaval of the land and partly to eustatic lowering of sea level during the Pleistocene.

This Tertiary-Quaternary emergence was followed by a Quaternary, but not more closely dated, immergence whose upper limit is marked by impressive shore features at an average altitude of 50 to 60 feet and was probably due to sinking of the land. Whether this terrace is a correlative of the Monastirian terrace on the Mediterranean and Jobberns' 40 to 60-foot terrace in New Zealand is doubtful. The next and last great event deciphered by Krige is regression of the shore line from the 50 to 60-foot terrace to the modern stand. This emergence has left marked shore features at 20 and 14 to 12 feet altitude. The 20-foot terrace was formed during a time of warmer water than at present, as shown by shells in its deposits. It is explained after R. A. Daly by higher stand of sea level due to shrinking of the ice sheets during the postglacial temperature maximum, which prevailed from about 7000 to about 3000 years ago.

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THE LOST SEA OF THE ANDES

Delair, J. B., and Oppe, E. F.; in *The Path of the Pole,* Charles H. Hapgood, Chilton Book Co., Philadelphia, 1970.

Outstanding among the unsolved problems of the recent geological history of South America are those connected with that part of the Cordillera where Bolivia and Peru meet. There, in the heart of the Andes at an average elevation of 12,300 feet, extends the highest lacustrine basin in the world, the Meseta or Altiplano, on the floor of which occurs a succession of remarkable lakes.

The largest of these, Lake Titicaca, is navigable, being some 110 miles long, 35 miles wide and 890 feet deep at the maximum. Its waters are only slightly brackish and support the only species of seahorse (Hippocampus) known to live in a land-locked body of water. Hippocampus is a typically marine creature and, with Allorchestes and a few other oceanic forms inhabiting this lake, strongly suggests that the present fauna of Lake Titicaca has survived from a time when the lake communicated directly with the ocean.

Lake Poopo, some 180 miles southeast of Titicaca and 12,051 feet above sea level, receives its water from Lake Titicaca via the sluggish Desaguadero River; despite the fact that it is about 50 miles long and 20 miles wide, its greatest depth is a mere 9 feet and its water so salt that fishes reaching it from Titicaca seem unable to propagate in it.

The waters of Poopo seep seasonally southward through the Lacahahuira River into the shallow, marshy, and very briny Lake Coipasa---12,031 feet above sea level---which has no outlet. It is of very uncertain extent, much of its southern portion forming a vast salt desert some 50 miles by 35 miles in area. Still farther south is the immense salt plain of Uyuni, which, at slightly over 12,000 feet above sea level, is about 80 by 70 miles in area. It is joined in the southwest by a long chain of small salt, saltpeter, and borax lakes and marshes lying on the floor of a winding valley nearly 100 miles in length but only 5 to 8 miles wide.

The sequence is further defined and its strangeness enhanced by continuing south over the Bolivian border to northwestern Argentina. There another series of salt deserts and large saline marshes reaches southward as far as the southern extremity of Atacama province while in the valley between the eastern slopes of the Cordillera and the Sierra de Cordoba is another succession of enormous salt lakes, the largest of which are Salinas Grandes, Sal de la Rioja, and Pampa de la Salina.

Discussing the salinity of the lakes of the high plateau, Professor Arthur Posnonsky of La Paz observed:

> Titicaca and Poopo, lake and salt-bed of Coipasa, salt beds of Uyuni---several of these lakes and salt-beds have chemical compositions similar to those of the ocean. He pointed out that Lake Titicaca is....full of characteristic [saltwater] molluscs, such as Palude-

strina and Ancylus, which shows that it is, geologically speaking, of relatively modern origin.

Hans S. Bellamy, who gave the problem of the salinity of this region very considerable thought, had the following to say:

> The region in which the feeders of Lake Titicaca rise consist almost exclusively of old crystalline, and younger volcanic rocks; Triassic formations, from which salt is usually derived through extraction, are markedly absent.
>
> Hence the presence of so much salt in the Bolivian Tableland can only be accounted for by postulating a former connection of the great lacustrine basin with the Ocean, and by assuming the eventual evaporation of this body of water when the connection with the Ocean was at last severed.

The modern oceanic character of the faunas of these lakes and the chemical composition of the salt deserts support this conclusion. Additional confirmation is to be found in the recent age of the strand-lines left by this ancient sea on the slopes of the mountains enclosing the Altiplano. Bellamy called this body of water the Inter-Andean Sea. Indeed, when H. P. Moon wrote his account of the geology of the region he put great stress on the "....freshness of many of the strand-lines and the modern character of such fossils as occur."

A few miles south of Lake Titicaca lies the celebrated ruin site of Tiahuanaco, a collection of shattered edifices of some ancient civilization, itself outside the present inquiry but bearing very definitely upon the radical changes which have occurred throughout the Altiplano within geologically very recent times. Of these ruins A. Hyatt Verrill wrote:

> Although the ruins are now over thirteen miles from Lake Titicaca there are reasons to think that in the days when the city was occupied it stood on the shores of the Lake itself or on an arm, or bay, for traces of what was apparently a dock or mole are to be seen just north of the principal ruins. If so the lake has receded....

Bellamy refers to a "canal" which appears to have surrounded the principal group of ruins at Tiahuanaco, including the structure referred to hereafter as the "fortress" and adds:

> Some explorers of the site of Tiahuanaco are of the opinion that the "canal" was, at most, only a "dry-moat," and hence will not concede that the peculiar rectangular depressions near the ruins were once actual docks or harbour basins.
>
> But the proofs in favour of our assertion that Tiahuanaco was once a harbour-town are stronger than any of the objections put forward by more superficial observers.
>
> Firstly: there is a rapid fall in level from the edge of the territory which bears culture-remains to the floor of the territory which we say was covered by the waters of the Inter-Andean Sea.... The difference in level is about 35 feet north of Tiahuanaco proper....
>
> Secondly: while the soil of the territory which we say was above the water-level contains numerous ceramic fragments and other remains, the former sea-bottom yields practically nothing but the stone-

rings with which the fishermen of that time used to weight their nets.
Thirdly: the "dumps" of roughly squared stone blocks [with which the edifices at Tiahuanaco were built] are found only on territory which formerly was sea-bottom.

Bellamy concluded from this last fact that the builders of Tiahuanaco, who obtained their material from quarries many miles distant---for structures which in their skilled and accurate masonry alone remain a mystery---floated their stone blocks in a roughly squared condition on large rafts and that the foundering of these occasionally would leave "dumps" of, in effect, raw material where now found. He made another observation of like force:

> Moreover, the "dry-moat" must have been a water-bearing canal because the great sewer, which drained the overflow of the pond on the platform of the "fortress" of Akapana discharged into it (ibid.).

The salient proof, and one wholly relevant in present review, that Tiahuanaco possessed a waterfront rests upon discernible traces of alkaline incrustations on the sides of the huge stone blocks forming a part of the above-described mole, harbor-basin, or canal wall.

The line of these incrustations corresponds closely with that of the strand-line on the slopes of the surrounding mountains, about which Bellamy wrote:

> It was carefully surveyed for a length of about 375 miles.
>
> And then it was established that it is not "straight." It was found that the Inter-Andean Sea....was not merely a Lake Titicaca of higher level extending far to the south, but that its level showed a slant of a most peculiar character in relation to the present ocean-level, or, which amounts to the same, relative to the present level of Lake Titicaca.
>
> The level of the Inter-Andean Sea revealed by the ancient.... strand-line was higher to the north of Tiahuanaco and lower to the south.
>
> The actuality of this peculiarity cannot be doubted, for it was established independently by different persons at different times, using different methods of surveying.
>
> The northernmost point at which the former strand-line of the Inter-Andean Sea....has been surveyed is on the mountain-slopes near Sillustani and to the west of Lake Umayo in the Peruvian department of Puno.
>
> There the former littoral is about 295 feet above the present level of Lake Titicaca, whose surface is 12,506 feet above sea-level.
>
> At Tiahuanaco, at the southern end of Lake Titicaca, the same strand-line is 90 feet above the level of that great sheet of water, and 4 feet below the coping stones of the parapets of the long-dry harbours and docks and canals of that mysterious metropolis. The ancient strand-line and the ruined prehistoric city are linked beyond any doubt.
>
> The height of the strand-line relative to the ocean-level decreases the further south we go. At the northern end of Lake Poopo on the mountain slopes south of Oruro it is 12,232 feet above sea-level, or 181 feet above the level of Lake Poopo, or 274 feet below the

level of Lake Titicaca, or 364 feet below the level of the same ancient strand-line in the latitude of Tiahuanaco.

Still further south, it is discernible just a few feet above the level of Lake Coipasa. It becomes lost in the Salt Desert of Uyuni some 12,300 feet above sea-level.

From Sillustani to beyond Lake Coipasa, a distance of about 375 miles, the strand-line dips about 800 feet.

A peculiarity of the dip is that it seems to be progressive. In the first quarter of the distance it is only about a foot and a quarter per mile, while in the last fourth it increases to more than two feet per mile....

The strand-line....is very distinct. It consists not only of notches cut into the rock by the prolonged action of shore waves, and of fan-like delta deposits of mud and gravel which former streams dropped on meeting the ancient water's edge, but chiefly of conspicuous deposits of white lime, of a thickness of many feet, upon the red sandstone, or brown porphyry and amorphous slate, or grey granite and andesite.

This white streak, which is drawn along the slopes of the mountain-chains surrounding the Altiplano, and visible on the islands of Lake Titicaca like a chalk-line, is the residue of certain calcareous algae, chiefly of alga characea.

This lowly organized plant, which contains about 80 per cent of lime, is still found growing in certain shallow shore parts of Lake Titicaca. It only thrives in slightly muddy water down to a depth not exceeding three feet.

The phenomenon of this slanting strand-line is generally thought to be due to an "imbalanced rise" of South America out of the waters of the ocean. These forces, it has been argued, lifted the continent to a greater height in the north than in the south, thus explaining why the level of the former Inter-Andean Sea is not parallel with that of either Lake Titicaca or the present ocean.

On the basis of paleontological and hydrological evidence, Bellamy believed that in geologically recent time the whole Cordillera was violently upheaved, and the Inter-Andean Sea thereby caused to vanish, the remnants of which have, over long periods of time, shrunk to their present vestigial condition.

Remarkable confirmation of the immensity of this uplift is represented by the ancient agricultural stone terraces surrounding the Titicaca basin. These structures, belonging to some bygone civilization, occur at altitudes far too high to support the growth of crops for which they were originally built. Some rise to 15,000 feet above sea level, or about 2,500 feet above the ruins of Tiahuanaco, and on Mt. Illimani they occur up to 18,400 feet above sea level; that is, above the line of eternal snow.

Posnansky, who described these terraces as practically endless, concluded that the entire Altiplano region was formerly at a much lower level than at present. It is clear, however that other areas of the Cordillera underwent profound changes also; Dr. E. Huntington noted from aerial survey photographs of arid and desert regions in Peru:....an unexpected number of old ruins, and an almost incredible number of terraces for cultivation, showing how some ancient race had cultivated formerly fertile tracts, now absolutely desiccated. (pp. 281-286)

• The Wave-Planed Guyots

DROWNED ANCIENT ISLANDS OF THE PACIFIC BASIN

Hess, H. H.; *American Journal of Science,* 244:772-791, 1946.

Abstract. Some one hundred and sixty, curious, flat-topped peaks have been discovered in the Pacific Basin between Hawaii and the Marianas. They appear to be truncated volcanic islands rising about nine to twelve thousand feet from the ocean floor. The flat summit levels generally range from three to six thousand feet below sea level. Some less well-developed ones are deeper. The flat upper surface is commonly bordered by a gently sloping shelf a mile or two wide. The summit surfaces are apparently not all of the same age since adjacent peaks may have flat tops which differ in elevation by as much as a thousand feet, though in some cases groups of peaks do have the same elevation. The relationships to atolls of the Marshall Islands group indicate that the surfaces are older than the atoll formation. An hypothesis is tentatively advanced suggesting that the summit surfaces are very old and possibly represent marine planation surfaces in a Pre-Cambrian ocean in which reef building organisms did not exist. It is suggested that the present depths of the surfaces may be accounted for by the relative rise of the ocean surface as a result of accumulation of sediments on the floor. Thus the deeper the surfaces are the greater their age.

Part 1. Description. A large number of curious, flat-topped peaks have been discovered scattered over millions of square miles in the Pacific basin. These peaks are roughly oval in plan and their slopes suggest volcanic cones. The remarkable feature about them is that they are truncated by a level surface which now stands approximately 750 fathoms (4500 feet) below sea level. For convenience in discussing these submerged flat-topped peaks which rise from the normal ocean floor, the writer will henceforth call them "guyots" after the 19th century geographer, Arnold Guyot.

Betz and Hess (1942) discussed the major features of the floor of the North Pacific. This was in the nature of a broad areal reconnaisance of the largest features of this extensive region. Since 1942, Hess has spent two years at sea in the western Pacific and has thus had the opportunity to fill in some details which bring to light many new relationships and necessitate some modification of ideas originally set forth. The data presented in this paper were obtained on random traverses incidental to wartime cruising on the U.S.S. Cape Johnson. What passed beneath the ship was recorded but it was not feasible to investigate further such interesting features as were encountered. Nevertheless it is evident that much information can be obtained on the geological history of an oceanic area by judicious use of available techniques. It is a vast and intriguing field for research under more auspicious peace-time conditions.

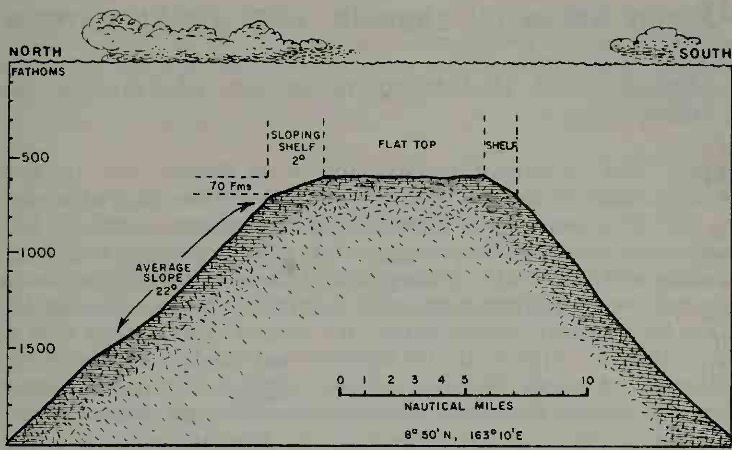
Scope of Present Investigation. From random sounding traverses across or merely grazing guyots an attempt will be made to construct a picture of their physical features. The data collected on the cruises of the Cape Johnson have been supplemented by soundings obtained from the files of the Hydrographic Office, U. S. Navy. The origin and age of the flat upper surface of guyots represent the main problem of this paper. Secondarily the relation of guyots to atolls of the northern Marshall Islands will be discussed.

Areal Distribution of Guyots. The distribution of known and suspected guyots is shown in Fig. 1. [Not reproduced] Roughly they are known to occur north of the Carolines and east of the Marianas and Volcano Islands between latitudes 8° 30' North and 27° North and longitudes 165° West to 146° East. None has been found west and south of the above boundaries though this area has been at least as well explored as the former. North and east of the region outlined above it appears from scattered soundings that the area containing guyots does extend to 45° North and 165° West. Some of the seamounts in the Gulf of Alaska described by Murray (1941) almost certainly are guyots whereas others appear to be of a different character. Twenty bona fida guyots were encountered at sea by the writer and some 140 more are indicated by soundings on Hydrographic Office charts and documents. Considering sparseness of deep sea soundings in parts of the area mentioned above, it is likely that a large number of undiscovered ones are present.

Physical Features of Guyots. One of the best profiles obtained across a guyot was one encountered south of Eniwetok on October 6, 1944, in latitude 8° 50' North, longitude 163° 10' East. This guyot is about 35 miles in diameter at the base, and the truncated upper surface is about 9 miles in diameter. The top is remarkably flat at a depth of 620 fathoms. The outer rim of the top is bevelled by a gently sloping shelf one or two miles wide (slope 2° to 3°). The outer margin of the gentle slope is about 70 fathoms deeper than the inner margin. This gentle slope breaks abruptly to 22° at its outer margin. The profile from the edge of the shelf to the normal ocean floor at 2600 fathoms is, as might be expected, concave upwards. From an average of 22° at the top it gradually decreases in steepness until it forms a smooth tangent with the ocean floor at the bottom. Figure 2 (A and B) below is a reproduction of the sounding traverse across the guyot. (Only Fig. 2A reproduced.)

Guyots vary widely in size. One a few miles northeast of Eniwetok has a flat summit only a couple of miles across (latitude 11° 45' North, longitude 162° 55' East); whereas one some distance farther northeast apparently has a flat upper surface 35 miles wide and has a diameter of 60 miles at its base (latitude 14° North, longitude 167° 30' East). In general they appear to be circular or oval in plan. No correlation has been noted between the depths of the flat upper surfaces and the depths of the surrounding ocean floor which normally ranges from 2600 fathoms (15,600 feet) to 3100 fathoms (18,600 feet). The observed depths of the flat upper surfaces of typical guyots range from 520 fathoms (3120 feet) to 960 fathoms (5760 feet), with most values concentrated near the center of this group (800 fathoms). Thus the guyots rise from 10,000 to 15,000 feet above the ocean floor. The flat tops of guyots in general do not exhibit accordance of summit levels. It is quite common to find groups of guyots in a relatively small area with flat tops varying several hundred fathoms from one to another among the group. Less commonly two or three guyots in a group will have approximately the same depth.

A few guyots were found to have upper surfaces which were gently undulating rather than flat. These undulating or hummocky surfaces have a maximum relief of about 40 fathoms. In most cases the flat surface can



Tracing of a fathometer record of a typical guyot, showing the characteristic flat top.

be seen here and there in the profiles and it passes <u>beneath</u> the hummocky material (Fig. 3). Judging from the evidence most guyots have been swept clean of the fine sediments which must be continually settling upon them. In the case of the rare, hummocky ones it would appear that the fine precipitates had for some reason not been completely swept off. It is rather surprising that the normal guyots are swept clean since water currents at such depths as these are thought to be slight. One must look to occasional bottom stir up by tsunami though possibly currents related to tides might be strong enough. Once the sediment on these isolated, flat-topped peaks is stirred up, very little of it would be expected to fall back on top of the guyot. It would be dispersed over the surrounding area.

Though few guyots show any suggestion of terraces on their outer slopes, one large guyot near latitude 20° North, longitude 148° East has a well developed flat upper surface at 800 fathoms and projecting from under its southeastern margin there appears to be a terrace or older guyot with a flat upper surface at 1100 fathoms. In the area between Wake Island and Johnston Island there are a number of normal guyots rising from hilly areas which have numerous flat or nearly flat surfaces between 1100 and 1900 fathoms. These hilly areas with flat or nearly flat surfaces have as yet been insufficiently explored to understand the relationships they exhibit. They may represent areas of older, deeper guyots partly buried by sediments, but until a more detailed examination of them can be made, their nature will have to remain rather obscure. Such areas do not appear to be common elsewhere. Some of Murray's Gulf of Alaska seamounts possibly also fit into this category. The great majority of guyots rise from the normal ocean floor. (pp. 772-779)

FLAT-TOPPED ATLANTIS, CRUISER, AND GREAT METEOR SEAMOUNTS

Heezen, Bruce C., et al; *Geological Society of America, Bulletin*, 65:1261, 1954.

Abstract. The Atlantis, Cruiser, and Great Meteor seamounts rise from a broad ridge or plateau which extends from the Mid-Atlantic Ridge at 37° N. 32° W. southeast to Great Meteor Seamount at 30° N. 28° W. The Atlantis Seamount, briefly explored in 1947 and 1948, was found by echo sounding and submarine photography to have a fairly flat bedrock summit area at about 180 fathoms covered in some cases by cobbles and in other cases by current-rippled sand. Its slopes are covered with sand or ooze symmetrically rippled at 400 fathoms and marked by slump features in 570 fathoms. A small piece of volcanic agglomerate was dredged from 400 fathoms on the north slope. About a ton of flat pteropod limestone cobbles was dredged from the summit area. One of the cobbles gave an apparent radiocarbon age of 12,000 years ± 900 (J. L. Kulp). The state of lithification of the limestone suggests that it may have been lithified under subaerial conditions and that the seamount may have been an island within the past 12,000 years. Oxygen isotope paleotemperature measurements made by C. Emiliani give evidence that the depth of deposition was less than the present depth of the seamounts. The Cruiser and Great Meteor seamounts studied in 1952 have larger flatter summits at 150 and 165 fathoms depth. Photographs of the sandy summits do not show ripples or cobbles. Symmetrical ripples were photographed on the slopes in depths of 1200-1400 fathoms. A reversed seismic refraction station was made on Cruiser Seamount. These youthful "guyots" may have originated as volcanoes which were later capped by limestone and more recently have sunk beneath the sea.

A VISIT TO THE NEW ENGLAND SEAMOUNTS

Heirtzler, J. R., et al; *American Scientist*, 65:466-472, 1977.

In the Atlantic Ocean there is only one extensive linear chain of submerged seamounts---the New England Seamounts. They extend for about 1,600 km southeast from the coast of New England, and a somewhat separate group of peaks called Corner Rise continues this chain for another 500 km.

....

[Seamounts are among the few prominent features of the deep-sea floor. They seem to have a volcanic origin but many of their features are still enigmatic. This article describes the New England Seamounts and dives undertaken in a research submersible to explore them. Only the more mysterious observations are excerpted.]

The more than 30 major peaks in the New England seamount chain are interspersed with numerous smaller unnamed peaks and hills which have not been looked at closely because the usual oceanographic research ships cannot resolve small features at such great depths. The sea floor varies in depth from about 2 km on the continental rise to about 5.5 km in the Sohm Abyssal Plain on the eastern end of the chain. Some of the peaks rise 4 km above the sea floor---twice the height of Mt. Washington in the White Mountains of New England and comparable to the major peaks in the Alps. None of the seamounts, however, comes within 1 km of the sea surface.

....

The geologic ages of these seamounts are not known with any degree of certainty. Ziegler recovered shallow-water limestones from his dredges on Bear and Mytilus seamounts and tentatively dated them as Eocene (45 million years ago). Presumably these peaks sank to their present depth since their formation; they could be older than the limestone but not younger.

....

[The first dive with the Alvin submersible took place on Corner Rise. At 2,035 m, native rocks were found heavily encrusted with manganese.]

For the next 100 m upslope the bottom was mostly sediment covered with some relatively recent (probably Pleistocene) mollusk shells. There were a few scattered rocks, some extremely vesicular and scoriaceous. On previous reported occasions oceanographic ships had dredged rocks of this type, but they were thought to be cinders from the furnaces of old steamships. We now think they may be indigenous and deserve more serious study.

....

[At a depth of 1,800 m a 200-m high cliff was encountered.]

Near the base of this cliff Alvin passed quickly over a series of very striking topographic features that can best be described as small buttes. They are no doubt erosional in nature and, in fact, resemble eroded basaltic structures in central Iceland. Because they have dimensions of a few meters it was awkward to photograph them with the narrow field of view of our cameras; Figure 3 is a sketch of them.

....

[Another dive was made at Rehoboth Seamount, halfway along the New England Seamount chain. Alvin started at a depth of 3,000 m.]

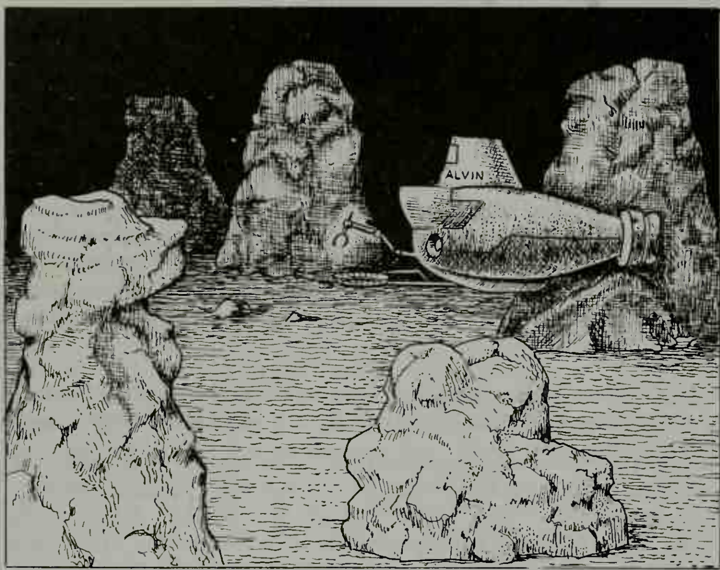
Many sponges, sea urchins, and fish were observed. No live corals were seen here, but in some areas manganese covers dead coral. It would seem unlikely that environmental conditions in the deep ocean have changed sufficiently over the recent geological ages to make large coral populations extinct, but that cannot be ruled out.

....

[The last dive was on the Mytilus Seamount, located on the continental rise 70 km south of the main axis of the New England Seamount chain.]

At a second sampling station, the rocks contained prominent algae strands in a calcite matrix. The algae has been identified as Melobesia, a family that now grows on the outer-most ridges of reef breccia platforms in less than 100 m of water (R. Johnson, pers. comm.). Its occurrence at the greater depth offers firm evidence that this seamount has subsided by 3,000 m.

....



The research submersible Alvin *inspecting strange undersea buttes.*

SUBMARINE GEOLOGY OF THE GULF OF ALASKA

Menard, Henry W., and Dietz, Robert S.; *Geological Society of America, Bulletin,* 62:1263-1285, 1951.

Abstract. The floor of the Gulf of Alaska is a smooth plain sloping gently to the southwest. Thirty-five major submarine mountains, ranging in relief from 3500 to 12,400 feet, are known to rise above the plain. The seamounts appear to be of two types and have been separated into two topographic provinces.

In one province the symmetry, slope angles, and alinement of the seamounts indicate that they are volcanoes. Most of the shoaler seamounts in this province have flat tops at a depth of 400-500 fathoms. The flat tops, as much as 8.5 miles wide, apparently were produced by wave truncation near sea level. One seamount situated on the axis of the Aleutian Trench has a flat top at a depth of 1380 fathoms; it appears to owe its unusually great depth to subsidence related to the formation of the trench.

The seamounts in the second province are elongate and are found on low ridges. Profiles are asymmetrical and irregular; none of the seamounts are flat on top, although four are much shoaler than the flat-topped seamounts in the first province. By reason of their topography and their relation to the trend of a Pliocene-Pleistocene orogenic belt, the seamounts are thought to be orogenic mountains.

The geological history of southern Alaska suggests that the eastern part of the Aleutian Trench originated in early Tertiary time. It also suggests that an earlier trench, now filled with sediment, existed in Meso-

zoic time at the present site of Kodiak Island and the Kenai Peninsula. The eastern part of the Aleutian Trench has an asymmetrical, V-shaped profile unlike the profiles of other major oceanic trenches. The unusual profile suggests that this part of the Trench may have a deep filling of sediment.

BASALTIC CONE SUGGESTS CONSTRUCTIONAL ORIGIN OF SOME GUYOTS

Christensen, M. N., and Gilbert, C. M.; *Science,* 143:240-242, 1964.

A flat-topped, conical accumulation of more or less horizontally stratified basaltic cinders and tuff-breccia occurs in the desert of eastern California within the area once occupied by Pleistocene Mono Lake. It stands on the northern shore of the present lake, well below the late Pleistocene highwater level, and is known simply as Black Point. The basaltic debris consists largely of perfectly clear, pale-brownish-green glass having a refractive index of about 1.57. Such glass, in contrast to the dark brown semiopaque variety clouded by iron oxides, has heretofore been considered evidence of subaqueous eruption. The peculiar form and structure of Black Point also seem to have resulted from subaqueous pyroclastic eruption and accumulation. The characteristics of this cone may, therefore, provide evidence regarding the internal structure and origin of some guyots and seamounts.

Interpretation of submarine volcanic forms has been based of necessity on comparison with forms of subaerial volcanoes. Except for the "table mountains" of Iceland and the "tuyas" of northern British Columbia which were built within lakes in ice sheets, volcanoes with primary flat tops have not been recognized. Hence, the flat tops of guyots have been considered "anomalous," requiring special explanation. The flat tops of guyots are generally considered to have been produced by erosional truncation of volcanoes by wave action at or near sea level. The presence of basaltic debris on the tops and flanks of guyots has seemed to support this hypothesis. The basaltic cone at Black Point indicates, however, that flat tops and basaltic debris alone do not prove the erosional origin of guyots. It suggests, on the other hand, that these features may result from subacqueous pyroclastic eruptions, providing support for Nayudu's suggestion that some guyots may be primary constructional features of submarine vulcanism.

. . . .

EXPOSED GUYOT FROM THE AFAR RIFT, ETHIOPIA

Bonatti, Enrico, and Tazieff, Haroun; *Science,* 168:1087-1089, 1970.

Abstract. A series of originally submarine volcanoes has been found in the Afar Depression. Some of the volcanic structures are morphologically similar to oceanic guyots. One of them consists of strata of finely fragmented and pulverized basaltic glass. The fragmentation of the lava

is probably the result of stream explosions taking place during the submarine eruption. The flat top of this guyot is considered to be a constructional feature; by analogy, it is suggested that not all oceanic guyots are necessarily the result of wave truncation of former volcanic islands.

• Historical Displacements of the Land and Sea Floor

SENSATIONAL CHANGE OF ATLANTIC BOTTOM

Anonymous; *Nature,* 112:331, 1923.

A sensational report of a change of level of the bed of the Atlantic between Cape Town and St. Helena was made on the authority of the Eastern Telegraph Co. last week. It was stated that a cable repair-ship found a depth of three-quarters of a mile at a place where the chart showed a depth of three miles when the cable was laid in 1899. Changes of the level of the ocean floor have often been brought to light by soundings, but the actual rise or fall is reckoned in a few feet or fathoms, and nothing of such a stupendous character as a change of more than two miles has ever been established by surveys. Decrease of depth could, of course, be caused by accumulation of the products of an eruption of a submarine volcano, and in such an event the rise of level would be local and the material would soon be worn down. Both Vesuvius and Etna began their careers as submarine volcanoes, and Sir Archibald Geikie records a number of submarine eruptions in his "Text-book of Geology," though nothing approaching the building of such a pile as would be required to produce the difference of level reported above. All that can be said at present, therefore, is that an actual uplift of the dimensions reported in so short a time is unthinkable and that the accumulation of volcanic material to produce the change of depth is extremely improbable. Confirmation of the accuracy of the old sounding as well as of the new will be required before any scientific significance can be attached to the report.

THE JAPANESE EARTHQUAKE OF SEPTEMBER 1, 1923

D., C.; *Nature,* 114:70, 1924.

Shortly after the Japanese earthquake of September 1, 1923, Mr. Takeo Kato, on behalf of the Imperial Earthquake Investigation Committee, made reconnaissances through the districts of violent shocks, especially those around Sagami Bay. He has published a preliminary report on this field study in the Journal of the Geological Society of Tokyo (vol. 30, No. 361), including some definite estimates of the loss of life and property.

....

A remarkable upheaval of the ground took place, it is said, within a few minutes after this earthquake, over an area of about 2000 square miles, including the islet of Hatsu-shima, the headland of Manazuru, the northern border of Sagami Bay, the Miura and Boso peninsulas. The greatest upheaval (about 8 feet) occurred at Tomizaki, along the southern coast of the Boso peninsula, and it is remarkable that here the ground settled down more than a foot within one month after the upheaval. According to the soundings made by the Navy Hydrographic Office, conspicuous changes in depth, of 50 fathoms and more, have occurred at various places in the deepest portion of Sagami Bay. Soundings are still being carried out in the Bay, while many levelling parties of the Military Department are engaged in ascertaining the changes in elevation throughout the earthquake area.

....

SUBMARINE CANYONS AND OCEAN-FLOOR CHANNELS

The major submarine canyons put the Grand Canyon of the Colorado to shame, for many are much deeper and longer. They cut deeply into the continental shelves and slopes all around the world. Some seem continuations of terrestrial rivers; others exist in their own right. As with many geological features described in the book, the question of origin is paramount. The submarine canyons are so much like ordinary river valleys that early students of the phenomenon decided that the submarine canyons must also have been eroded by rivers when the oceans were much lower. The objection then as now is the need to account for the removal and reappearance of a couple miles of sea water. Even though the guyots could also be explained by the disappearance of sea water, geologists found this hard to swallow. Of the alternate theories proposed, turbidity-current erosion has been the most popular. Turbidity currents are dense flows of water-suspended sand and clay with high erosive power. Turbidity currents undoubtedly exist, but have they been frequent and strong enough to gouge out mile-deep canyons in solid rock?

The wide channels that flow across the nearly flat ocean bottoms may also be the work of turbidity currents. The lack of gravitational impetus would seem to weaken hypotheses involving water and/or turbidity current erosion. Other theories may prove fruitful, as they have in the case of similar channels along the bottoms of the Great Lakes. These features have been ascribed to fracturing.

• Mystery of the Submarine Valleys

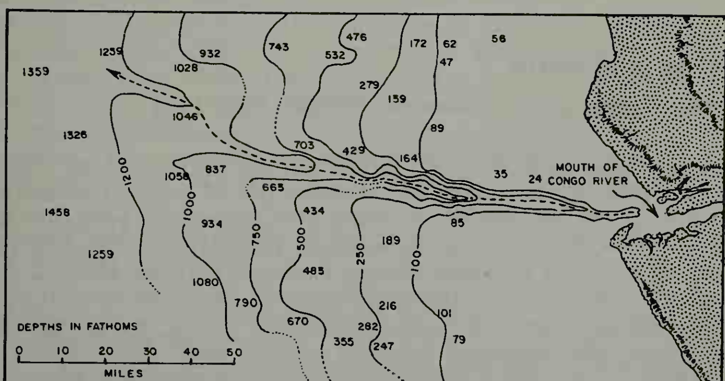
SUBMARINE VALLEYS OFF THE AMERICAN COAST AND IN THE NORTH ATLANTIC

Spencer, J. W.; *Geological Society of America, Bulletin,* 14:207-226, 1903.

[An excerpt from one of the first important papers on submarine canyons begins this section. Obviously, much better data are available today, but Spencer's early interpretations are most interesting.]

On the Origin of the Submarine Valleys. The origin of submarine valleys attaining a depth of even 1,000 or 2,000 feet in the continental shelf, and whose outer edge is submerged 300 or 400 feet, although implying a recent elevation of 2,000 or 3,000 feet, need scarcely be called into question. While these channels pass through canyons and descend abruptly into the deeper valleys which open out into embayments in the great continental slope to depths of 12,000 or 15,000 feet, it may seem difficult to explain these lower reaches by the hypothesis of atmospheric action during a period of emergence on account of the stupendous changes of level of land and sea required; yet the writer has ventured to adopt this hypothesis, in which he has been confirmed by many years of research. But from the broad standpoint the complex conditions doubtless qualify the simple hypothesis of the former elevation of the land with its consequent sculpturing by atmospheric agents. While some of the valleys may be attributed to tectonic or orogenic, or occasional ones to volcanic causes, no explanation based on these causes has been worked out in detail; consequently the author has been led, after presenting the facts given in this and other papers, to emphasize particularly the resemblances between these submarine valleys and land features, with the conclusion that the former were sculptured on the great continental slopes by atmospheric agents, which implies a greater change of level of land and sea than the 2,000 or 3,000 feet above mentioned. If it were a question of simple elevation, it would amount to 12,000 or 15,000 feet higher than at present along the border of the continent. This great elevation, however, may have been much reduced by an unequal bending down of the continental slope, or indeed to some extent by a shifting of the oceanic waters. Then also arises the question, What became of the waters, and also what were the causes of these great continental movements, about which we know nothing? The problem thus becomes so complex that the writer has to confine himself to the study of the resemblances above mentioned. While the features along the Atlantic coast are repeated on the eastern side of that basin and elsewhere, the author could not possibly imply a general drainage of the basins, but rather that there have been alternations, whereby great regions have been elevated while others have been depressed, as, for instance, the West Indian islands alternating in altitude with the lands of Central America. We know that in the epeirogenic movements the changes of level are unequal, with the rate of elevation or subsidence increasing or diminishing, and from the writer's observations such rates increase on approaching mountain regions and diminish in the direction of the plains. This, extended to the great continental slopes, would favor the theory of their having been abnormally bent downward; consequently the land may not necessarily have stood 12,000 or 15,000 feet higher than now, although the bottom of the slopes had been emerged to that extent. Still the land stood very much higher than at present, probably sufficient to give rise to glacial conditions in the north.

While the amphitheaters, coves, or canyons indenting the edge of the submerged continental shelf are known to have a breadth increasing from 3 miles (that of the Hudson) to 5 or 10 miles, or where farther down the continental slopes the valleys open into embayments of 20 or 30 miles, even that breadth is no greater than can be seen in the lower reaches of many land valleys. It is seldom that we are able to restrict the channels to their actual breadth for want of closer soundings, such as have been made along a part of the Hudson valley and along the submerged extension of the Congo river, the last of which I may be permitted to refer to as a most detailed piece of work in revealing buried channels. Here the soundings were taken so as to obtain contours at given depths apart, which were often not more than half a mile. Thus Mr. J. Y. Buchanan found the depth of the river to be 900 feet at a distance of 20 miles above its mouth, where there is an obstructing bar. At 35 miles from the coast line the canyon has a breadth of 6 miles and a depth of 3,000 feet below the submerged plateau. The 6,000-foot contour of the continental slope recedes landward for 30 miles at this point. Beyond, Professor Edward Hull finds that the valley at over 7,500 feet indents the great slope for 20 miles landward. On account of the excellency of this study, the map of the Congo channel is here reproduced.



Soundings in the vicinity of the Congo submarine canyon, as sketched in 1903.

Again, outside the region of the present study we find many illustrations better revealing the form of the valleys than those so far determined off our own coast. Thus on the chart between Jamaica and Central America there is a submarine plateau rising almost to sealevel, and in the accompanying illustration this may be seen in places incised by narrow channels, and, again, these, uniting from the opposite side of the submarine plain, divide it into separated banks or islands. These suggest, not merely a moderate elevation that formerly obtained, but also one of considerable amount, as, for example, those seen between Jamaica and Haiti, where the lower plateaus are indented by the 500 and 1,000 fathom contours.

One other point may be again referred to here---the gradients of the valleys down the continental slope. As the great descent is usually restricted to a comparatively short distance, the mean declivity of the valleys at first seems too great for comparison with those of the land, but, as we have already found, these are often characterized by abrupt steps, with more gentle gradients between, similar to the valleys descending from the high plateaus of Mexico and Central America or the tributaries of the Colorado canyon, which descend 3,000 feet in perhaps 10 miles. But, in order to reveal their true character, the soundings must be made close together for this purpose, as the mean slope gives us no information whatever; and so, for the present, the best the writer can do is to compare them with land valleys from high plateaus, which is justified in the study of the Floridian channel, which descends by long stretches, with gradients of a foot or less per mile, as small as that of the Mississippi, succeeded by precipitous steps like those from one submarine plateau to a lower.

To cover all the questions raised would far exceed the limits of this paper, the object of which is to record the facts given, with a brief statement of the writer's explanation of these most interesting phenomena. (pp. 220-224)

SUBMARINE CANYONS

Anonymous; *Geographical Review,* 27:681-683, 1937.

The attention that is being given to submarine canyons of the continental shelf has probably raised a question in the minds of many of those interested concerning the nature and accuracy of the material available for this study. The reasonable accuracy of methods recently developed by the United States Coast and Geodetic Survey has been outlined by Paul A. Smith (The Accuracy of Soundings and Positions Obtained by Methods Used in the United States Coast and Geodetic Survey, Trans. Amer. Geophys. Union, Sixteenth Ann. Meeting, April 25 and 26, 1935, Washington, 1935, Part 1, pp 9-14). He states that the error of soundings may be within 1 per cent in depths of 10 to 200 fathoms and within 3 per cent in depths greater than 200 fathoms. For position, where visual-fix ranging near the shore is feasible, the error ranges from 1:500 to 1:1000; out of sight of land, where radioacoustic ranging is used, the error may range from 1:200 to 1:500. Such accuracy is remarkable. Privately conducted surveys in which a hand reel was used have been described by F. P. Shepard (Detailed Surveys of Submarine Canyons, Science, Vol. 80 (N.S.), 1934, pp. 410-411; see also his "Canyons off the New England Coast," Amer. Journ. of Sci., Ser. 5, Vol. 27, 1934, pp. 24-36). There is therefore the beginning of an accurate base map on which submarine geology can be delineated (see also pp. 625-636 of this number of the Review).

Successful dredging has been carried on in the canyons of the Atlantic coastal plain by H. C. Stetson (Geology and Paleontology of the Georges Bank Canyons, Part I, Geology, Bull. Geol. Soc. of America, Vol. 47, 1936, pp. 339-366) and of the California coast by Shepard. Both succeeded in breaking fragments of rock from the canyon walls. In 1934 Stetson obtained samples of coarse sandstone, greensand and indurated silt ranging from Upper Cretaceous to late Tertiary in age from the steeper walls of Georges Bank canyons. In the summer of 1935 Shepard (Geological Mapping of the Ocean Bottom, Science, Vol. 82 (N.S.), 1935, pp. 614-615, using similar dredging equipment, obtained fragments of rock ranging probably from Eocene to Pleistocene in age from five canyons off the California coast. Of 15 canyons examined up to this year, 12 showed rocky walls, some even granite. The presence of fossils in many of the samples means that identification need not rest on purely lithological grounds.

A radical improvement in methods of sampling the softer bottom deposits, whereby cores more than eight feet long can be obtained in deep water, has been developed by Piggot (C. H. Piggot: Apparatus to Secure Core Samples from the Ocean-Buttom, Bull. Geol. Soc. of America. Vol. 47, 1936, pp. 675-684; "Core Samples of the Ocean Bottom," Carnegie Instn. News Service Bull., Vol. 4, 1936, pp. 83-87.) It should furnish results of great importance. The refraction seismograph has been adapted to work at sea down to 100 fathoms (Maurice Ewing, A. P. Crary, and H. M. Rutherford: Geophysical Investigations in the Emerged and Submerged Atlantic Coastal Plain, Part I, Methods and Result, Bull. Geol. Soc. of America, Vol. 48, 1937, pp. 753-802). The surface of the crystalline basement beneath the Atlantic coastal plain (presumably corresponding in part to the Fall Zone peneplane) has been traced from the inner margin of the coastal plain to the edge of the continental shelf. Near the edge the crystalline basement lies beneath 12,000 feet of less consolidated material; the abyssal slopes of the ocean are some 4,000 feet higher. As a result of this work, according to Miller (B. L. Miller: Geophysical Investigations in the Emerged and Submerged Atlantic Coastal Plain, Part II, Geological Significance of the Geophysical Data, ibid., pp. 803-812), we can be fairly certain that the submarine canyons of the Atlantic coastal plain are entirely incised in rocks of Mesozoic or Cenozoic age.

A rather full statement of the canyon problem and its historical background up to 1933 was made by Shepard (F. P. Shepard: Submarine Valleys, Geogr. Rev., Vol. 23, 1933, pp. 77-89). He has, however, as a result of later data (see below), apparently partly abandoned the theory developed there. More recently Smith has enumerated field studies and theories suggested (P. A. Smith: Submarine Valleys, U. S. Coast and Geodetic Survey Field Engineers Bull. No. 10, 1936, pp. 150-155). At the risk of repetition, some of the major theories advanced in the last four years are reviewed here.

In 1934 Davis (W. M. Davis: Submarine Mock Valleys, Geogr. Rev. Vo. 24, 1934, pp. 297-308) proposed that, where shore-line topography is favorable for localized ocean currents, outward-flowing bottom currents compensating inward drift of surface water might develop or keep open submarine valleys. "It is possible that the shore waters, made turbid ....[at times of severe onshore winds] by wave action, would thus gain an increased specific gravity that would facilitate their descent into the colder water of the depths." Whereas Davis made no point of this increased density and treated it as an accessory circumstance, there is a similarity here to the density current later suggested by Daly.

Whereas Davis considered processes going on today, Daly (R. A. Daly: Origin of Submarine "Canyons," Amer. Journ. of Sci., Ser. 5, Vol. 31, 1936, pp. 401-420 suggests canyon cutting under special conditions during the Pleistocene. The theory, in brief, demands a 300-foot eustatic drop of sea level during formation of the icecaps. Most of the continental shelves were then exposed. The waters, weighted with sediment from the mud banks on the outer margins of the shelves and from rivers, slid down the continental slope, thus producing a density current. Concentration of current action in preexistent irregularities of the slope led to excavation of the canyons. Daly's theory has received the support of Kuenen (P. H. Kuenen: Experiments in Connection with Daly's Hypothesis on the Formation of Submarine Canyons, Leidsche Geol. Mededeelingen, Vol. 8 1937, pp. 327-351). Shepard discusses aspects unfavorable to this theory (F. P. Shepard: Daly's Submarine Canyon Hypothesis, Amer. Journ. of Sci., Ser. 5, Vol. 33, 1937, pp. 369-379).

Stetson has reviewed the problem of subaerial and submarine origin of the canyons, discussing subaerial processes in greater detail, but at the time of writing did not consider the evidence warranted complete rejection of either view. He has tested currents in the Georges Bank canyons and demonstrated that normal tidal currents are not significant as an erosive agent.

Hess and MacClintock (H. H. Hess and Paul MacClintock: Submerged Valleys on Continental Slopes and Changes of Sea Level, Science, Vol. 83 (N.S.), 1936, pp. 332-334) have put forward the hypothesis that, possibly under the influence of some stellar body, the rotation of the earth was suddenly decreased and a rapid change in the shape of the hydrosphere resulted, depressing sea level in low latitudes and raising it in high latitudes, though the authors themselves point out that a sudden change in the speed of rotation is a formidable objection to overcome. Shepard has raised additional objections (F. P. Shepard: Submerged Valleys on Continental Slopes and Changes of Sea Level, ibid., pp. 620-621). A. C. Veatch also has considered a theory taking into account the influence of a stellar body (see Smith, Submarine Valleys, p. 154), in which a change in the lithosphere may have taken place.

In 1936, on the basis of recent Russian investigations, Shepard (F. P. Shepard: The Underlying Causes of Submarine Canyons, Proc. Natl. Acad. of Sci., Vol. 22, 1936, pp. 496-502) suggested the formation of an enormous dome-shaped icecap about four miles thick over the entire Polar Regions and a greatly extended Antarctic icecap. This, according to his figures, would lower sea level some 3000 feet. Before glaciation there were depressions of the continental slope resulting partly from diastrophism, landslide, and the submergence of true river valleys by diastrophism in an earlier period. Recession of the sea by 3000 feet during formation of the icecap allowed rivers to flow out over the exposed shelf into preexistent depressions of the slope and excavate canyons to the level of the sea.

The problem is surrounded with difficulties. Objections have been raised regarding the efficacy of submarine currents. For the most part the submarine canyons do not suggest faulting or collapse of solution channels. If the canyons are entirely of subaerial origin, the shelves of the world may have been uplifted some 8000 feet or more sometime since late Tertiary, maintained temporarily during stream cutting, and again depressed. In the light of existing knowledge this is hard to accept. The ocean bottom may have been depressed. Field (R. M. Field: Structure of Continents and Ocean Basins, Journ. Washington Acad. of Sci., Vol. 27, 1937, pp. 181-195) suggests that "there may have been profound, local, Quaternary movements in the basin itself; and that these movements may have affected ocean level, especially if there were coincident movements in the floor of the Pacific." We are then faced with the necessity of re-elevating the ocean bottom in order that sea level may again resume approximately its former position. Water may have been removed from the ocean to form great icecaps. The recent suggestion of a 3000-foot eustatic drop in this way does not account for the lower 3000 to 5000 feet of canyon. But we have greatly improved techniques for obtaining information, and considerable enthusiasm is being shown by workers in this comparatively new field.

COMPOSITE ORIGIN OF SUBMARINE CANYONS

Shepard, Francis P.; *Journal of Geology,* 60:84-96, 1952.

Abstract. The investigation of submarine canyons is still in its infancy, and complete reversal of ideas may come from further studies. However, the information which has become available in recent years offers an explanation which seems to eliminate the necessity of calling upon the inadequately supported hypotheses of submarine erosion or huge sea-level changes. The new explanation includes: subaerial excavation of portions of the canyons at various times during the past when the margins were elevated above the ocean level; building of deltas on the outer slopes during this excavation; submergence of the canyons, with some accompanying fill but with preservation of the canyons through slides and turbidity currents acting along the old canyon axes; reshaping of the old deltas, with some enlargement of shallow trenches characteristic of steep delta fronts; marine deposition on the old land surfaces into which the canyons were cut but concurrent maintenance of the canyons by slides, so that the canyon walls grew higher as the submergence continued; and, finally, the reshaping of the canyon heads by the Pleistocene sea-level changes of a few hundred feet.

This composite sequence is supported in part by the detailed soundings obtained recently off the San Diego area, where delta-like features have been found out beyond the rock-walled canyons. These supposed deltas are trenched by marginally rimmed valleys similar to those of the Swiss lakes. The hypothesis is also supported by new evidence showing the adequacy of submarine mass movements in keeping open the canyon heads. Finally, the evidence for large-scale submergence of continental margins and of oceanic islands is becoming continually more complete. On the other hand, the new reasons offered for supporting submarine origin of the canyons are shown to be based on misunderstanding of the character of the canyons. The advocates of submarine erosion continue their failure to observe what is actually taking place on steep aqueous slopes where sediment is available for the erosion they infer.

GREAT BAHAMA CANYON

Andrews, James E., et al; *Geological Society of America, Bulletin*, 81:1061-1078, 1970.

Abstract. Recent surveys and sampling of the V-shaped canyon that cuts into parts of the broad troughs separating the Bahama Banks have given a greatly improved picture of this gigantic valley and the processes operating to shape it. The canyon has two major branches, one following Northwest Providence Channel and the other the Tongue of the Ocean, which join 15 mi north of New Providence Island, and continue seaward as a submarine canyon with walls almost 3 mi high. These, so far as we know, are the world's highest canyon walls (either submarine or subaerial), and the canyon length, including the branch in Northwest Providence Channel, is at least 150 mi, exceeded only by two submarine canyons in the Bering Sea.

Bottom photographs from the outer portions of Northwest Branch and Tongue Branch show wall rock, rounded cobbles, and boulders along their axes, as well as ripple-marked sand to indicate that importance of currents moving along the canyon floor. Further evidence that erosion has at least kept the valleys open as the Bahama Banks grew comes from the winding courses and the numerous tributaries that descend the walls from the shallow Banks, particularly on the south side of Northwest Branch. The possibility that limestone solution has been important comes from the finding of more depressions along Northwest Branch than in other submarine canyons of the world, and the discovery of caverns along the walls by observers during deep dives into Tongue Branch in the Alvin and Aluminaut. It seems to us highly probable that the modern canyons are due primarily to submarine erosion, partly re-excavating old filled troughs.

OUR SHRINKING GLOBE

Landes, Kenneth K.; *Geological Society of America, Bulletin*, 63:225-240 and 63:1069-1074, 1952.

[In this address to the AAAS in 1951, Landes nicely summarizes some data which tend to support the past existence of much lower sea levels. If sea levels were truly many thousands of feet lower in the recent past, where did the present oceans come from? Was catastrophism involved? What of man during this period? The enigmatic submarine canyons underscore this mystery.]

Submarine Canyons and Allied Features

Factual Data. It was dissatisfaction with all current explanations for submarine canyons that started me on this study. The many theories advanced to explain these features are described and discussed by Shepard.

So much has been written about submarine canyons in recent years that it will not be necessary to describe them in detail. A most comprehensive account of their distribution is given by Shepard. They cut the submerged continental slopes and shelves of all continents and of many islands including the Bahamas. Most of the larger canyons connect with rivers, and as a general rule with the larger rivers. Smaller canyons notch the continental slope but do not penetrate far into the continental shelf. Most of the canyons that do approach the present shore line have been diminished and even obliterated through infilling brought about by shoreline processes.

Many canyons have cut through the mantle into underlying bedrock. The bedrock encountered ranges in vulnerability to erosion from shale to granite. Studies made of the canyons off the California coast have shown the presence along the canyon walls of limestone, well cemented sandstone, conglomerate, basalt, and granite as well as soft Tertiary material. The maximum depth reached by the canyon floors is certainly greater than 12,000 feet and may even be greater than 15,000. This is the stumbling block that prevents widespread acceptance of canyon cutting by subaerial erosion.

The authorities are in rather general agreement that the canyon cutting took place during the Pleistocene. The bedrock incised is as young as late Tertiary. Veatch and Smith state that the greatest erosion along the Atlantic-facing continental slope was during the first and last glacial stages. Shepard and others have pointed out that some of the canyons in higher latitudes were modified by glacial excavation. These canyons not only have the characteristic cross section of glaciated valleys, but some contain moraines.

Another submerged feature suggestive of erosion is the terrace. According to Tolstoy "the continental slopes are now known to show in many cases a step-like succession of horizontal or imperceptibility sloping shelves or terraces". The same author notes evidence of terracing on the flanks of the flat-topped submerged mountains (seamounts or guyots) rising above the ocean floor southeast of Cape Cod. The mid-Atlantic Ridge between depths of 10,000 and 15,000 feet contains "a succession of flats which for the lack of any better term have been called terraces". Emery describes "deep terrace-like structures on the flanks of Eniwetok Atoll at a depth of about 4500 feet. This compares closely with the depth of the flat top of the seamount tied to the northwest side of Bikini Atoll by a narrow neck. Bikini itself has a terrace at a depth of 13,000 feet.

At least 35 mountains rise to heights of 3,500 to 12,400 feet above the floor of the Gulf of Alaska. Some of these have the symmetry, the slope, and the alignment of volcanoes. Most of the shallower mountains have flat tops at a depth of 2400 to 3000 feet. Some of the flat tops are as much as 8 and 9 miles in diameter. Similar seamounts have been found elsewhere, especially in the western and central Pacific. These truncated cones rise 9000 to 12,000 feet above the ocean floor, and the flat summit levels range as a general rule from 3000 to 6000 feet below sea level. The flat top is in many instances bordered by a gently sloping shelf which extends outward 1-2 miles. The summit levels of adjacent peaks may differ by as much as 1000 feet. Many seamounts have been used as foundations for atoll construction.

There is fairly general agreement that seamounts are volcanic cones that have been truncated by wave erosion. The flat submerged banks may have similar origin.

Ripple marks have been photographed on the sea floor at depths as great as 4500 feet. Shallow water faunas, in addition to the reef-building types previously mentioned, have been found at even greater depths. Examples range from Foraminifera to larger mollusks. Sand, gravel, and even cobbles have been dredged from the floors of submarine canyons far from shore and to depths of 12,000 feet or more. Recent coring in the

Atlantic, along the eastern continental slope of North America, has shown the presence of beds of sand interbedded between layers of clay referred to as abyssal in type. However, I am skeptical in regard to the precise dating given these ocean-bottom deposits, based on Foraminifera. If I read Phleger correctly all the Pleistocene species of Foraminifera are still living. There are cold-and-warm-water types, and as the ice sheets advanced these types shifted south, later to return with the retreat of the ice. Therefore a "normal post-Wisconsin assemblage of Foraminifera known to be living in the region at the present time, could equally well be assigned to one of the pre-Wisconsin interglacial stages, or perhaps even to an intersubstage of the Wisconsin itself.

Subaerial Erosion Hypothesis. The subaerial hypothesis as an explanation for the submarine canyons is as old as the discovery of the canyons themselves. It is based on the striking parallelism between canyons cut by rivers running off the land and the canyons cut into the submerged continental slopes and shelves. Shepard has summarized the evidence favoring subaerial erosion of the submarine canyons. These valleys resemble land canyons in every possible respect with one exception, which is discussed later. The submarine canyons have steep walls with V-shaped cross sections. They follow a winding course and have accordant tributaries. The dimensions are comparable to those of larger land canyons. Some have wide flat floors toward the outer end, and others terminate in deltas. Natural levees have been observed. Hess noted that some of the submerged river valleys of the Bahamas even show a trellis pattern, presumably due to the structural situation.

An undaunted few have tried to explain the extreme sea-level fluctuation necessary to permit canyon cutting by subaerial processes. Shepard and duToit have invoked warping of the continental borders. Hess and MacClintock convinced that no answer other than subaerial erosion can be the right one, suggest as a possible solution a change in the ellipticity of the sea surface perhaps due to sudden decrease in rate of earth rotation. Von Engeln postulates interior earth conditions which wouldproduce a temporary increase in density. This would cause the ocean bottoms to sink to greater depths, and sea level would "decline in a significant degree".

My explanation is that during one of the Pleistocene glacial epochs the ocean basins subsided to such an extent that sea level as lowered the 15,000 feet or whatever is needed to account for subaerial canyon cutting. I have calculated that if all the sea floor now lying at depths below 13,300 feet (4000 meters) were to subside 20,000 feet, all the ocean floor above 13,300 feet of water depth would be emergent. This would expose all our submarine canyons except, perhaps, the mouths of the deepest ones. I cite this figure merely to show that unheard-of subsidences are not necessary to expose the canyon-cut continental slopes. Furthermore, this extreme subsidence only had to happen once. To obtain the other glacial epochs, a sealevel lowering of 3000 feet probably would have been sufficient. The deep-sea floor (below 4000 meters) would have to subside a little over 5000 feet to produce this emergence.

I do not know which of the four Pleistocene glacial epochs was the one of maximum withdrawal, but I suspect that it was one of the later ones, for there is some evidence of higher-level deltas through which the present canyons have cut. Each sea-level lowering would cause resumption of excavation and headward erosion in those parts of the valleys lying above that particular ocean-water level. Each resubmergence stopped the canyon cutting, but by the end of the Wisconsin epoch a few canyons had eroded headward across the entire width of the shelf. The upper ends of many of these submerged valleys were subsequently filled by shoreline processes of erosion and deposition.

Although a few others have been willing to consider a sea-level lowering of several thousands of feet, owing to ocean-floor subsidence, they have not been able to swallow a return of sea level to within a few hundreds of feet of its former position, and have therefore dropped the idea with considerable dispatch. According to my concept of the mechanics of contraction, it would be even stranger if the sea level did not return to the same approximate level as before! When the ocean basins subsided, owing to a contracting interior, a condition of isostatic disequilibrium was established. Very shortly, in terms of geologic time, the continents also subsided and came to rest at the level of isostatic equilibrium.

At least two other arguments have been raised opposed to subaerial erosion of the under-water canyons. The one exception to the complete parallelism between submerged canyons and those on the continents is the long profile. In the case of the mature land streams this profile is concave. It is not concave in the Monterey sea valley and in other submarine canyons with the possible exception of the Congo. However, I do not believe that one should expect a young consequent stream running down the continental slope to show a normal profile. It was fusily engaged in converting its initial slope to a normal profile when submergence interrupted the job. The mighty Congo came closer to finishing this conversion than most other streams. Another argument is the cutting of canyons in partially enclosed seas such as the Mediterranean and the Sea of Japan to depths far below the level of the sill separating the sea from the open ocean. The best explanation that comes to mind is that graben faulting within the enclosed sea has dropped the canyon area below its original level.

I concur with Hess and others in believing that the flat-topped seamounts or guyots are volcanoes truncated by wave erosion. The lowering of present sea level from 3000 to 6000 feet would be adequate. The discordance in summit elevations can be explained in two ways: (1) the higher volcanoes (in terms of depth to the flat top) were not even in existence when the lower ones were truncated by wave action, or (2) erratic grabening of the fragmented Pacific Ocean floor has dropped the seamounts varying distances.

Other Suggested Explanations. Opposed to the concept of subaerial erosion are some of the most highly respected and revered heroes of modern geology. Most of the substitute ideas produced by this galaxy of mental stars although ingenious are none the less unpalatable. The leading alternate explanation is the turbidity-current hypothesis. Sired by Daly and nurtured by Juenen, and by Ewing and associates, the turbidity-current hypothesis reached maturity with the publication of a symposium in 1951.

Briefly, turbidity currents are silty underflows that have been observed in Lake Mead and several other artificial lakes in the United States as well as Lakes Geneva and Constance in Europe. They have also been produced synthetically in a tank, and there is no doubt that under proper conditions silty water slides down the sloping floor of reservoir, lake, or tank much like water flows under air.

Proponents of turbidity currents credit them with depositing the deep off-shore graded sand deposits (coarser clastics such as the cobbles are supposed to ride down on submarine landslides) and with carrying shallow-water form aminifera out to depths far beyond their normal habitat, as well as cutting canyons into the continental slope and shelf.

Turbidity currents have not been found in the ocean in spite of the fact that some mighty rivers carry sediment to the heads of submarine canyons having gradients far steeper than those found on the floor of Lake Mead. It is perhaps more than a coincidence that none of the witnessed examples of turbidity currents have been where silt-laden masses of fresh water entered larger masses of salt water. Where rivers, such as the Congo, enter the sea, the fresh water rides out over the salt water, carrying its sediment with it until the checking of velocity causes the sediment to sink into and through the underlying quiet salt water.

I claim that the finding of graded clastics and misplaced (shallow-water) faunas deep beneath the sea is not prima facie evidence that they were carried there by turbidity currents; that the finding of cobbles does not prove that they were transported by submarine landslides; and that photographs of ripple marks lying at a depth of 4500 feet do not necessarily mean that they resulted from current action operating at that depth. In any other environment, sand, gravel, and cobbles are recognized as stream deposits, especially where they occur on canyon floors, and in the fans and deltas at the mouths of canyons. Misplaced faunas are found at great depths in rigid reefs, and their position there is generally recognized as due to subsidence, but we are told that loose, misplaced forams must have been carried in! I likewise believe that deep seafloor current ripples, like the truncated seamounts, are relics of shallower water.

What manner of logic allows us to accept evidence, such as marine strata, of a sea-level far above present datum of 25,000 feet, but causes us to run from evidence of a sea-level depression of 25,000 feet? By what reasoning do we assume that current sea level is also (within 200 or 300 feet) minimum sea level? Would it not be just as logical to assume that the present sea level (when the continents and the ocean basins are in isostatic adjustment) is closer to median sea level? And when we do lower sea level a couple of hundred feet why do we limit that lowering to the amount of water that could have been removed to make ice caps and mountain glaciers? We raise sea level thousands of feet by diatrophism. Is this a one-way process? Why can't we lower sea level the same way? What is so sacrosanct about current sea level? (pp. 231-235)

POLYGENETIC ORIGIN OF MONTEREY SUBMARINE CANYON

Starke, George W., and Howard, Arthur D.; *Geological Society of America, Bulletin,* 79:819-826, 1968.

Abstract. Monterey Submarine Canyon, one of the world's largest and deepest, heads immediately offshore in Monterey Bay on the central California coast. Starke (1956) reported the presence of a deep buried canyon inland from, and aligned with, the head of the submarine canyon. Cumulative well records, gravity surveys, and field investigations strongly suggest that the buried ancestral canyon was eroded by fluvial processes, and that the present submarine canyon originated, at least in part, by the flum-

ing out of the ancestral canyon by dominantly submarine processes. Other submarine canyons off unstable coasts may also be polygenetic in origin. The presence of the ancestral canyon provides additional information on the deformational history of this part of the central California coast.

WHEN THE MEDITERRANEAN DRIED UP

Hsu, Kenneth J.; *Scientific American,* 227:26-36, December 1972.

[After describing the discovery of salt plugs and evaporites beneath the Mediterranean (both suggesting this Sea had dried up at one time), Hsu goes on to relate the discovery of submarine canyons around the edge of the Mediterranean. These deeply cut gorges are taken as evidence of much lower water levels in the past. Could the very similar submarine canyons on oceanic shores indicate that the oceans were also thousands of feet lower at one time in geological history?]

Soon after we returned to port Ryan received a letter from a Russian geologist, I. S. Chumakov, who had learned of our findings through an article in The New York Times. Chumakov was one of the specialists sent by the U.S.S.R. to Aswan in Egypt to help build the famous high dam. In an effort to find hard rock for the dam's foundation 15 boreholes were drilled. To the Russians' amazement they discovered a narrow, deep gorge under the Nile valley, cut 700 feet below the sea level into hard granite. The valley was drowned some 5.5 million years ago and filled with Pleocene marine muds, which are covered by the Nile alluvium. Aswan is 750 miles upstream from the Mediterranean coast. In the Nile delta boreholes more than 1,000 feet deep were not able to reach the bottom of the old Nile canyon. Chumakov estimated that the depth of the incision there might reach 5,000 feet, and he visualized a buried Grand Canyon under the sands and silts of the Nile delta.

Chumakov was not the only one who had been puzzled. Oil geologists exploring in Libya had also had their share of surprises. First, their seismograms would register anomalies; there were linear features underground transmitting seismic waves at abnormally high velocities. Drilling into the anomalies revealed that they are buried channels incised 1,300 feet below sea level. The geologic record tells the same story: vigorous down-cutting by streams and sudden flooding by marine waters at the beginning of the Pliocene. Frank T. Barr and his coworkers of the Oasis Oil Company, based at Tripoli in Libya, concluded in a report that the Mediterranean must have been thousands of feet below its present level when the channels were cut. They could not get their manuscript published in a scientific journal, since no one would accept such an outrageous interpretation. (p. 35)

• Ocean-Floor Channels

DEEP-SEA CHANNELS

Dietz, Robert S.; *Geological Society of America, Bulletin,* 63:1244, 1952.

Abstract. Modern fathograms are tending to establish the common presence of riverlike channels traversing the deep sea floor. These channels have a low gradient, a shallow relief compared to submarine canyons, and are commonly leveed. It is suggested that they are formed by low-density turbidity currents. They are apparently of great importance in down-slope transportation of sediment and in forming "alluvial aprons" in the deep sea. At least some of these channels are extensions of submarine canyons incised in continental slopes.

Southwest of Ceylon, the Swedish Deep Sea Expedition crossed five trough-shaped and leveed depressions in an otherwise flat bottom which are probably striking examples of such channels. Three of these are more than a mile wide and 200-250 feet deep. (By comparison the Mississippi near New Orleans is half a mile wide and about 50 feet deep below its levees.) The sea floor of the Indian Ocean between India and Malaya appears to be a gently southward-sloping sedimentary plain. Foredeeps separate this plain from most of Malaya and Ceylon. Thus the Ganges submarine canyon appears as a possible source for some of these deep sea channels even though it is 1000 miles to the north.

EQUATORIAL ATLANTIC MID-OCEAN CANYON

Heezen, Bruce C., et al; *Geological Society of America, Bulletin,* 71:1886, 1960.

Abstract. Most submarine canyons are furrows cut into the continental margin, but mid-ocean canyons have been found in the abyssal plains. A mid-ocean canyon is a steep-walled, flat-floored, persistent linear depression 1-5 miles wide and a few to more than 100 fathoms deep. Such features have been discovered in the northwest Atlantic east of Newfoundland, south of Nova Scotia, in the Gulf of Alaska, and east of Ceylon in the Bay of Bengal. A new mid-ocean canyon was discovered by the Research Vessel Vema of Fortaleza, Brazil, and traced for 350 miles. Unlike former mid-ocean canyons which occur in abyssal plains, this equatorial mid-ocean canyon runs southeast along the continental rise and parallels the continental margin. Sounding lines have not revealed any connection between the westernmost end of the canyon and the nearest continental-slope canyon. Cores taken from the floor contained sand and gravel, which indicates that the canyon, if not formed by turbidity currents, at least acted as a channel for them.

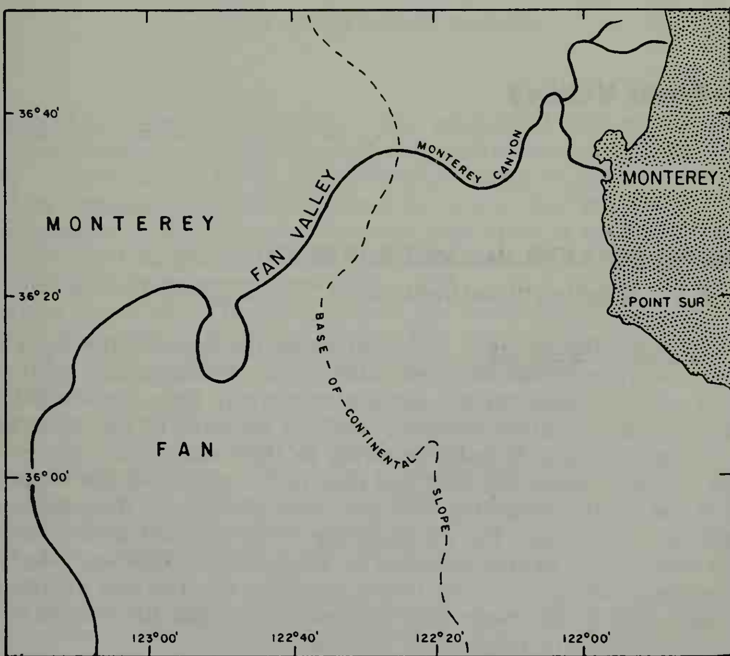
The parallelism of the Mid-Ocean Equatorial Canyon with the continental margin on one hand and the mid-oceanic ridge on the other suggests a

tectonic control. However, the morphology of the canyon and its sediments suggest an origin through the action of turbidity currents.

MEANDER IN VALLEY CROSSING A DEEP-OCEAN FAN

Shepard, Francis P.; *Science*, 154:385-386, 1966.

Abstract. Seaward of most submarine canyons there are large sediment fans comparable to the fans at the base of mountain ranges. Many of the submarine caves are cut by valleys called fan-valleys which usually connect with the mouths of submarine canyons. Loop-like bends or meanders characterize the channels of rivers in their lower flood plains, but have never been found in the shallow channels that cross the alluvial fans at the base of mountain canyons. Therefore, it was surprising to find that the channel in a very deep submarine fan-valley of Monterey Bay, California, has a tight meander.



Meander in the valley crossing the deep-ocean fan off Monterey, California.

A MEANDERING DEEP-SEA CHANNEL

Ryan, William B. F., et al; *American Geophysical Union, Transactions,* 48:142, 1967.

Abstract. A deep-sea channel has been surveyed on the Ganges cone in the Indian Ocean. In a water depth of over 4000 meters the channel shows well-developed meanders repeating in a regular sinusoidal pattern, over a survey distance of 50 km along the channel axis. Levee heights above the channel floor reach 35 meters where the channel width is 3 km. A wide, flat terrace from 10 to 15 meters in height above the channel floor is observed on the inside of each meander bend. The bends have radii varying from 2 to 8 km, and the meanders are believed to persist along the major course of the channels across the large sedimentary cone. Photographs of the sea floor reveal the existence of weak bottom currents in the channel. The absence of massive graded silt or sand beds in the upper 1 meter of a core of silty lutite from the same location indicates that significant turbidity currents have not traveled through the channel during the last several thousand years.

• Lake-Floor Valleys

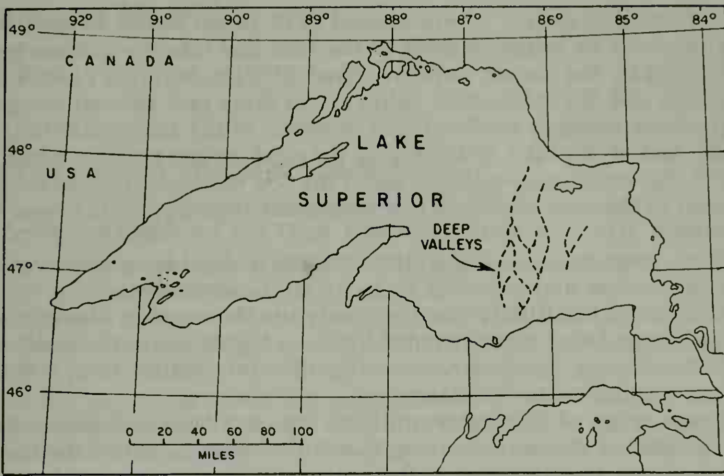
SUBMARINE VALLEYS IN LAKE SUPERIOR

Laidly, W. T.; *Geographical Review,* 51:277-283, 1961.

The 1957-1958 Discovery. Although soundings done by the Lake Survey are planned and conducted for exploration of the hydrographic features only to the extent needed for the navigation charts, they sometimes disclose features of scientific interest. Such is the case of the re-sounding done in the eastern part of Lake Superior in 1957 and 1958. The re-sounding in the western end of the lake had generally confirmed the superficial showing of the earlier sounding that the depth changes in the western end are practically uniform. The re-sounding in the eastern part also confirmed in general the depths obtained by the earlier sounding, where they were coincident, but the greater detail provided showed that depths in the eastern part vary widely over short distances and that the bottom is marked by a network of ridges and valleys.

Figure 1 indicates the principal valleys disclosed by the 1957-1958 survey. In places the bottoms of these valleys are more than 700 feet below the tops of the intervening ridges, and the valleys range in width from half a mile to several miles. The greatest depth recorded is 1333 feet, which places the valley bottom at that point about 731 feet below sea level. Depths on the adjacent ridges are only 565 feet on one side of the valley and 793 feet on the other.

. . . .



Deep valleys in Lake Superior.

Origin of the Submarine Valleys. The geological history of Lake Superior accounts for the valleys and ridges disclosed by the 1957-1958 survey. The western arm of the lake lies within a structural basin developed in Precambrian lava flows and sediments and overlying shales and sandstones. Except for small areas just north of Sault Ste. Marie, the entire Canadian shore is made up of Precambrian flows and contorted and broken sedimentary, metamorphic, and igneous rocks, all more than 500 million years old. The east side of the Keweenaw Peninsula and the shore line eastward to Sault Ste. Marie are covered with Cambrian sandstones, which are overlain to the south by younger sediments, predominantly limestones.

Strong fractures were developed in the region. Relative movement of thousands of feet occurred along great faults, such as those on the Keweenaw and Bayfield Peninsulas. The rocks of the center of the basin were thrust up and over adjacent younger rocks. Since that time the topography has been modified by warping of the earth's crust, by everyday weathering and erosion, and, perhaps most remarkably, by the work of the Pleistocene glaciers.

More than three hundred thousand years ago great sheets of ice, probably more than a mile thick, invaded the area from the northeast. At the eastern end of the lake the ice---armed at its base with sand, cobbles, and boulders---ground, crushed, and quarried its way to the south, following the trend of ridges of lava flows. Farther west, Michipicoten Island formed a dam that diverted much of the ice to the east and west and in its shadow limited the work to the excavation of deep, continuous valleys, well below sea level, in pre-existing fracture zones. A sample from a shoal northwest of Caribou Island consisted mainly of angular fragments of sandstones, an indication that the Cambrian sandstones extend northward almost to Michipicoten Island.

On the Canadian shore, where glacial drift is not thick, several large river valleys can be followed down to the lake and into the submarine valleys disclosed by the recent survey. Sand fills the bottoms of both the river valleys and the submarine valleys. In their last retreat the glaciers must have been working for hundreds of years in the same position, gouging out the bed of the lake and dumping detritus on the present south shore.

West of the submarine-valley region the ice was split into several lobes. One worked to the east of the Huron Mountains, another to the west of them, into Keweena Bay. A third lobe was split off by Superior Shoal, and it modified the western arm of the lake, cutting and grinding and breaking the weak sediments and carrying them off to the southwest.

When the ice front finally receded, only ten thousand to eleven thousand years ago, large lakes were trapped between highlands to the south and ice to the north. Strong beaches were built, then left behind as new outlets were found and the water level dropped.

The latest stage of development of the lake has been influenced by the upward rebound of the earth's crust that followed removal of the ice load. In the last eleven thousand years the northeast shore seems to have risen six hundred to seven hundred feet relative to the land at Duluth, with the result that water has backed up the southern rivers, while new cliffs and waterfalls have been cut around the north shore.

MOUNDS AND PIMPLED PLAINS

Natural earthen mounds exist all over the world but seem best-developed in the United States. It is also in the U.S. that speculation about mound origin has led to heated exchanges in several scientific journals. Several careful scientists have been ridiculed because they proposed that pocket gophers might have constructed the mounds. A frozen-ground-plus-erosion theory has been hawked as the <u>only</u> solution in the most reputable publications. It is indeed the question of origin that provides the major motivation for including mounds in this book.

A second reason must be the overwhelming quantity and precision of the best-developed fields---called rather rudely "hog-wallow prairies." The major centers in Washington and along the Gulf Coast contain hundreds of thousands of beautifully sculpted mounds that must stimulate the curiosity of the most blase geologist.

Many mound fields are well south of the region where periplacial phenomena might be blamed for their formation. Every one of the score or so theories has defects, so we can still call the Mima Mounds and their kin mysterious.

Many other natural mounds exist, such as the doughnut-shaped mounds of Alberta, the Arctic pingos and earthquake blow-out mounds. These, too, are included in this section. They may provide clues to the solution of the mound riddle.

• The Mima Mounds

THE MYSTERY OF THE MIMA MOUNDS

Scheffer, Victor B.; *Scientific Monthly*, 65:283-294, 1947.

On the prairies of western Washington near the southern tip of Puget Sound are scattered thousands of large earth mounds whose origin has puzzled observers for more than a century. On Mima Prairie some of the mounds are higher than a man's head and have a content of 50 cubic yards. The mounds are smooth and round, like great spheres nearly buried in the earth. In many cases, the hollows between the mounds are filled with cobblestones up to the size of a football. In the spring of the year, when the mounds are covered with shite-and-yellow daisies and green bracken ferns, they stand out clearly from their duller surround ings.

Wherever a mound has been sliced open by a roadway, a peculiar cross section is revealed. The typical mound is made up of soft black prairie silt mixed with pebbles up to the size of a walnut. The mound rests in a slight depression, or bed, in coarse, stratified glacial gravel, which continues downward for an unexplored distance. Thus, the typical mound is a biconvex lens, with the great curvature exposed to the sky and the lesser curvature pressed against the gravel. At the base of the mound, armlike structures of black silt extend into the gravel. These have been called "mound roots" by certain investigators.

The origin of the mounds has long been disputed. A few years ago, a student at the University of Washington suggested a novel theory to account for the mounds and invited me to join him in a search for supporting evidence. How we approached the problem and attempted to fit our findings into a convincing pattern has been described in a preliminary paper.

As we delved into the mystery of the Mima Mounds, it dawned on us that these formations are kindred to similar, though less spectacular, mounds strewn by the millions over the Western states from the Mexican border to northern Washington. Thus, the theory accounting for the mounds of Puget Sound---which we now accept---embraces also the countless mounds of similar shape and structure in the Western states. Because of certain peculiar features, Mima Prairie has served as a Rosetta stone in explaining the origin of other mound prairies.

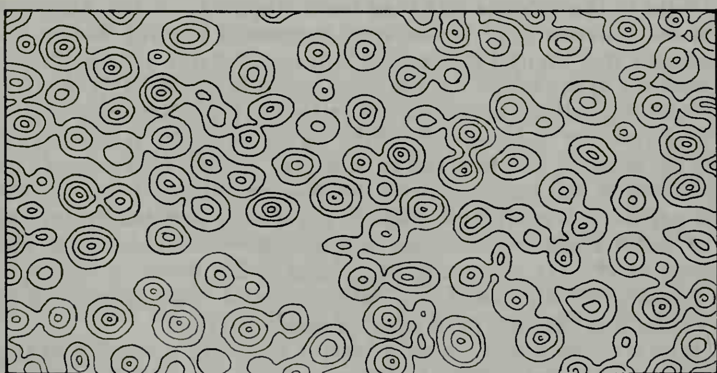
More than a century ago mound prairies drew the attention of travelers in the new West. In July 1842, Commander Charles Wilkes made a special trip to "Bute Prairie," south of Olympia, Wash., and dug into three of the mounds in an attempt to unlock their secret. He finally concluded that "they bear the marks of savage labour, and are such an undertaking as would have required the united efforts of a whole tribe." As indeed they would!

On the famous railroad survey of 1853-56, naturalists Gibbs and Cooper examined some of the mounds, and Gibbs suggested that "they might have been produced by the immense growth of the 'giant root,' (Megarhiza (Echinocystis) Oregana), forming a nucleus around which the soil has been gradually washed away." Cooper---a more conservative scientist---believed that the mounds were perhaps the result of eddy and whirlpool action at a time when the prairies were submerged beneath Puget Sound. When Gibbs returned to the East he described the mounds to Louis Agassiz, who "unhesitatingly" pronounced them the nests of a species of sucker. Professor Agassiz may be forgiven this opinion in view of the fact that he had not seen the mounds, some of which rise to a height of seven feet.

Joseph LeConte, geologist of the University of California, first saw the Puget Sound prairies in 1871. He was the first to point out the similarities among the mounds in California, Oregon, and Washington and he tried to show that their origin was due to "surface erosion under peculiar conditions." As he reconstructed their geological history, the prairies were left by a retreating body of water with a blanket of fine topsoil and a coarse subsoil; erosion started to remove the finer topsoil everywhere but in certain spots; weeds, shrubs, and ferns immediately seized upon these spots, or islands, and anchored the soil; then when the climate grew drier, vegetation was able to survive only on the higher (and richer) islands while erosion continued to gnaw at their bases.

Interest in the American earthmounds was aroused in faraway England. Geologist Alfred R. Wallace discussed a letter from his brother in California describing the "hog-wallow" region of the San Joaquin Valley.

> The surface thus designated [he wrote] may be represented on a small scale by covering the bottom of a large flat dish with eggs distributed so that their longer axes shall lie at various angles with one another, and then filling the dish with fine sand to a little more than half the height of the eggs.



Typical Mima Mound topography. Contour interval is about 2 feet.

The California brother attributed the mounds to "innumerable rills that issued from the retiring sheet of ice" of a glacier long since disappeared. (It is now well established that the San Joaquin Valley was at no time covered by ice.

Soon afterward, G. W. Barnes discussed the small hillocks that lie on the old sea terraces back of San Diego. He concluded that the San Diego mounds were produced---and are still being produced---by a peculiar combination of wind and water erosion in the presence of vegetation, as follows: prevailing winds deposit dust and leaves at the base of a shrubby desert plant; rain-water erosion cuts faster at the base of the mound than at the top; the shrub eventually dies; and, "deprived of its protection, the summit is reduced and the base widened as it is lowered, till finally a remnant of the deposit has become so assimilated and compact as to constitute a more permanent summit." Accompanied by Dr. K. O. Emery, I examined the San Diego mounds in 1943 and found them very like the mounds of Puget Sound.

In a resume in 1905, J. C. Branner disposed of a number of theories to account for the Western mounds and concluded: "The ant-hill theory seems to me the most plausible, but with our present knowledge it is far from satisfactory." He also dwelt on the concept that the mounds are the result of differential solution and concretion on a large scale.

Marius Campbell, of the Geological Survey, followed shortly with a paper summarizing the various hypotheses for the mounds that lie on the plains from Arkansas to the Pacific coast. He showed that naturalists had laid the origin of the mounds to the agency of humans, burrowing mammals (ground squirrels, gophers, and prairie dogs), ants, fishes, water erosion, chemical solution, wind action, physical and chemical segregation, glacial action, uprooted trees, and spring and gas vents. Campbell suspected the importance of burrowing mammals and ants, especially the latter, although he confessed his inability to understand their methods of operation.

In 1913, J. Harlan Bretz, of the University of Washington, published an article on glaciation of the Puget Sound region and therein described his careful studies of Mima Prairie. He concluded that the mounds were probably the result of water and ice action. In retrospect, it seems logical that Bretz should have associated the mounds with glacial activity since the region under scrutiny, where the mounds are better developed than anywhere else in the United States, marks also the farthest point reached by the Vashon Glacier, last of the Western ice sheets.

Ellis and Lee, in 1919, laid the origin of the San Diego mounds to "the action of wind as it sweeps through the sparse desert vegetation and blows away the loose soil except where it is held by plant roots." These investigators, like certain others before them, apparently did not realize that wind-built mounds are invariably <u>oriented</u> with the direction of the prevailing wind, whereas the mounds in question are either round or, if elongated, are aligned in no common direction.

The theory has been suggested, with variations, that the great power of freezing water has been instrumental in creating the mounds. The proponents of this theory may have studied the mound prairies of the North, but surely not those of the warm coastal plains of southern California.

In 1941, soil-scientist C. C. Nikiforoff published a long report on his studies of mounds in the Central Valley of California, principally in Tulare County. The mounds here are so similar in shape, size, and arrangement to those of Puget Sound that certain photographs from the two areas appear to have been taken from the same station. In two respects, however, the regions are different: in Tulare County the mounds are underlain by a stiff clay hardpan and in the rainy season may be surrounded by water a foot or two deep, whereas in Puget Sound the mounds are underlain by coarse gravel and rarely, if ever, stand out as islands. Nikiforoff concluded that the "hog-wallow microrelief" was perhaps the result of groundwater pressure from the Sierra Nevada pushing up through countless "windows", now represented by mounds, in the hardpan of the valley.

The mounds in the Central Valley are so numerous, or were when the pioneer farmers arrived on the scene, that a special implement, the "Fresno Scraper," has been devised for the purpose of leveling them off and making the ground fit for cultivation. The machine is still widely used.

The foregoing statements high-light the history of research on Mima-type mounds. In 1941, Walter W. Dalquest was engaged in a survey of the mammals of the state of Washington. As he extended his field observations to the prairies near Mima, he was at the same time enrolled in a course in glacial geology at the University of Washington. Here he learned that the origin of the prairie mounds was a mystery. About then the idea struck him that the mounds are the handiwork of pocket gophers over untold periods of time. When he broached the idea to old-timers born and raised on the prairies, they commonly put tongue in cheek and cautiously remarked, "W-e-e-l, they must have been pretty big gophers." This is a not illogical conclusion in view of the fact that the Mima Mounds are among the most spectacular---if not the largest---structures created by any mammal.

The gopher of the Western states, _Thomomys_, is a ratlike, brownish rodent that burrows in the soil of prairies and mountain meadows and along stream channels in the desert. It seldom ventures aboveground (as does the ground squirrel) and never enters the shade of the forest (as does the mole). It feeds on fleshy roots and often pulls an entire plant, root-first, into its subterranean chamber. The "pocket" part of the gopher's name refers to a deep, fur-lined pouch in each cheek. The pouch is about the size of an ordinary thimble and is used for carrying food, nesting material, and dirt. With this pouch to serve as a hod, with a pair of powerful forepaws for digging, and with the ability to run backward as well as forward in its burrow, the gopher is well equipped to excavate its labyrinthine tunnels.

Our theory of the origin of the Mima Mounds by gopher activity may be summed up as follows: A few tens of thousands of years ago, the Puget Sound prairie was laid down by rivers draining from the Vashon Ice Sheet. At first, the rivers were powerful and were able to carry the large boulders now found in the substratum of the prairie. Later, the rivers were quieter and were able to carry only the fine silt that, richened and darkened by the addition of grass-root humus, now composes the topsoil.

As soon as vegetation captured the raw new soil, we suppose that pocket gophers came in from the unglaciated country to the southward, advancing perhaps a few hundred feet in a gopher generation. By the time they reached the southern end of Puget Sound they encountered a barrier, the evergreen forest that had been racing against them to occupy the new land. There they were stopped, and, to the present day, no gophers are found on the lowlands of the Pacific coast north of southern Puget Sound. To be specific, the northern limit of the gopher range is Point Defiance Park, in Tacoma.

We can picture then, thousands of years ago, gophers rooting through the thin silt of the Puget Sound outwash in search of plant roots. At certain places they dug deeply into the gravelly subsoil in order to make nest chambers well protected from prowling bear, wolf, or wildcat. Areal spacing of the nest chambers corresponded to the size of the "territory" of each animal. The center of an old territory now marks, we believe, the center of a modern mound.

In excavating for its nest chamber, the gopher was instinctively led to dig deep into the bedded gravel, regardless of the effort involved. When the animal ran into a large boulder it undermined the obstruction and allowed it to settle. Thus, we now find, at the base of most mounds, a concentration of coarser materials. On the other hand, in foraging daily for food over its home range, the gopher was driven by less powerful instincts. When it encountered a bothersome rock in its path, it simply passed around it, shoving dirt along as it went. Thus, we find plainly exposed in the intermound hollows large boulders that were doubtless at one time buried in the topsoil.

Where the mound and its bed are in contact, there are found "mound roots," long a puzzle to geologists, which are simply abandoned gopher tunnels now filled with black silt contrasting in color with the yellow gravel around it. (They call to mind the peculiar devil's corkscrews, or Daemonelices, of the Nebraska sediments. Once described as fossil plants or animals, the corkscrews are now generally believed to be the casts of burrows of extinct rodents.) We can imagine that, in cases where a gopher mound was abandoned by its owner for some reason or other, the nesting chamber collapsed and caused a depression at the crest of the mound, a characteristic feature of many of the mounds on Mima Prairie.

In fancy, it is easy to picture the start of a Mima Mound. It is less easy to account for its growth. For reasons that may never be known, the gophers carried more dirt toward the nest than away from it. Perhaps some biologist will suggest an experiment whereby the growth of a Mima-type mound can be studied from start to finish. At present, we do not know whether the mounds on the Puget Sound and other prairies are still growing, whether they are in equilibrium with the forces tending to reduce them, or whether they are shrinking.

In reviewing our evidence in support of the gopher-origin theory, we realize that most of it is indirect. We cannot say that we have seen a gopher, or a family of gophers, build a giant mound. Yet, as each new fact with regard to the mounds is uncovered, it seems to strengthen the gopher theory. And, what is perhaps more important, no counter-theory based on the action of nonliving forces(such as wind and water) approaches a satisfactory explanation of the peculiar structure and arrangement of the mounds. The following facts have led us to our conclusions:

1. Mima-type mounds are distributed along the Pacific Coast exclusively in the range of the pocket gopher. On the north, both the mounds and the gophers terminate abruptly in the vicinity of Puget Sound.

2. Burrowing animals with habits similar to those of the gopher, namely, the ground squirrel (Citellus) and the mole (Scapanus), are known to occur on many of the mound prairies. We may deduce, however, that these animals are not pertinent to the formation of mounds since there are no ground squirrels in western Washington and no moles on most of the mound prairies of California.

3. Mima-type mounds are found only where there is a thin layer of workable soil on top of a dense substratum. It is significant that the substratum is of no particular geological formation. Thus near San Diego

and Fresno, the substratum is a hardpan of cemented soil; a few miles southeast of Mount Hood, in Oregon, the substratum is basaltic rock; and in Puget Sound it is bedded gravel.

4. Where gophers are working in deep sandy soil unlimited by a basement they never form Mima-type mounds. In other words, their up-and-down movements are not restricted or localized. In deep soil near Olympia, Wash., only fifteen miles from the mound display at Mima, gophers have been working for untold years, and the surface of the ground is still so level that it is used as an airfield.

5. The usual agent in the formation of hillocks and mounds is geological deposition of one kind or another. This agent can hardly be responsible for mounds of the Mima type. Deposition, whether by ice, wind, or water, depends on a moving vehicle, and movement always results in a deposit which is aligned in one general direction. Mima-type mounds, as may be seen from aerial photographs, are unoriented. Also, deposition does not produce round mounds on a sloping terrain, as are occasionally seen on the gopher prairies.

6. For similar reasons, the agency of erosion may be dismissed. Erosion is generally the result of a moving vehicle. We may point out, further, that on the Puget Sound prairies, the mounds are draped the year around with a mossy turf that protects them from wind and rain-water erosion. And, in countless cases, the hollows between the mounds are completely closed depressions from which there is no rapid outflow of water---simply drainage through the porous gravel bed.

7. Only by a liberal use of the imagination can we conceive of a set of geological forces capable of producing the elaborate structure of the mounds, namely: the fluffy, instratified soil of the mound adjoining a distinctly bedded substratum; the presence of "gopher-size" rocks in the mound as compared with the heavy cobbles beneath and beside the mound; the curious dip in the substrate beneath the mound; the mound roots; and the sunken depression usually found on the summit.

The reader may be distrubed to learn that <u>there are no gophers on Mima Prairie</u>, where climax examples of the mounds appear. This fact is of little importance, however, since there is clear evidence that gophers once lived there. Through some unknown agency---fire, flood, or pestilence---they were wiped out. Once gone from the prairie, they would not return, for the prairie is now isolated from surrounding gopher range by a river and a forest. Since the Mima Prairie Mounds are identical in structure with others only a mile away where gophers <u>are</u> found at the present time, we feel confident in stating that both series of mounds are of common origin. And, as we have pointed out, Mima Prairie is only one among scores of plains along the coast where Mima-type mounds occur.

Finally, we should like to pose three questions, the answers to which some enterprising naturalist may be led to seek:

First, what are the dynamics of mound formation? Were the present mounds built in a matter of years? Centuries? Do conditions of the environment favor their growth at the present time?

Second, does ground water at certain times of the year and in certain localities act in the same way that a soil hardpan does, to force the gophers into mound-building activity?

Third, how widespread in North America are gopher mounds of the Mima type? Shortly before his death in 1942, government naturalist Vernon Bailey told us that he had puzzled over Mima Prairie for years and wondered whether some giant gopher might have lived there long ago. He also said that in his extensive travels he had seen similar formations in southwestern South Dakota, southwestern Louisiana, eastern Texas, and many other parts of the West. Only in Calfironia, Oregon, and Washington have we had an opportunity to study them.

THE MIMA MOUNDS

Kelly, Allan O.; *Scientific Monthly*, 66:174-176, 1948.

I read with a great deal of interest the article in the October number by Dr. Scheffer, "The Mystery of the Mima Mounds."

Excepting the gopher theory, I have heard all the other explanations he says have been advanced for the origin of these mounds and some others that he did not mention, including buffalo wallows, beaver mounds, prehistoric elephant wallows, and that they were made by shovel-nosed sharks when the land was submerged. The last theory was advanced by an oil driller who had found shark's teeth in the area around Bakersfield, California, where these mounds cover hundreds of square miles. The gopher theory is new to me, but I think I can disprove it.

First, gophers do not work in a manner that would tend to form such mounds. The University of California found at its cattle experiment station near Fresno that gophers, when fenced off from their natural enemies so that they are unmolested, work the soil quite evenly, so that each year the mounds of soil they pile up tend to make a sort of summer fallow job of cultivation. This cultivated soil produces a better crop of grass the following year, and hence gophers do not deplete the soil. They cultivate one part of an area one year and another part the next. They do not move the soil or other material toward a central point.

Second, gophers and squirrels will not live in these mound areas, commonly called "hog wallows," if there is any other more suitable terrain, the reason being that these mounds provide their natural enemies, coyotes and foxes, with a good cover for close approach. It is not nature's way---that gophers could have survived for long ages by building good cover for their enemies.

Dr. Scheffer mentions these mounds being found near San Diego, California. This is true. They are found on most of the coastal mesas from San Diego northward into Orange County and southward into Lower California. San Diego County also provides examples of these mounds under different conditions and different terrain. They are found in a number of inland valleys with narrow canyon outlets and at elevations of 200-4,500 feet. El Cajon Valley near San Diego is about 200 feet in elevation; San Marcos Valley, 350 feet; Ramona Valley, 1,500 feet; and Mendenhall Valley, 4,500 feet. All these inland valleys in San Diego County have one thing in common: they have narrowly restricted drainage outlets. The great Central Valley of California has the same characteristics, only on a larger scale.

It is my contention that these mounds are gigantic ripple marks made by deep water flowing slowly out of these valleys through the narrow openings. The same thing can be seen on a small scale in any tidal basin where the outgoing tide leaves mud flats. The size of the ripple marks on these mud flats will be found to vary with the depth of the water and the rate of flow. The deeper the water, the larger the mounds, provided there is a wide expanse of flats where the water begins to flow faster in channels; then the bottom will be smooth or in ridges paralleling the direction of flow.

If we could view the floor of the ocean between Florida and Cuba where the Gulf Stream moves quite swiftly (for an ocean current), then we might see such giant ripple mounds as we now see on dry land. Again, if we could fill any of the valleys mentioned above, or the great Central Valley of California, with muddy water several hundred feet deep and allow that water to drain out through its narrow outlet to the sea, we would get the same sort of mounds we see there today. A scale model of one of these valleys should prove this point. The ripple mounds in these valleys are never found on the steeper slopes or in the channels where the current was gentle.

I agree with Dr. Scheffer that these mounds may be found on any type of substrata, glacial gravel, basaltic rock, clay, hardpan, etc. This proves that their origin had nothing to do with ground water or drainage. He asks how widespread are these "gopher mounds of the Mima type?" I have not heard of their existence elsewhere in the world, but if I am correct in my theory of their origin, they should be found all over the world wherever the land was suitable in topography for their formation.

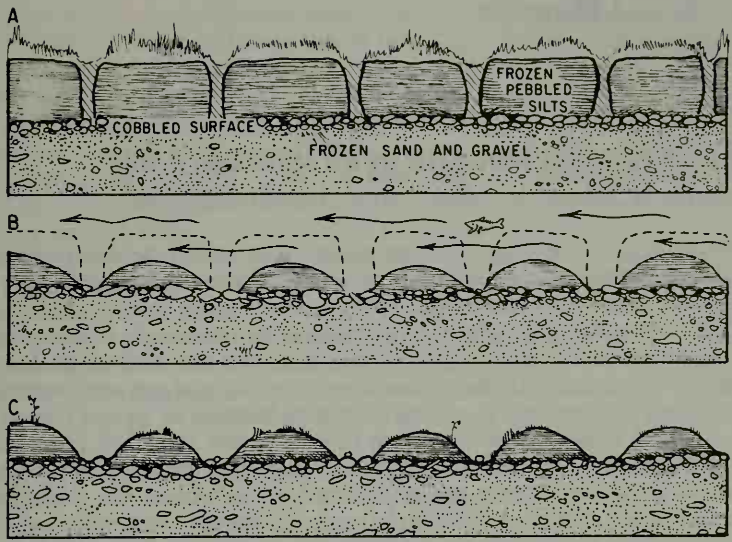
THE MYSTERY OF THE MIMA MOUNDS

Jackson, Howard E.; *Natural History*, 65:136-139+, March 1956.

R. C. Newcomb of the U. S. Geological Survey contended in 1940 that the Mima Mounds were the collapsed remains of buckled blocks of frozen ground, such as can be observed over wide areas in Alaska today. He deduced that during the last Ice Age, the ground in the Tenino-Mima prairie area froze, contracted, and cracked in a patterned network. Ice formed in the cracks and expanded into ice wedges, which caused the blocks of earth between them to bulge upward. When the ice melted, the earth bulges stood out as mounds.

Running neck and neck with Newcomb for the final solution was Arthur M. Ritchie, geologist for the Washington State Highway Commission. Ritchie began likewise with the frozen-ground theory, but he felt that some of the features of the mounds could best be accounted for by erosion of an ice network after partially thawing. He believed that floodwaters during the melting period washed away the thawed material from the unthawed cores of each earth block. The round frozen cores that remained after the flood became the mounds. In other words, he believed that the mounds had been "stripped" by floodwaters and not that they were just the "collapsed" remains of buckled polygonal blocks of frozen ground.

The spacing of the mounds, according to his explanation, was determined by the distances between the original earth polygons. These irregularly shaped blocks of earth thawed appreciably before the flood came upon them, but each block still had within it a core of frozen earth. The shape of this core would be rounded or mound-shaped, inasmuch as the thawing of an irregularly shaped block of earth is similar to the thawing of an ice



Development of mounds according to the "frozen-ground" theory.

cube: both become rounded, because the edges melt away more rapidly than the sides. Thawing thus gave to the mounds their basic shape, whereas the floodwater merely cleaned the thawed debris away from the frozen cores.

The timing of each event was an important factor in the analysis of the mounds. If the floodwater had come after the polygons had completely thawed, all of the material of which the mounds were composed would have been washed away. The same result would have occurred if the river had flowed over the mounds a long time.

Many times, flood rivers had been considered as the agency that might have produced them, but such a process acting alone would destroy the mounds rather than form them. So the real answer went begging until it was realized that the cores of each polygon must have been frozen, which saved them from destruction.

Troy L. Pewe of the U. S. Geological Survey threw in his lot with Ritchie. He had observed similar mounds near Fairbanks, Alaska. He said that field studies of permanently frozen ground showed that ice masses occur in networks but that when these masses melt, mounds are formed. At first he believed, like Newcomb, that the ground between the ice wedges sank down into the depressions left by the melted ice. He now agrees with Ritchie that erosion was all-important in the final development of the mounds. (p. 139, 162)

• Gulf Coast Mounds

"MUD LUMPS" AND MOUNDS NEAR NEW ORLEANS

Simons, M. H.; *American Naturalist*, 16:418-420, 1882.

While attached to a Coast Survey party working on the Mississippi river, I was informed that there were three "Indian mounds" back in the edge of the swamp; on examination they proved to be "mud lumps," but of a shape and material different from those at the mouth of the river. I have looked over various works on geology, but can find no notice of any of these elevations so far above the river mouth, and no very satisfactory explanation of the manner in which they are formed or of the forces forming them. The mounds above spoken of are on the left bank of the river, on the place of Mr. Louis Le Bourgeois, fifty-five miles above New Orleans, they are about one and a-half miles back from the river and just in the edge of the swamp. The largest one is 40 feet in height and 144 feet in diameter, conical in shape with no signs of a crater. 300 yards N. x E. from it is a smaller one, 15 feet in height and 80 feet in diameter. 250 yards E.N.E. is another, not more than 5 feet in height and 20 feet in diameter. Formerly the large mound was entirely surrounded by a circle of these small elevations, but they have been leveled during the process of cultivation. The surface soil around the mounds is the usual black alluvium of the valley.

Mr. Ogden, U.S. Navy, and myself cut into the large mound from the top to a depth of 18.5 feet, and found as follows: There were less than two inches of vegetable mold, and the remainder of the excavation was cut through a hard orange sand; it was so hard that the pick had to be used continuously; single valves of shells, apparently Corbula, were abundant as far down as we went; to a depth of ten feet the shells were mostly soft and calcareous, below that they were all silicified; limestone concretions were very abundant, though generally small; six feet below the surface there was a layer or bed of these shells, with the valves separate; this bed was three feet wide and long, and about three inches thick, and immediately underneath it the sand was black; in some case rough concretions were attached to the shells. There were numerous black spots about the size of buck-shot thickly scattered throughout the whole extent of the excavation; under the microscope these black spots proved to be aggregations of sand; we considered them probably the result of the destruction of minute shells. Eight feet below the surface there was a handful of blue clay and sand mixed, and a little below that a handful of fine gray sand. Half way down the side of the mound I found the same material and appearances, and at the beginning of the slope, the orange sand lay thirty inches from the surface; thirteen feet out from the bottom of the mound, it was necessary to cut through forty-seven inches of alluvium to reach the orange sand, and nineteen feet out it could not be found at all.

About 100 yards from the mound there was a deep ditch, in the bottom of which there was indication, in one place, of the orange sand, eight feet below the surface, but I think that it had been brought from a greater depth by crayfish. The large mound is thickly covered with a growth of magnolia, ironwood, cane and a species of wild climbing vine. During the summer season, as we were informed, flowers peculiar to the mound are found. From the regular shape of the large mound, broken only by holes dug by treasure-hunting negroes, it seems probable that the mound-builders may have shaped it to suit their ideas of symmetry. On the right bank of the river, some three miles back, and in the swamp, I was told by the negroes there were two other large mounds similar in appearance to the one described above. I did not have time to see and examine them. Below New Orleans I noticed two small irregular lumps, bearing evidence of a crater on one side, in one, and in the center in the other.

At Southwest Pass there is a mound, or elevated area, called a "salt mound," from the well of salt water in the center. The pilots told me that when these lumps, or areas, are thrown up, there are, at first, salt wells on them; the wells are very deep and boil up, apparently from escaping gas; ultimately the wells fill up and disappear. There are frequent vibrations, and horizontal and vertical movements of the land in the passes. On one of the lumps in Southwest Pass there is a well discharging an inflammable gas.

Professor Thomassy examined the LeBourgeois mound and pronounced it the result of the damming of a subterranean stream. Professor Lyell thinks that they may be caused either by the binding of the stratum of earth deposited in the bottom of the river by its own weight and motion, down the grade of the stream, or by the vertical pressure of accumulations of gas, or by both.

In one or two works on the antiquities of the mound-builders, there are notices of numerous anomalous mounds, generally of small size, scattered throughout the Mississippi valley. These may be mud lumps similar to the small ones surrounding the LeBourgeois mound.

PECULIAR EARTH-HEAPS IN MISSOURI

Blankinship, J. W.; *American Antiquarian,* 11:117, 1889.

While traveling in southern Missouri, my attention was attracted to a remarkable series of mounds along all water courses. I afterwards observed them as extending over nearly all the southwestern portion of the state, very abundant in many localities. They are in the alluvial soil, and are always near a water course or spring---barely more than a hundred yards distance. In Howell County, Mo., and Fulton County, Ark., they are more plentiful. They are often four feet high and thirty to forty feet in diameter---usually arranged in rows parallel to the stream and at a distance from fifteen to forty yards apart. They may be found around ponds which have no outlet and whose waters vary but little during the year. Much of the land is covered with heavy timber, which grows indiscriminately upon the mounds. I have examined several, but have found no evidences of human remains. They have been attributed by the inhabitants to beaver, prairie dogs, gophers, and Indians, both modern and ancient. It is possible they are the remains of houses built of sun-dried bricks.

ON THE HUMAN ORIGIN OF THE SMALL MOUNDS OF THE LOWER MISSISSIPPI VALLEY AND TEXAS

Veatch, A. C.; *Science*, 23:34-36, 1906.

The following extracts bearing on the theory of the human origin of the small mounds of the lower Mississippi Valley and Texas, resuggested in a recent issue of Science by Mr. D. I. Bushnell, Jr., may be of interest at this time:

Foster in his 'Prehistoric Races of the United States' gives the following data:

> "There is a class of mounds," remarks Professor Forshey in his manuscript notes, "west of the Mississippi Delta and extending from the Gulf to the Arkansas and above, and westward, to the Colorado in Texas, that are to me, after thirty years familiarity with them, entirely inexplicable. In my Geological Reconnaissance of Louisiana, in 1841-2, I made a pretty thorough report on them. I afterwards gave a verbal description of their extent and character before the New Orleans Academy of Sciences. These mounds lack every evidence of artificial construction, based in implements or other human vestigia. They are nearly round, none angular, and have an elevation hemispheroidal, of one to five feet, and a diameter from thirty feet to one hundred and forty feet. They are numbered by the millions. In many places, in the pine forests and upon the prairies, they are to be seen nearly tangent to each other, as far as the eye can reach, thousands being visible from an elevation of a few feet. On the Gulf margin, from the Vermillion to the Colorado, they appear barely visible, often flowing into one another, and only elevated a few inches above the common level. A few miles interior they rise to two or even four feet in height. The largest I ever saw were perhaps one hundred and forty feet in diameter and five feet high. These were in western Louisiana. There is ample testimony that the pine trees of the present forest antedate these mounds. The material of their construction is like that of the vicinity everywhere, and often there is a depression in close proximity to the elevation."
>
> Professor Forshey then proceeds to state that he encountered hundreds of these mounds between Galveston and Houston, and between Red River and the Ouichita; and they were so numerous as to forbid the supposition of their having been the foundations of human habitations; that the borrowing animals common to the region piled up no such heaps; and finally that the winds, while capable of accumulating loose materials, never distribute them in the manner above mentioned. In conclusion, he adds, "In utter desperation I cease to trouble myself about their origin, and call them 'inexplicable mounds.'"

Colonel S. H. Lockett, in his report on the topographical survey of Louisiana, speaks of them as follows:

> There is one feature observed in these prairies, as well as in much of the bottom lands of Ouachita and Moorehouse parishes, quite peculiar and striking, namely, a very great number of small isolated mounds. * * * They are thought by the inhabitants to be Indian mounds, and some of them have been excavated and Indian

relics found; but it is hardly probable that so many tumuli, so irregularly scattered over so large a scope of country, can all be the results of human labor, but rather of natural origin and then subsequently used in some cases as burying grounds for the aborigines.

De Nadaillac, in his 'Prehistoric America,' says:

> Between Red River and the Wichita they ('the Indian garden-beds') can be counted by thousands. According to Forshey, who described them to the New Orleans Academy of Sciences, these embankments can not have served as the foundations for homes of men. Other archeologists are more positive; they consider that these embankments were used for nothing but cultivation, and that they are intended to counteract the humidity of the soil, still the greatest obstacle with which the tillers of the soil of the plains of the Mississippi Valley have to contend.

The writer has assisted in the excavation of a number of Indian village sites and mounds in Indiana and Kentucky, and has observed and described Indian mounds and village sites occurring in various parts of Louisiana, and feels that the theory of human origin is in no way applicable to the great class of natural mounds which he has observed in Louisiana, Texas and Arkansas and along the Iron Mountain Railroad in southeastern Missouri. The idea of human origin suggests itself at once to every observer, and it strongly attracted the writer when he first examined these natural mounds in Louisiana in 1898, but more extended study showed such a hypothesis to be entirely inadequate. Opposed to this theory are the following facts: (1) The natural mounds in many cases do not occur in situations favorable for camp sites. (2) They often occur in elevated locations, where there is absolutely no reason for artificial 'elevated sites for habitations.' (3) Regarded as ruined habitations, or wigwam sites, it is very important to consider their vast number and the extent of territory covered. On this basis they would indicate, in many parts of Louisiana and Texas, an intensity and multiplicity of life not now duplicated in any rural community in the world. The sustenance of such vast communities would be entirely beyond the capabilities of the people who built the true Indian mounds. (4) The natural mounds generally occur on the poorest land in the northern Louisiana region, and this fact is strongly opposed to any supposed agricultural significance.

No one doubts that there are numerous Indian mounds throughout this region, but the natural mounds belong to an entirely different class and should not be confused in this discussion with the artificial ones.

THE SAND MOUNDS OF LOUISIANA AND TEXAS

Koons, Frederick, C.; *Scientific Monthly,* 66:297-300, 1948.

The small mounds that dot portions of the coastal plains of Louisiana and Texas, aptly called "the pimpled plains," have aroused speculation on their origin. Most of the observations so far reported have been superficial, and much of the evidence is merely theoretical or hearsay. When I first saw the mounds on a trip to Texas in 1903, I was told that they were caused by gas blowouts. Later my prolonged residence in Texas afforded opportunity for careful and lengthy study. It is my purpose to review briefly the literature on the subject, to state the results of my investigations on the composition of the mounds and their relation to the underlying strata, and to present my conclusions based on observations covering fifteen years.

The mounds under discussion extend from southwestern Louisiana along the coastal plain southward and westward toward Mexico. I have not observed them south of the latitude of Port Lavaca, Texas. The width of the belt of their occurrence is less than 100 miles and was about 60 miles wide where I made my study. They occur invariably on level plains having a surface soil of clay more or less mixed with sand, little or no drainage, and in regions of abundant periodical rainfall.

The surface soil of the type plain where my studies were made is about 18 inches in depth, underlaid in places by lenses of quicksand from 1 inch to 4 inches in thickness. Then comes 15 feet of clay so impervious to water that after a prolonged wet season of as much as three months' duration the clay at a depth of 3 or 4 feet will be apparently dry and present the same appearance to eye and touch that it does after an extended dry season lasting for months. This clay bed is underlaid by a sand stratum of 12 feet and that by another clay stratum of 4 feet. Under the latter is a stratum of water-bearing gravel and sand. The sand between the clay strata is dry at all times, regardless of the surface conditions. Moreover, the amount of water in the water-bearing stratum is in no way affected or controlled by local conditions of precipitation. There is no connection between the underground water and the surface.

The mounds themselves are circular, and their height varies as their diameters, but their relief is not over 24 inches. In composition they are identical with the adjacent soil, which is clay loam with a varying percentage of sand; but often the percentage of sand is slightly greater than that of the outside area. There is no rock of any kind in the soil nor in the underlying strata until the bottom of the second clay stratum is reached. However, where there is an underlying sand lens there may be found at the bottom of the sand a few pebbles of water-worn gravel, and in some localities there is a small percentage of ironstone nodules, or "buckshot."

Generally, for each mound there is a corresponding depression at one side, and sometimes, but not often, on two sides. These depressions are oriented in no particular way, are oblong, and their width and length vary as the diameter of the mound.

Some of the mounds are pitted at or near the center, usually by one, and rarely by as many as three, small pits.

The mounds show no regularity of distribution and exhibit no trend. There is no evidence of stratification of any sort. In diameter they range from 4 to about 30 feet, but a few are larger.

[At this point Mr. Koons discussed and rejected eight hypotheses that were suggested in previous literature to account for the origin of the mounds. They were: (1) Differential settling of sediments, (2) segregation of mineral matter, or concretion on a large scale, (3) vertical seepage of water under hydrostatic pressure, (4) gas blowouts, (5) wind drifts, (6) anthills, (7) uprooted trees, (8) manmade. We are omitting his arguments on these hypotheses and other references that he made to the literature because we are primarily interested in his own observations and conclusions.---Ed.]

As a result of my own observations and investigations on the mounds I offer the following solution to the problem of their origin: The mounds were made by the pocket gopher, Geomys bursarius, to enable the builder to keep out of the water. Where there is surface or underdrainage the mounds are not made because they are not needed.

Since the pocket gopher is found on the Great Plains from the south side of the Saskatchewan to the Gulf of Mexico, it may be objected that the gopher does not build mounds on other areas that are sometimes flooded. That is true; but it is also true that both surface and underdrainage are vastly superior to that of the pimpled plains. The surface gradient of the latter is from 3 to 6 feet per mile, which to the eye is a flat surface. The soil, as before mentioned, is thin. The mean annual rainfall at Houston, Texas, is about 50 inches, about twice that of the Great Plains, and is not evenly distributed throughout the year. When the weather is wet it is apt to be very wet for a long period, and of course the dry periods may also be quite long. The underlying clay subsoil being impervious to water, as before explained, the thin stratum of topsoil soon becomes saturated and then flooded. So there is a considerable difference in this respect between the Great Plains east of the Rocky Mountains and the pimpled plains. One familiar with the Gulf coastal plain may urge the objection that not all of it, even in the pimpled plains area of Texas, is of the character described. While that is a fact, it is also true that unless it is of the type character there will be no pimples. For example, there are localities where the type soil borders on an area of heavy, "black waxy" land, Beaumont clay, which is from 6 to 10 feet or more in depth. The line between the two is often rather sharply defined. There will be mounds on the one and none on the other. Why? The deep soil has a certain amount of underdrainage and, being deeper, much more water is required to saturate and flood it. Furthermore, few gophers will be found there. The gopher's favorite food does not grow very well on black land. Being like putty when wet and very hard when dry, it is difficult to work.

I had in mind, in mentioning the foregoing type locality bordering on black land, the southern part of Colorado County, Texas, southwest of the village of Garwood. Going west from Garwood, we traverse about a mile of black land, very sticky and very deep. It is moundless. After crossing the Mustang Creek we are suddenly out of the black land and on the pimpled plain, which is more or less sprinkled with the typical mounds. A journey of about 14 miles southwest brings us to Sandy Creek, which flows through a timber belt about 2 miles wide at that point. We are still in the type locality as to soil, except that in places the creek has built up levees. Gophers are abundant on these higher lands as well as on the plain, but there are no mounds.

The manner of constructing a mound is this: the gopher opens his burrow to the surface and piles up a mound of loose earth 2 to 3 feet in diameter and often as much as 18 inches high. He does not use this mound as a residence unless the water forces him to do so. As the plains are usually pastures and there are many cattle on them, the cattle paw and horn down the newly made mounds and scatter the fresh earth. The gophers rebuild it as occasion demands, and it is as often torn down. If the cattle do not demolish it, the weather eventually will; but I have never known the cattle to fail. Before the advent of the cattle there were buffalo which served equally well.

The material that was piled up was not taken from immediately under the mound, but was carried from a distance through a runway excavated to one side. Usually but one runway was made in the early history of the mound. This was extended, and the excavated material pushed up into place on the dump until the carry become too long; then a branch was made from the first run and earth carried from that until the distance again became too great, whereupon another branch was started; and so on. In that way the depression, which was caused by the eventual settling of the excavated area, came to be on one side of the mound and not all around it. It was simply a borrow pit from which material was taken for the fill: i.e., the mound. In that way the mound came to be made round and the depression oblong. The gopher in his tunneling sometimes went well down to the clay stratum, and if there happened to be a sand lens there he used it, for it was easy digging. In that way it came about that he sometimes put a trifle more sand in his structure than one finds in the surrounding soil. Often he made his mound near some small, shallow lagoon or natural depression. The bulbs of certain lilies were to be had there, and they were harvested when the water evaporated, as it was sure to do in summer. Around such places also grow sedges, Cyperus esculentus, which furnish desirable tubers, if we may judge by the amount harvested and stored.

I have now accounted for the mounds and the depressions, but what about the small pit or pits often found near the center? They are secondary, and the gopher had nothing to do with them. We must remember that the gopher uses the mound as an island of refuge and does not generally live there. He prefers to locate his living quarters and storehouse elsewhere, ordinarily. After he has first built up his small mound, and each time thereafter when he works on it, he plugs the opening to the surface when work stops. And he plugs it so skillfully that three minutes after he has finished one may cut a section through it with a spade and find it very hard to determine which part had been hole and which undisturbed soil. But he has neighbors, and when after some years of labor a fair-sized mound has been built up, it often happens that some skunk, civet cat, or mink decides that the mound is a nice, high site for a residence and makes a burrow. The newcomer may, and often does, strike the gopher's tunnel, which is enlarged to meet the needs of the invader. But the new burrow, unlike the gopher's, is kept open, since the occupant goes out and in nightly. It is this opening, enlarged by dogs or other animals digging at the entrance or by cattle stepping on the earth just over it and caving it in, that causes the small pits.

To prove the gopher hypothesis, I noted the initiation of mounds and made observations on their progress for some years. Two were noted about three miles apart on trails that I frequently traveled, and their locations marked for identification. They were observed shortly after the initial mounds were thrown up and were kept under observation some years. After five years both had attained fair size and would readily have been classed by the casual observer as "sand mounds." One of them was abandoned when it was included in a rice field and partly plowed down and later flooded by irrigation. I have never observed a new mound in an old rice field, no matter how long it may have been abandoned for rice culture, provided the check levees had not been plowed down. The gophers appropriated the levees and, not needing mounds, did not build any.

If this solution of the origin of the mounds in question be the true one, then a geological problem has been solved only to raise a biological one. Dare we charge an animal with such a radical change of life habits to meet special environmental needs? Does that noted hydraulic engineer, the beaver, neglect to build a dam where there is plenty of water? How did he become a dam builder in the first place? May not another rodent become an engineer?

I have been over a good deal of the Great Plains region from the Dakotas to the Gulf; the pocket gopher is found more or less in the entire territory, but nowhere except on the pimpled plains have I noted any such work as I have herein attributed to it.

In well-drained regions where gophers are present, they are evidenced by many small earth heaps, which are waste dumps for material excavated in making runways, but these are not enlarged and are merely byproducts in the construction of tunnels; whereas on the pimpled plains it would seem that the mound is more than that and that tunneling is sometimes carried on for the purpose of borrowing material from one place for use in another.

Obviously, we must call in expert evidence in the case and, since we have chased our geological constructor into a biological hole, we must consult the biologist.

The biologist says yes in answer to the foregoing questions and presents some evidence in support. The ground squirrel of the Columbia plateau occupies a region of abundant food, but water fails in midsummer. So he simply digs deep, shuts himself up, and goes to sleep until the following spring, according to Shaw. This habit is a local one. Allee, of the University of Chicago, cites the case of the blue heron, which in the forest regions of the East nests in tall trees, but in the treeless wastes of the Great Basin builds on the ground a structure of reeds and mud 4 or 5 feet high in order to place the nest above the water---an entire change of habit. Osgood, of the Field Museum [now the Chicago Natural History Museum], answered the questions in the affirmative and cited the case of the fire ant. On the flood plain of the Amazon thousands of these ants assemble into a compact ball that floats until the flood subsides. The outer individuals drown, but the queen in the center and the inner ones survive. Thus many animals adapt themselves to unusual environments.

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PIMPLED PLAINS OF EASTERN OKLAHOMA

Knechtel, Maxwell M.; *Geological Society of America, Bulletin,* 63:689-700, 1952.

Introduction. Low-relief topography, or microrelief, formed of innumerable closely spaced small hummocks or mounds, is a conspicuous feature of many large tracts of nearly level to gently sloping land in some states west of the Mississippi River, as well as in some other parts of the world. Figure 1, based on a map constructed by Price, shows a number of physiographic provinces wherein such mounds are reported to occur in the United States.

Such mounds are known as "prairie mounds", "hog-wallows" (California), "Mima mounds" (Washington), and "puffs" (Australia). The origin of the mound-studded surface, which in this country are commonly called "pimpled plains" has been a subject of much discussion for more than 100 years and has been attributed to various natural processes. Interpretations of their genesis set forth in the references cited involve such concepts as erosion by networks of rivulets; erosion by wind; "mud-volcano" phenomena; hydrostatic pressure of ground water; "concretionary action"; frozen-ground phenomena; construction by ants; termites; rodents; or aborigines.

The diversity of interpretations suggests that such natural-mound systems may have originated in various ways. Eventual agreement may nevertheless be attainable with reference to the origin of individual systems, or groups of systems, particularly where one and the same example of mound relief has been ascribed to different and seemingly incongruous processes. For instance, mound systems near Puget Sound, Washington, were attributed by Newcomb and Pewe to melting of ice wedges in networks of vertical fissures; Dalquest and Scheffer believed them to be the work of pocket gophers. It is scarcely possible that both concepts would survive a thorough-going analysis of the controversial phenomena involved. In other cases, interpretations based on dissimilar processes may prove to be essentially compatible---a contingency implicit in the suggestions of Newcomb and Pewe, but also with the soil-erosion hypothesis of LeConte.

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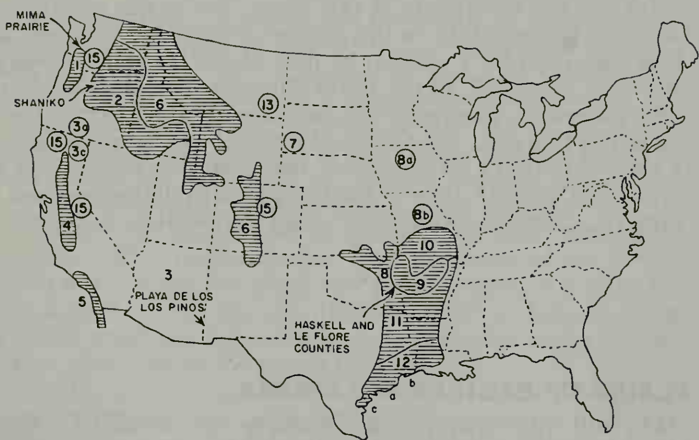


Map of the United States indicating the geomorphic provinces where pimpled plains occur: (1) Puget trough; (2) Columbia plateaus; (3) scattered localities in the Basin-and-range province; (4) California trough; (5) Pacific Border terraces; (6) southern Rocky Mountains; (7, 13) river terraces in the Great Plains; (8) Central Lowlands; (9, 10) Ozark-Ouachita region; and (11, 12) the Gulf Coastal Plain.

The Pimpled Plains of Eastern Oklahoma. Pimpled plains are extensively developed in the Arkansas River valley and the Ouachita Mountains. They appear on airphotos, as multitudinous small, rather uniformly spaced, bright or dark patches of ground, most of which are subcircular. The center of each patch coincides approximately with the apex of a mound 2 to 4 feet high. The distance from center to center, generally between 50 and 100 feet, is rather uniform for any one locality, and commonly the margins of the patches are separated by approximately half that distance. Locally, however, the patches are much broader than the interspaces and are of various polygonal shapes.

Many road cuts expose the materials of the mounds and the surfaces on which they rest. A typical mound consists of loess-like material that is partly clay and contains small pellets of limonite, as well as a few subangular fragments of sandstone lithologically like that of local bedrock units of Pennsylvanian age. Most of the rock fragments are 2 inches or less in greatest dimension and are distributed at random. The loesslike material rests with a sharp contact on a flat, nearly level floor that commonly consists of heavy clay, or claypan, lighter in color than the material composing the mound. In places the floor material approaches the consistency of hardpan. The origin of the materials of the mounds and the deposits immediately underlying them calls for more study and is not dealt with here. Additional information concerning them, including a number of mechanical analyses and descriptions of soil profiles, is given by Knobel, Boatright, and Boatright in describing the Conway very fine sandy loam and the Le Flore silt loam, the only mound-forming soil materials mentioned among the various units shown on their map.

The writer has commented as follows upon the bedrock associated with the pimpled plains of eastern Oklahoma, their range of altitude and the time of their origin:

"Many of the mounds occur within areas of bedrock exposure but their areal distribution bears no direct relation to that of any of the different bedrock units. Some of them occur also on ancient gravel terraces and others on the higher parts of the Recent alluvial plains along the larger streams.... Those in Le Flore County occur at altitudes ranging through several hundred feet though they are present only on nearly level surfaces and gentle slopes. For example, on the gently sloping upper surface of a prominent hogback a mile south of Bokoshe mounds occur approximately 400 feet above the Arkansas River level; within half a mile of these and 300 feet lower are others on the higher parts of the alluvial plain along Buck Creek.

"Clearly, the mounds on all such plains were formed since the region attained essentially its present stage of geomorphic development and can therefore scarcely be older than late Pleistocene."

....

Summary. The pimpled plains of eastern Oklahoma are evidently assignable to a category of surficial phenomena, sometimes called Polygonboden, which in some parts of the world includes features attributable to permafrost. The intermound furrow networks visible on airphotos of localities in eastern Oklahoma are comparable in pattern and coarseness of texture to the great polygonal networks of ice-filled fissures that commonly form in perennially frozen ground, but the eastern Oklahoma patterns bear an equally close resemblance to those of fissure networks caused elsewhere by desiccation and are comparable in some respects to intermound furrow patterns that appear to have originated, in some other parts of the United States, as a consequence of columnar jointing in the bedrock under the furrows. The data at hand offer little, if any, support to the possibility that the Oklahoma patterns are associated in origin with jointing in bedrock; they do, however, appear to establish desiccation as a possible agency in the origin of these patterns.

The transformation from systems of prismatic blocks enclosed by fissures to systems of mounds comparable to those of the pimpled plains may, apparently, be accomplished by one or more of three processes: (1) expansion of material that accumulates in the fissures; (2) subsidence of the ground along the fissures; and/or (3) erosion by rivulets which may form along the fissures. Assuming that the intermound furrow systems of eastern Oklahoma are related in origin to systems of fissure polygons due to desiccation, the mound relief there may be attributable to widening of grooves that have resulted from subsidence of the ground along the fissures of the polygonal networks.

Because the mound systems are present at various altitudes and occur locally on alluvial surfaces close to the present stream levels, the mound relief of eastern Oklahoma is probably not older than late Pleistocene.

• Other Mounds of the Mima Type

NATURAL MOUNDS

Campbell, Marius R.; *Journal of Geology,* 14:708-717, 1906.

Recently the subject of natural mounds has attracted unusual attention, and a number of persons have described their occurrence and attempted an explanation of their origin.

What are here designated as natural mounds are low, broad mounds, varying from 10 to 140 feet in diameter, and from a few inches to 5 or 6 feet in height. They are wonderfully symmetrical, both in plan and in elevation, and generally they closely approach a circle in outline, but in places they are slightly elliptical, and where such is the case the major axes of all mounds in the vicinity have a common direction.

Figure 1 [omitted] is reproduced from a photograph of a group of slightly elliptical mounds occurring on the old sea terrace back of San Diego, Cal., at an altitude of about 380 feet. Frequently the mounds are closely bunched, as shown in the figure, but they occur also singly and in small groups.

According to the descriptions of various writers, the composition of the mounds vary considerably, probably being affected by the character of the local material. As the writer has observed them in California and in Arkansas, they are made up of clay, or clay with a slight admixture of gravel, depending upon the character of the underlying subsoil; but in

Texas and Louisiana, according to report, they are made up largely of sand, and in Missouri of chert fragments from the Carboniferous limestones.

So far as the writer has observed or has been able to obtain references to them, mounds of a similar character occur in abundance in Louisiana, Texas, Arkansas, Missouri, Kansas, Indian Territory, Arizona, California, Oregon, Washington, Mexico, and Argentine Republic. Generally they are reported as occurring on low, flat lands; but Turner has described and figured similar topographic features covering low hills on the east side of the San Joaquin valley in California, and recently Hill has noted their occurrence on the high plateau of Mexico, nearly 7,000 feet a above sea-level.

To account for the origin of these mounds various hypotheses have been advanced, but in most cases they are speculative only and have little or no foundation in fact, or they are based upon limited observations and fit only the conditions prevailing in one locality.

It is altogether probable that the mounds which have been noted in various parts of the country are not exactly similar and have not had a common origin, but this cannot be proven until they have been more carefully studied, and studied by one person who can compare the mounds in different localities and judge whether or not they are all due to the same cause.

The principal hypotheses may be summed up as follows:

1. Human agency.
2. Animal burrows, such as ground squirrels, gophers, and prairie dogs.
3. Ant hills.
4. Water erosion.
5. Chemical solution.
6. Wind action.
7. Physical or chemical segregation.
8. Glacial action.
9. Uprooted trees.
10. Spring and gas vents.
11. Fish nests.

From the widespread distribution of the mounds it is evident that, if they have a common mode of origin, this mode of origin must be such that it will fit a variety of climatic, geologic, and topographic conditions. On this basis it is easy to rule out as general causes a number of the above hypotheses without discussing them in detail. For instance, on the sea terrace back of San Diego, Cal., where the mounds are beautifully developed, or on the prairies south of Tacoma, Wash., the hypothesis which attributes their origin to fish nests might be applicable, for those localities have in recent geologic time been under water; but certainly it would not be applicable to the mounds which occur in other parts of the country. The spring and gas-vent hypothesis might fit the conditions prevailing in Louisiana or Texas, but mounds are just as abundant in areas in which neither of these agencies has acted. It is evident, therefore, that this hypothesis cannot have a broad application, and consequently may be eliminated. The mounds resulting from uprooted trees have been cited as analogous to the mound in question, but such a hypothesis would never have been advocated by a person thoroughly familiar with the mounds in their best development. We should be obliged to presuppose the existence of giant sequoias over the low arid region of southern California and Arizona, and over the moist humid prairie of Texas and Louisiana. Manifestly this is absurd and may be disregarded. Glacial action might be appealed to in explanation of the mounds of Washington, but evidently is not applicable to the great number of mounds found in southern California and the Mississippi valley.

By this method of elimination the number of hypotheses has been reduced to seven, but these seven have a far greater degree of probability, and hence will have to be considered in detail before they are discarded.

The hypothesis of physical or chemical segregation was proposed by Branner, but absolutely no evidence was advanced in support of it. He says:

> One other theory has been in my own mind for several years, but it is almost entirely without observations to support it, and it is perhaps too vague to be clearly expressed. The idea is that in solutions of certain kinds, long exposed to weathering agencies, chemical reactions possibly take place around centers that result in the transfer of minerals in solution, and the precipitation in nuclei that are now represented by the position of the mounds, while the withdrawal of these minerals from the intervening areas causes the depression around the mounds.

Purdue found himself at a loss to account for similar mounds in the Arkansas valley, and took refuge behind Branner's vague hypothesis, but likewise failed to produce any direct evidence to substantiate it. Manifestly in the present stage of our knowledge this hypothesis has no support, and, until such evidence is presented, it need not be considered.

The question of wind action is not so easily disposed of; doubtless many mounds have been produced by such action, and probably many others of an entirely different origin have been modified by the action of the wind. Nevertheless the great number of natural mounds are far too symmetrical in profile and in plan to have been formed by wind-blown material. Usually it is supposed that dunes may be recognized by their unsymmetrical shape, while the mounds are noted for their symmetry; consequently the only resort was to suppose that they are the result of wind acting in various directions. It is possible to conceive that fine, dry material may be heaped up by winds blowing first from one direction and then from another, producing a measure of symmetry; but when one considers the vast territory over which these mounds occur both in dry and in humid climates, it is evident that such special conditions could not have prevailed, and thus we are forced to drop this hypothesis.

We are thus reduced to five hypotheses, but, since No. 2 and No. 3 are essentially the same as far as the mode of origin is concerned, we may say that the choice lies among four hypotheses: animal burrows, erosion, solution, and human construction. These hypotheses involve two fundamentally different processes, construction and destruction, and it seems possible to determine definitely which of these processes has taken place.

Many writers have argued that the mounds are the result of erosion, but in most cases they have realized that under normal conditions such forms could not have been produced, and hence they have been compelled to assume unusual conditions, but rarely have they stated clearly what were the unusual conditions.

Practically all of the mounds observed by the writer are located on smooth surfaces, and generally on level plains. Where the mounds are close together they may touch and the slope of one merge into the slope of its neighbor, forming a concave surface; but where mounds are scattering, the space between is always flat, being in reality a part of the surface of the plain. In arguing for erosion this fact has generally been neglected, or it has been assumed that the inter-mound surface is not a plain. Thus Barnes, in describing the mounds at San Diego, illustrated in Fig. 1, gives a profile showing the mounds separated by a concave surface. The mounds in this locality were examined very carefully by the writer, and in every case where they were not in actual contact the space between them is flat and not concave, as represented in Barnes's profile. It therefore seems that much of the misapprehension regarding the origin of the mounds is due to imperfect observations and assumptions that are not warranted.

When one considers the way in which surfaces are eroded, it is manifestly impossible to produce a flat surface unless that surface is at base-level, or the process of erosion is controlled by a barrier or by underlying hard rocks. If the surface was at base-level, and the plain a base-level plain, it would mean that the cycle of erosion was practically complete, and in that event the mounds would be reduced as well as other portions of the surface, unless in some abnormal way the mounds were protected from the action of erosion. In order to protect mounds with such symmetrical, spherical surfaces, one would have to suppose a circular segregation of hard material, which certainly would call for unusual conditions. It is true that analogous topographic forms have been produced by such conditions as shown by Gilbert and Gulliver as existing in the Tepee buttes of eastern Colorado. In that case the symmetrical form is due to the protective influence of a calcareous core, which is supposed to have been of fossil origin. In the case of the mounds, however, no one has reported any protective material, except in a few cases where gravel has been noted in more abundance in the mounds than elsewhere. Gravel might answer as a protective cap, but such accumulations are not universal, for in hundreds of cases observed by the writer in Arkansas no gravel is to be found, either in the mounds or in the soil in the vicinity.

Although the evidence given above seems to show conclusively that mounds are not the result of erosion nor of solution, the writer is able to produce more positive evidence that will appeal to everyone, whether he is familiar with the processes of erosion or not.

During the month of April, 1906, the writer had an opportunity to observe thousands of mounds in the valley of the Arkansas between Little Rock and Fort Smith. They are abundant everywhere on the lowland above the flood-plain of the river, and while many of these have been cut through in grading for railways and highways, it is difficult to find a fresh section in which the structure and composition of the mounds are well shown. At last a mound was found on the Paris road about 3 miles northwest of Dardanelle, Ark., which recently had been dissected by a small stream flowing by the roadside, and a fresh section was exposed. Figure 2 is a photograph of the mound as it appeared in the section. (Figs. omitted.)

The plain upon which the mound appears is flat and composed of a deep subsoil of yellowish-white clay, formed by the decomposition of Carboniferous shale. The clay is homogeneous and structureless, except that it shows a tendency to vertical cleavage in much the same way that such cleavage is shown in loess. At the surface and for a depth of from 6 to 12 inches the clay has been opened up and reworked by grass and tree roots, and a small amount of carbonaceous matter has been incorporated in the clay, giving it a slightly darker color than it had originally.

The mound which had been dissected was approximately circular before it had been cut away, with a diameter of about 60 feet and a height of 4 feet. The diagram in Fig. 3, which is drawn to scale, gives a good idea of the size and shape of the mound as it was seen in profile. The underlying clay subsoil is shown at A, the ordinary soil at B, and the line separating them was visible as an approximately straight line entirely across the mound. The material composing the mound is essentially like the soil on either side; that is, it is reworked clay, probably derived from the underlying subsoil.

The above section shows clearly that the body of the mound is composed of material exactly like the surrounding soil, which is derived from the underlying clay; and consequently it is a fair inference to suppose that the mound material came from the same source; but, whether this be true or not, the arrangement of the materials proves conclusively that the mound was built, and is not a residual left by erosion or solution. Since in this case the evidence is positive that this mound is not the result of erosion, and also since, in the opinion of the writer, the general evidence against such a mode of origin, at least for the mounds of Arkansas and California, is conclusive, the two hypotheses of erosion and solution, as applied to the great multitude of mounds in the southern part of the United States, may be dropped.

The case is now narrowed down to two modes of origin---namely, human construction and the action of burrowing animals.

Although much has been written regarding the human origin of these mounds, the arguments against it are so strong that it may be classed with the other hypotheses which have been disregarded. It is doubtless true that similar mounds have been erected by prehistoric man, but it is absurd to suppose that the countless millions of mounds which exist in the regions noted above have been the result of human activity.

This disposes of all the hypotheses, except that which ascribes their origin to the action of burrowing animals; but whether the mounds are due to ants or to small rodents, the writer is unable to say. Personally he inclines to the ant-hill hypothesis, but there is little or no evidence to determine which is correct. No burrows or chambers of any kind have been discovered in the mounds, and in the case observed by the writer no differences were observed in the character of the underlying clay, which would indicate the former presence of chambers, even though they are now filled. No excavations were noted in the neighborhood which could have supplied outside material for the mound, and consequently it is assumed that this material must have come from a long distance under ground, and the minute channels through which it was transported have been closed by material falling in from above or carried in by water in suspension.

The constructional feature of the mound is considered to have been proved in this particular case, but it still remains to account for the agent that performed the work. It is believed, however, that careful work in trenching some of the best preserved examples of these mounds would furnish some evidence to determine this part of the question, but such investigations have never been undertaken, at least not on an extensive scale.

THE PARRAMORE ISLAND MOUNDS OF VIRGINIA

Cross, Clark I.; *Geographical Review,* 54:502-515, 1964.

The Parramore Island Mounds. Parramore Island is one of the very low offshore islands that fringe the Delmarva section of the Eastern Seaboard. It consists of a relatively elevated complex head of sand dunes and wave-built features in the north with two more or less parallel prongs of elevations (a relative term) extending southwestward. Between these "heights" the flatness of a shallow pond and marsh is broken by mounds. To the south marshy ground, barely above sea level, spreads out westward into mud flats that give the island its maximum width, 11,800 feet, near the midpoint. The island is 8.4 miles long and terminates in the southwest in a long finger of sand. Elevations of more than thirty feet but less than forty are frequent in the north. Little Beach, an isolated feature with a moundlike structure near the center of the island, rises to more than forty feet.

Parramore Beach slopes gently seaward, and shallow water extends for a considerable distance offshore. Especially in the south the beach shows evidence of advanced wave and current erosion. When the United States Geological Survey's Wachapreague Quadrangle, 1:24,000, with topography by planetable surveys 1957, is matched with the adjoining Little Machipongo Inlet Quadrangle, based on 1942 aerial photography, erosion of about four hundred feet seems apparent. Rough comparison between the Geological Survey's topographic maps of 1931 and 1961 indicates a regression of 1200 to 1500 feet at the one point that could be reasonably established on both maps. The island now presents a meager dune line to wave attack over much of its extent. It appears, like the low coastal islands nearby, to have suffered from storm-induced inundation, with resulting widespread horizontal sand movement inland. Lagoonal clay, containing stubs of vegetative growth, now outcrops in the neritic zone facing the Atlantic, proof of substantial inland migration of the beach.

The mounds of Parramore Island have major features in common, but no general description will suffice. Variety, however, seems to be primarily in size. Aerial photographs have established that the mounds are concentrated in the central five-mile section of the island, where they occur from the beach inland for not more than three-quarters of a mile and occupy about 25 percent to about 75 percent of the area. From the ground they are seen to occupy closer to 25 percent, since vegetation exaggerates the area on the aerial photographs.

The pattern of occurrence appears to be oriented to the pond and marsh inland and to be at variance with the present beachline. The overall pattern suggests an original orientation to a former beachline now destroyed by migration of the beach. There is a definite arrangement of largest features on the lagoon side and more numerous, but much smaller, mounds adjacent to, and apparently extending into, the surf.

Aerial photographs show that the mounds have a well-defined circular shape except where two or more have coalesced. With few exceptions they have a white, sandy, more or less barren center, often depressed but usually appearing as the high point. This center may be crudely outlined by trees or shrubs that considerably overtop the adjacent vegetation. Also, especially in the larger mounds, there is a concentric-circle arrangement, marked by tonal and textural differences on the photographs. Stereoscopic examination indicates very slight differences in elevation between the rings. Such differences are particularly evident where a mound has been subjected to inundation. The lower ring segments definitely show the effect of the sweep of running water. Field checking revealed that some mounds have a very narrow ring of small shrubs, which exhibits no observable difference in relief from the inner circle or from the area outside. On the Wachapreague Quadrangle many mounds in the area under discussion rise to the ten-foot contour, but none reach fifteen feet. Examination of a number of mounds in the field has substantiated this low range in relative relief, though no height measurements were taken.

A soil auger reached water at four feet in the center of a typical mound; sixty feet outward, water was about six inches below the surface. These sites were beyond the normal influence of the tide. Only sand was encountered in this series of test borings, though a few shell fragments were picked up at four feet, the limit of the auger in saturated sand.

The largest single mounds are about five hundred feet in diameter, though an aggregation of three is about twelve hundred feet at its greatest extent. From this maximum, diameters range downward to a few feet. Little Beach, which may be related genetically to the mounds, is about a half a mile long. Unfortunately, it was not possible to examine this isolated feature; if it is a mound, it is indeed extraordinary.

A number of mounds are sharply set off from adjacent lower land, or from other mounds, by broken bodies of water, which may also follow a rough concentric-circle pattern. There is a suggestion of subsidence or compaction that may have been accompanied by a system of small faults. The only pond traversed was about thirty inches deep. It had a firm bottom under an inch or two of muck, indication of a rather recent development.

It seems pertinent that mounds similar to those on Parramore Island are also found a few miles north of Cape Hatteras under like environmental circumstances. (pp. 506-511)

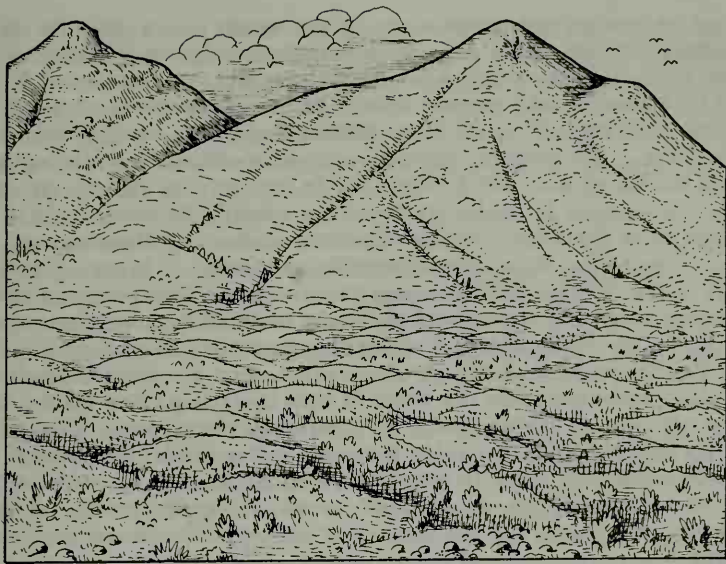
THE HILLOCKS OR MOUND-FORMATIONS OF SAN DIEGO, CALIFORNIA

Barnes, G. W.; *American Naturalist,* 13:565-571, 1879.

The surface geology of many sections of the Pacific slope is characterized by innumerable hillocks or small mound-like formations, either sparsely distributed or occupying quite densely areas of considerable extent. These formations, variable in size and structure in accordance with local conditions concerned in their production, exist in many parts of California and on the coast north of it, and are especially abundant and well defined in Southern California.

The following conclusions are based upon observations of them chiefly in the vicinity of San Diego:

In their most common type the mounds may be described as rounded eminences, or knolls, rising from one to four feet above the surrounding surface or the depressions between them, and ranging from ten to fifty feet in diameter. They are generally nearly circular and distinct,



Sketch of the San Diego mounds.

but are, in some instances, confluent or elongated. They are separated by wide and irregular areas or by narrow intervening depressions, the latter containing, in stony places, accumulations of cobblestones. They are confined to no geological structure or quality of soil, and are found on sloping lands, on the higher mesas and lower levels.

Any attempt at an explanation of their origin and the mode of their formation must be based upon the assumption that they are modern modifications of the earth's surface and are due to natural agencies; and evidences abound on every hand that the causes concerned in their production are still active in the formation of new and in the maintenance of the old ones; and hence in this vicinity they may be seen in all the stages of their growth, from small rudimentary cones to the fully developed knolls.

Several agencies acting successively or simultaneously have been concerned in these formations. Each mound marks a spot where formerly grew a shrub or cluster of shrubbery, which served to fix its location and which exercised an important influence in the successive stages of its development. The shrubs which seem to have been chiefly instrumental in these results are the Rhus laurina, the Simmondsia californica and the Isomeris arborea; the former undoubtedly having been principally instrumental in the creation of the more recent as well, perhaps, as the most ancient ones in this vicinity. These plants are fitted for the office they perform by the nature of their growth, which is in compact groups or clusters, with many stems starting from the earth near together, the branches and foliage forming a dense mass resting closely upon the ground, and with beds of massive roots; while the distribution of the groups is strikingly similar to that of the mounds in their typical form and arrangement.

Dust set in motion and borne along by the winds is arrested by the shrub and, together with its fallen leaves, accumulate within and around it, and, as is seen in thousands of instances in this vicinity, an elevation of many inches is produced in this manner alone, in many cases covering the lower branches, and in case of the Simmondsia especially, nearly enveloping the whole plant. The gopher, subsisting upon roots and preferring for its operations the loose soil about them, is, in exceptional cases, an adjunct of the wind in heaping up material about the plant. Of the thousands of these clusters of shrubbery which have come under my observation, a very large proportion show unquestionable evidences of these agencies in elevations more or less marked about them, the surface portions of them at least being generally composed of a light loam of dust and decaying leaves. While the loose earth of which the deposit is composed is protected by the branches and foliage of the plant, the more solid earth beneath is also protected from the wash of rain by its massive roots, while all around erosion goes slowly on, facilitated by the peculiar susceptibility of the soil to wash, a quality familiar to the casual observer.

Instances doubtless exist in which the mounds have been more or less fully developed without the aid of those forces which elevate the earth above its original level, but the shrub and the rain wash have been constant factors.

In the course of time the plant dies---is smothered by the drift which nearly covers it, or is destroyed by the fires which annually sweep over extensive tracts of country. Thus deprived of its protection, the winds in turn, and the rains which fall upon it wear down the top of the loose deposit, and to some extent widen its base. While this is going on the surrounding earth, or interspaces, are being continually lowered by the action of water. The wash always being greater at the base than at its summit, its tendency is to perpetually maintain or increase the prominences.

The presence of beds of roots, well preserved as well as in the different stages of decay, within many of the more modern fully formed structures, upon the surfaces of which it is known from observation that no vegetation has grown for many years, is strongly suggestive of a relation between them of cause and effect. In the oldest ones all traces of the original roots have long since disappeared.

A well known effect of timber and shrubbery everywhere is to impede the drainage of water which falls among it, and so these groups of plants serve to diffuse the currents---which would otherwise be concentrated into gulleys---whose meanderings may be traced in all directions among the mounds, thus conducing to the symmetry of their form and arrangement.

The influence of wash in these results is the most marked on moderate slopes, though sometimes seen on quite steep ones and on comparatively level places, but if upon levels, the latter are so situated as to receive the gathered waters from neighboring slopes. In a situation of this character near at hand the water, after traversing a surface of considerable extent among fully developed mounds, converges into a gully and a surplus flows off to the sea.

Evidences of the potent agency of the winds in results of greater magnitude than these need not be adduced. We need only refer to the sand dunes of Scotland and the shores of the American lakes. It is a matter of common observation here that during the prevalence of one of the "sand storms" of a few hours duration, which visits us once or twice annually, several inches of dust is deposited in places suited for its lodgment, yet the work here ascribed to the wind is mainly carried on by prevailing breezes from the ocean. In situations exposed to concentrated wind currents or their sweep over loose earth or traveled roads, the cones are the most sharply defined, showing that in such circumstances the work goes more rapidly on.

As a minor and exceptional agency I may mention that in the later stages of the formations large excavations are sometimes made by the burrowing of animals, which are afterwards filled with debris, while the matter thus brought to the surface remains to augment the elevation. Hills formed in open spaces by animals do not constitute nuclei for mound-formation; composed as they are of a substratum in which no grass or other vegetable takes root and protects them from dissolution, they crumble away leaving but a bare and level spot.

To recapitulate; in the incipiency of the formation the elevation is composed entirely of a deposit heaped often abruptly about the plant, but pretty soon the influence of erosion is manifest in the subsidence of the base.

Next the plant perishes, and, deprived of its protection, the summit is reduced and the base widened as it is lowered till finally a remnant of the deposit has become so assimilated and compact as to constitute a more permanent summit or it has totally disappeared, leaving the summit at or below its original base.

Reasons for the appearance of these phenomena so exclusively on the Pacific slope and the arid plains of the West, are that the combination of causes resulting in their production there are seldom found elsewhere, to wit: the growth of shrubbery in compact clusters suitably distributed, with low and dense foliage, the presence of burrowing animals, the great susceptibility of the soil to wash and, I may add, the steady prevalence of winds from a single quarter, and the absence of forests which would otherwise influence winds and surface drainage.

Note.---Since the foregoing was written it has been suggested to me by a gentleman whose opinions have much weight, that the wind exercises an influence in excavating the earth around and between the shrubs of which the mounds are a sequence. While there is no evidence of such action in this vicinity, the explanation doubtless holds good in sections of the country in which a loose or sandy soil prevails. The mounds of this vicinity are found almost exclusively on the upland which, when dry, is quite firm and is not perceptibly acted on by the wind, yet sweeping over a considerable surface it gathers enough of soil, in time, to make large deposits about the shrubbery. Sandy soil is exceptional, and is found usually only in the valleys which are comparatively small in extent. In such situations the suitable vegetation does not so commonly exist, there is more protection from the winds, and the rains, generally light, are so readily absorbed that no surface-wash takes place.

It has also been suggested that pebbles and rocks form nuclei around which accumulations of soil remain and conduce to the production of the hillocks. It must be conceded that this is possible, and in certain qualities of soil and with certain kinds of rock quite probable. In this vicinity, however, in no stage of the process are the stones imbedded in the mounds found to be bare, or protruding, or to hinder in any manner the action of water on the soil; on the contrary, in a soil so easily disintegrated by water, the stones hold their positions by an uncertain tenure, and are so readily rolled from their cavities, as the earth is washed away from them, as to rather facilitate than retard the process of erosion.

SAN JOAQUIN VALLEY HOG WALLOWS

Whitney, Dudley J.; *Scientific Monthly*, 66:356-357, 1948.

About twenty-five years ago a member of the staff of the Citrus Experiment Station, Riverside, California, who was investigating soil problems in Tulare County, wrote an article for the California Cultivator on the origin of hog wallows. In this he stated that the finest specimens of hog wallows in the state were in the Lindcove district, close to the foothills and about 13 miles east of Visalia. His idea was that the mounds were formed by clumps of vegetation holding wind-blown soil.

Because I was then, as now, living upon and working hog-wallow land and also writing occasionally for the Cultivator, I was much interested in this. A plant pathologist of the county, with whom I discussed the matter, did not agree with the above theory and thought that the mounds were formed by clumps of water plants catching and holding sediment washed down from the hills.

After this second theory was published in the Cultivator, a flood of letters and suggestions on the origin of the mounds came in, including all that were given in the article on Mima Mounds in The Scientific Monthly (October 1947) except that of their building by pocket gophers. If the mounds in the San Joaquin Valley were built by any mammals, it was evidently by ground squirrels, but even that seems more than improbable.

Neither the gophers nor the squirrels needed to construct mounds in hog-wallow land in order to find a place to live. Although there is much hardpan in hog-wallow land, it varies in depth, thickness, and quality, and there is always enough space above the hardpan for the animals to burrow in, so that the construction of mounds was unnecessary. Also, in former days, before systematic poisoning of ground squirrels was done, they gave no sign of building large mounds like these on flat or gently rolling land. Mounds where they do work lose their smoothness, instead of remaining round and smooth. The influence of pocket gophers on the shape of the mounds seems insignificant.

In fact, all theories for the origin of these mounds seem to have more faults than merits. None give satisfaction to more than a few individuals. The most satisfactory way around here to explain them seems to be that they are composed of material left over when Paul Bunyan built the Sierras long ago. That theory is more pleasing than accurate.

Nevertheless, there is a good deal of data by which we can approach the problem of the origin of these mounds. The local term, "hog wallows," is of course very misleading. In thinking of wallows one visualizes circular depressions in flat or gently rolling country, such as might be formed by animals wallowing in mudholes and causing them to increase in area and depth. Hog-wallow land is the reverse of this: it is composed of mounds, not depressions, sprinkled over fairly flat or gently rolling areas.

These hog-wallow lands have certain marked characteristics that should be helpful in studying the manner of their formation. The material composing them is reddish, indicating a fairly high iron content. This is true not only of the San Joaquin Valley hog wallows, but of hog-wallow land in other parts of California.

Next, and this is a very significant feature of the case, the soil neither expands on getting wet nor shrinks and cracks in drying, but retains its size and shape at all times. When dry in its wild state, it cements together like a brick. Incidentally, this causes the growth of vegetation on the mounds to be scanty, though grass may be abundant in the flat areas around the mounds. Raw hog-wallow land during the dry, hot summers thus appears barren and infertile. Actually, it is rich in mineral plant food and makes some of the finest fruit and grape country in the state when it is leveled, subsoiled, and irrigated. After a few years of irrigation and tillage, it often tends to become dark rather than red, and a stranger would not dream that it had once been covered with hog wallows.

The fact that the soil in these mounds does not shrink and crack on drying is one of the reasons that the mounds retain their shape. If they cracked on drying, the slopes would evidently gradually flatten and the mounds would disappear. Also, the fact that the material sticks together when wet and cements together when dry indicates that it was not brought into place by wind.

Incidentally, in much of this hog-wallow land, there are depressions here and there where ponds of considerable size form in wet seasons and endure, perhaps, for several months; the soil on their beds is a kind of adobe that cracks as it dries.

These depressions and the fact that hog-wallow land is often quite rolling near the hills suggest that the hog wallows did not form on a flattened lake bed, for then there would be no appreciable depressions in the land and it would not be rolling.

It is also worth noting that usually the more rolling the land, the larger the mounds. As the surface tends to flatten, the mounds tend to become smaller and lower. The fact that many hog wallows are on rolling land therefore suggests that it was not made by normal sedimentation, but that the material forming it was laid down in a hurry. Incidentally, too, water could never stand between mounds on rolling land as it is seen to stand between the mounds in San Diego County (p. 291, October SM). (The lower picture on page 287 shows how hog wallows often exist on rolling land where water drains off quickly.)

Another significant feature is the composition of the material of hog-wallow lands. In typical hog-wallow land here in Tulare County and the San Joaquin Valley generally, the soil proper is composed of very fine material in which there are considerable sand, fine gravel, and even pebbles up to a good throwing size.

These pebbles seem to have had a varied origin in both composition and in movement from their original position. Some are well rounded by water, and some are uneven---friction has done little more than smooth the edges and corners.

Although the higher hills in this locality are mainly granite, many of the hills at the edge of the valley are of gabbro and related femic material, and the hog-wallow land seems to have been derived more from them than from the granite. The iron in it indicates this, also the high calcium and magnesium content. Many of the rough pebbles in the hog-wallow land seem to be made of magnesite, which has been mined in places in these hills. The gravel and pebbles occur both in the mounds and the land underlying the mounds. In the nature of the case, if the mounds had been made by wind-borne material, the pebbles would not be there.

The rounded and partly rounded pebbles, the sand, and fine gravel indicate deposit by water in some way or another; but the fact that these are well mixed with fine clay indicates that the material was brought into place as a whole, evidently at about the time that the land surfaces in these places took form. Patches of hog wallow on rolling land (p. 291, October SM) surely could hardly have been laid down gradually, on lake bottom.

The failure of every other theory for their origin, with the above-mentioned conditions, has therefore suggested to me the possibility that the mounds were formed by the uneven settling of considerable thicknesses of soft, unconsolidated material that was laid down hurriedly, but this provides no explanation of why mounds should form, or why they should take such well-rounded shapes if they did form in such settling. To the extent that this hypothesis has merit, it does little more than provide another unsatisfactory hypothesis for their origin.

As to their being built by pocket gophers, as has been suggested for the Mima Mounds of the Puget Sound country, this seems out of the question, for the hog-wallow mounds at least. Gophers live in such land, but give no sign of helping to make the mounds.

Mounds seem to exist only on certain kinds of land laid down under unusual conditions. From the pictures of the Mima Mounds in Washington, it seems unbelievable that gophers ever built mounds containing such large stones, or that they could do so if they tried. It seems probable that the origin of the mounds will always remain a mystery, though the cobbles of the Mima Mounds of Washington and of the hog-wallow lands of California indicate that rapidly moving water had much to do with the origin of both. The mounds of California retain their shape because the soil does not crack when dry, but cements firmly together. The soil of the Washington mounds may or may not cement together, but the size and number of the stones in them would nevertheless help to retain their shape.

NATURAL MOUNDS IN CAPE COLONY

Schwartz, Ernest H. L.; *Geographical Journal,* 27:67-69, 1906.

The interesting discussion that has been going on in the columns of Science with reference to the subject of Natural Mounds in the United States, which was noted in the Monthly Record for August, has prompted me to write the following note on a similar occurrence in the coastal districts of Cape Colony. It has long been a subject of interest to me, and I have several times tried to come to some conclusion in regard to their origin, but, like Mr. Veatch, have not been able to satisfy myself that any explanation brings us nearer the solution of the problem. The theory that they are disintegrated ant-hills, favoured by Prof. Hilgard, brings in the least amount of speculation, for ant-hills are very prevalent all over South Africa, and I have even seen them on Micham common, near London, distributed over the surface in the same manner as our natural mounds occur in South Africa. Mr. Purdue's objection that the ant-hills found in among the natural mounds are very much smaller than the latter is not of such weight in the Cape Colony, as the species of termites that formed the mounds---supposing for the moment that the ant-hill theory holds good---

may very well have been the same as that which builds the huge ant-hills in Rhodesia, but which have died out in the south of the sub-continent. The bones of the eland and rhinoceros in the sand-dunes round Cape Agulhas show that these animals, now confined to the north of the Orange river, once lived in the country of the natural mounds, and as it is probable that climatic change, as well as the presence of the white man, has exterminated the larger animals in the south, so it is not unreasonable to suppose that the Rhodeesian termites once lived in the south also.

In the colony the mounds may be seen in any sandy ground near the coast, covering the surface with bare patches; but the want of vegetation is due, I think, not to the nature of the soil, but to the baking of the surface, after it has been wetted by the rain, by the intense heat of the sun. Where a wheel has gone over one of the mounds and broken the hard crust, bushes spring immediately. In cultivated land the farmers aver that these hillocks are more productive than the rest of the soil, and Mr. Juritz, senior analyst of the colony, mentioned in his address to the British Association in Cape Town, that a levelling of these hillocks results in an increase of the fertility of the soil all round.

The most accessible place for seeing these mounds is on the lower slopes of the hills of Bokkeveld and Witteberg beds on the top of the Hex river pass, on the main line to Johannesburg; they appear as red splotches on the bush-covered slopes. The elevation here is only a few inches, and the diameter some 5 or 6 yards. In the Malmesbury district they occur on the flats below the hills, and are formed of light yellow argillaceous sand. Here they have usually a depression in the centre, which is often occupied by a clump of arum lilies, although the surrounding country is far too dry for these moisture-loving plants to exist.

After seeing these Malmesbury mounds I went into the Ceres Karroo, and at Hartnek's kloof found an actual spring bubbling up from sandy ground, and round each of the eyes there was a perfect circle of grass, raised a few inches above the general surface. I afterwards saw many of these sand fountains, and for a time my mind veered round to an aqueous origin for the hillocks.

East of Worcester, however, near the station Over Hex, there is a large tract of country under the Langebergen, covered by a fine yellow alluvium, not unlike loess in texture, and a great portion of this is occupied by gigantic hillocks some 8 to 12 feet high and some 10 yards in diameter. In places these are so closely packed that the bases mutually impinge; the angle of slope varies, but often is as acute as in a volcanic cone. There are many good sections of the mounds available along the railway here and in the road-cutting, but nowhere is there any internal structure visible; the whole substance of the hillock is the same throughout, and consists of fine argillaceous sand like the surface soil, without the least sign of vegetable or animal remains included in it. The soil becomes so hard where it is allowed to dry quickly after being moistened, that square blocks can be dug out and sun-baked, and can then be built into walls, where they will stand unprotected for many years.

In the red-sand country of Bushmanland the mounds also occur, and the substance of the hillock is more argillaceous than that of the surface soil; the bushes grow closely packed together on these spots, which are perfectly circular, although the rest of the ground is sparsely covered except after rain, when the grass grows. I never noticed our donkeys feeding on these clumps, however, although the luxuriance of the bush ought to have attracted them.

Another possibly connected phenomenon is that of the small patches of poison veld that occur in among the ordinary veld with apparently no cause for the nature of the bush. I know two such patches in the colony, one high up under a krantz in the Nieuweveld, and the other in the open plains north of Matjesfontein. The areas are a few acres in extent, but there is no demarkation between the good and the bad veld; the bush is the same in both, and the farmers say that the plants absorb their poisonous properties from the soil. That these areas are very poisonous I had ample experience, for when I was outspanned near the Matjesfontein patch, a drove of slaughter-oxen came down from Sutherland and wandered into the poison area, and three or four were immediately stretched stiff on the ground. Similarly, a little blue iris that grows plentifully throughout the country is some places, Baviaan's Kloof, for instance, and at certain times of the year, becomes very poisonous to cattle, while at other places it is apparently harmless.

The opposite of the hillock veld is the Kommetje [saucer] veld, where the ground is honeycombed with little shallow depressions. I have not seen a typical spot, but on the flats to the north-east of Fort Beaufort there is a fair example of this kind of surface. The ground was cut level by marine denudation, and in the shelves at present awash with the tide there is a layer of calcareous sand, which becomes hardened into limestone by the deposition of calcium carbonate. The process by which this is brought about is probably that the sea-water, containing a certain amount of lime in solution by reason of a small amount of carbonic gas held in it also, becomes left behind at low tide, and becomes warmed by the heat of the sun; when this happens, the carbonic gas is driven off, and the lime is thereby precipitated, and goes to cement the sand-grains together. The limestone forms low reefs enclosing shallow pools, which are alive with shore-forms of marine life. It seems probable, then, that when the sea retreats from off such a shelf the hard rims of these pools will persist, and afterwards, when they become removed, together with all the other material deposited on the hard rock when it was awash, the lime of the rims will sink into the underlying surface and harden it; the flat surface will be thus parcelled out into areas within which the rock will be softer, and under the action of denudation will become covered with shallow depressions. The true kommetje veld, however, has been described to me as one succession of circular hollows in similar aggregation to that of the hillock, and thus the hillock and saucer may be related in origin. The discussion of depressions, however, includes that of the pans in South Africa generally, some of which are 20 miles in diameter, and the subject is too complicated to be referred to in this note.

EARTH MOUNDS IN UNGLACIATED ARCTIC NORTHWESTERN AMERICA

Porsild, A. E.; *Geographical Review,* 28:46-58, 1938.

On the otherwise low and featureless coastal plain of the North American continent from Point Barrow eastward past the delta of the Mackenzie River to the first outcrop of rock east of the Horton River are scattered curious, isolated, more or less conical mounds, which have been mentioned and commented on by nearly all travelers since the days of Franklin. In literature the name "gravel or earth mound" seems to be fairly well established. The Eskimo name pingo, meaning a conical hill, which has come into universal use in the north, is here introduced as an alternative.

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In the Mackenzie District the mounds, or pingos, are most numerous in the peninsula separating the Eskimo Lakes from the Arctic Sea. This is a low, undulating plain about 200 miles long and from 20 to 50 miles wide. Heights nearly 500 feet above sea level are found a short distance east of the Mackenzie in the Caribou Hills, the remnants of a ridge that formerly extended from the Richardson Mountains, west of the delta, through which the river has broken in recent times. From the east branch of the Mackenzie a low spur extends eastward for about 25 miles. The eastern part of the peninsula is very low and, no doubt, recently emerged from the sea. A few pingos of the type formed by hydraulic pressure are found on the slopes of the Caribou Hills; pingos of the other type are found on the low, marginal plain. There are said to be some pingos on the coastal flats east of Cape Bathurst, but these have not been seen by the writer. There are a few on the mainland south of the Eskimo Lakes; a large number are found on Richards Island; and some are even found on very small islands off the coast. Numerous small pingos are found in the alluvial Mackenzie Delta.

This type of pingo is nearly always round or slightly oblong in outline. It ranges in height from a few feet to as much as 230 feet from base to summit; few, however, are more than 100 feet in height, and the average height is probably between 40 and 75 feet. Pingos reaching a maximum height of 300 feet are mentioned in literature, but it seems that the height of every one of these was estimated. This type invariably occurs in low, lake-filled country, where from the top of one pingo as many as 25 can sometimes be seen within a radius of a few miles. The smaller pingos always present an even, rounded surface and are completely covered with vegetation; but most of those reaching a height of 50 feet or more are ruptured or split open by an irregular system of fissures. In the largest the fissures have widened and give the top a broken, craterlike appearance. In those oblong in outline the fissures appear along the main axis and generally extend well down the sides. (pp. 49-50)

ORIGIN OF THE PALSA MOUNDS

Anonymous; *Nature,* 246:64, 1973.

The energy exchange properties of palsa mounds is the subject of a recent paper by Railton and Sparling (Can. J. Bot., 51, 1037; 1973), who provide a new approach towards understanding these mounds of peat with frozen cores which are abundant in the mires of high latitudes.

The word 'palsa' originated in Lapland and most of the research which has been undertaken on these features has come from Finland and the Soviet Union. In Finland palsas are only found north of the coniferous forest limit in areas with a mean annual air temperature of -1° C and an annual precipitation of less than 400 mm. The palsas of that region are often irregularly shaped and may attain lengths of 200 m.

In the search for an explanation of the origin of these phenomena an initial question requiring solution is the start of their formation. By means of pollen analysis accompanied by radiocarbon dating, Salmi (Proc. 3rd Int. Peat Congr., Quebec, 182; 1968) came to the conclusion that palsas in Lapland fall into two groups, one of which began formation around 5000 BC and the other at about 3000 BC. The age of a palsa, however, did not seem to be related to its size. Other Finnish workers have found palsas of more recent origin and are less inclined to regard palsas as relics of past climates.

Railton and Sparling align themselves with those who believe in a continuous cycle of formation and erosion of the palsa mounds. They base this belief on their observation that all size classes of palsas are represented in their study area in northern Ontario and also that these classes exhibit a complete intergradation. They do not attempt to justify the assumption that palsa size is a function of palsa age, an assumption which appears rather tenuous in the light of Salmi's work.

They do, however, demonstrate some interesting relationships between palsa size and vegetation cover. Palsas containing a high percentage cover of Sphagnum fuscum were mainly less than 60 cm high and less than 7 m long. Lichen-rich communities with, for example, Cladonia alpestris, C. floerkeana, C. rangiferina, were found mainly on mounds greater than 60 cm in height. On the basis of these observations Railton and Sparling suggest that palsas develop continuously, and probably originate as Sphagnum fuscum hummocks on the mire surface. They become invaded and dominated by lichens during growth and finally erode and collapse. It is possible that the changes in heat exchange properties associated with the development of a lichen cover could account for the process of palsa development.

To test the feasibility of such a model Railton and Sparling measured the energy exchange properties of the different vegetation types. Total albedo was least on the general mire surface, increased in the Sphagnum fuscum hummocks, was greater still in hummocks dominated by lichens and reached a maximum in mature palsas. The obvious question which follows is whether these increases in albedo associated with palsa development are adequate to account for their negative heat budget and hence their growth. A consideration of the total energy budgets of palsas led Railton and Sparling to the conclusion that the differences in albedo were not sufficiently great when compared with other energy exchange factors, and they are inclined to regard changes in the soil heat flux as being of greater importance. Thermal conductivity in peat decreases as the peat dries. Drier peat on the top of hummocks would lose heat less rapidly in summer, so helping to preserve the permafrost core. If this is so, then the lichen cover so often associated with mature palsas should be regarded as a product of mound development rather than a cause.

(The mounds described in the two preceding articles may be pingos, as defined in the next item. WRC)

• Pingos

SUBMARINE PINGOS IN THE BEAUFORT SEA

Shearer, J. M., et al; *Science,* 174:816-818, 1971.

An abrupt shoaling of the ocean floor in the Beaufort Sea was first noticed in 1969 by hydrographers aboard the C.C.G.S. John A. MacDonald, a Canadian icebreaker escorting the tanker S.S. Manhattan through the Canadian Arctic to Prudhoe Bay, Alaska. The shoal manifested itself as a rapid rise of the sea bottom from 49 to 23 m below sea level, over a horizontal distance of 200 m. This rapid rise was followed immediately by an equally rapid drop to 49 m. On the return voyage from Prudhoe Bay both ships skirted the shoal by passing to the north of its position, and no attempt was made to relocate the feature. For local reference the shoal was christened the "Admiral's Finger."

In response to a lack of detailed bathymetric information on the western Arctic, as typified by this incident, the Canadian Hydrographic Service in 1970 embarked on an extensive mapping program in the Beaufort Sea and adjacent regions.

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Unexpectedly, this detailed survey revealed a large number of underwater mounds interrupting an otherwise smooth sea floor. Each mound bore, in size and shape, a superficial resemblance to the Admiral's Finger. As far as could be inferred from detailed topographic examinations by means of launches, the mounds were generally irregular and asymmetric in form, with one side steeper than the other. The diameters of the bases averaged 400 m, and the elevations, from base to peak, 30 m. In most cases, a shallow (0 to 10 m) moat or depression surrounded the base of the feature.

A total of 78 mounds was located in the survey area, with minimum depths above their summits ranging from 15.4 m to more than 45 m. Their distribution appeared to be random. Several were grouped in clusters, others were paired, and the remainder were scattered singly within the 70-m isobath.

During the same period, similar features were discovered outside the survey area by investigators aboard the C.S.S. Hudson and C.S. S. Parizeau, who were engaged in hydrographic and scientific activities. Seven were identified on the east side of Mackenzie Canyon (at 69^{o} 55' N, 137^{o} 10'W) by means of side-scan sonar. A seismic reflection profile was obtained over another feature located at 70^{o} 51' N, 131^{o} 72' W, just to the east of the survey area described above. These observations indicate that more shoals may exist on the unmapped portions of the continental shelf of the Beaufort Sea, particularly since the seven mounds located by means of side-scan sonar were not detected by the ship's echo-sounder. The implications with respect to deep-draft shipping in the western Arctic are serious, since the features represent a hazard to navigation in ice-infested waters.

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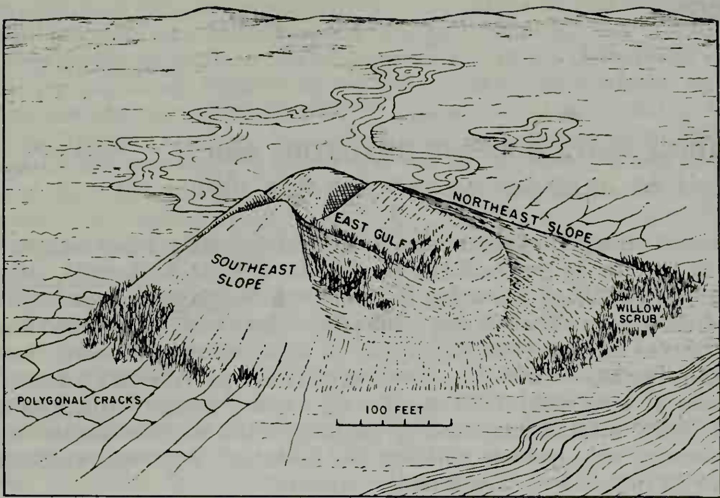

A pingo in the Mackenzie Delta, Northwest Territories, Canada. (Adapted from Geological Society of America, Bulletin, *67:1120, 1956.)*

• Other Types of Mounds

THE ORIGIN AND SIGNIFICANCE OF PRAIRIE MOUNDS

Gravenor, C. P.; *American Journal of Science,* 253:475-481, 1955.

Abstract. Locally, the ground moraine of the western prairies is covered with till mounds. The mounds---which from the air resemble giant doughnuts---average 300 feet in diameter and 15 feet in height, and in most cases have a central depression which lies 3 to 4 feet lower than the outer rim of the mounds. It is believed that the mounds originated as debris-filled pits on a stagnant ice surface and that the melting of the ice left the pit fillings as mounds. The mounds and associated features over parts of western Canada are probably related to slow wastage of the ice in a downslope direction.

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Description of Mounds. Aerial views of prairie mounds show that they are nearly circular and in most cases have a central depression. The mounds average 300 feet in diameter and 15 feet in height. The central depression is generally 3 to 4 feet lower than the elevation of the outer rim of the mounds.

For the most part the mounds are composed of clayey till. An exception to this general rule is found, however, in the mounds which exist on the southwestern border of the Viking moraine. At this location several mounds were found which are formed primarily of till but contain masses of contorted and slumped stratified silts and clays. It is significant to note that similar inclusions of stratified sediments have not been found in the ground moraine adjacent to the mound fields.

The intermound trenches are quite flat except where the mounds occur on the edges of, or in areas of, recessional moraine. Drilling operations in the mound field east of Hemaruka showed that the mounds and the intermound trenches are underlain by a minimum of 40 feet of clayey till. With the exception of a 3-foot layer of silty till cover on the rim of the mounds, there was no difference noted between the till in the mounds and the till in the intermound trenches.

In some places the intermound trenches are covered with a thin layer of sand which contains a few pebbles and shows evidence of rude sorting. This veneer of sand is not confined to the mound areas but is found over much of the ground moraine of east-central Alberta.

The mounds in the Watino area of Alberta, described by Henderson, are only 5 to 10 feet in height, but the diameters are approximately the same as those found in east-central Alberta. The Watino mounds are composed largely of till, and the intermound spaces are covered with a layer of silt 2 to 3 feet in depth.

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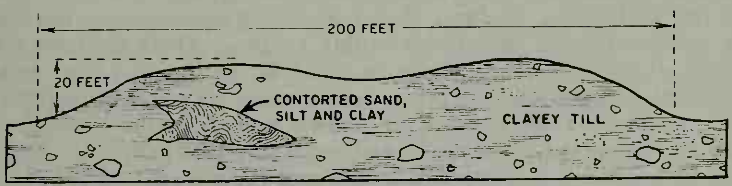

Cross section of a typical doughnut-shaped mound from the Canadian prairies.

SCABLAND MOUNDS OF EASTERN WASHINGTON

Freeman, O. W.; *Science,* 64:450-451, 1926.

On the channeled scablands of eastern Washington are found thousands of nearly circular mounds composed of different material than would be formed from the weathering of the basalt that is the chief bedrock of this region. The mounds only occur on top of the bare basaltic rock of the Columbia Plateau. They never occur on granite, schists or quartzite that occasionally outcrops. Neither do they occur on the loessial hills of Palouse soil or in peat swamps scattered through the scablands.

The mounds average practically circular. Careful measurements failed to show any greater elongation in one direction than another. The highest point of the mounds is the center. They thus differ in shape from ordinary sand dunes. The mounds are of all sizes, from a few feet across to over one hundred feet and average around thirty to forty feet in diameter. They rarely exceed three or four feet in height above the scabrock. The material composing them is loess like and differs so markedly from soil formed from basalt that little of it can be derived from that source. It appears to have been brought in from elsewhere and deposited by the wind. The source of the material was probably the soft lake beds of the Ellensburg formation of south central Washington and the finest outwash material of the glacial period. Where I have studied the mounds in the northern half of the scabland area they practically without exception occur above a depression in the basalt. The depression is sometimes shallow, making the cross-section of a mound lens-like; in other cases it has steep sides like a pothole. In either case the basalt under the mound is very little weathered and makes a sharp contact with the mound. Such weathering as occurred resulted in chipping off small fragments of the basalt from the sides of the depression which are scattered through some of the mounds, chiefly in their lower part.

The work of Bretz (Jour. of Geol., Vol. 23, pp. 139 to 149, Vol. 31, pp. 617 to 649) on the channeled scablands shows that the Spokane flood from a rapidly melting ice sheet removed the surface soil from the basalt and by the suction of the swirling torrent plucked out from the stream beds great chunks of the jointed lava, leaving its surface in a highly pitted condition. We only find the mounds in places where the basalt's surface contains depressions. The mounds are found in the midst of level areas, on the sides of hills, at the edge of rock terraces and even on top of small isolated hills of basalt. They occur both in the timbered and treeless parts of the scablands. In fact, they may occur anywhere on the bare basaltic rock and never elsewhere in this region. Their absence from the surface of crystalline rock is accounted for by the fact that such rock is denser and that potholes or other depressions were not worn into its surface. A considerable number of mounds have been cut through in road and railroad cuts, and a few wells and vegetable pits have been dug in them. Besides examining such, I have trenched several others. In the areas so far examined I have invariably found that the mounds occur over a depression in the scabrock. In the bottom of the depression there may be gravel and a few boulders washed in by the Spokane flood and some chips of basalt from the weathering of the sides; aside from this the depression is filled with the loess that composes the mound that rises above it. Some of the depressions are shallow with gentle slopes, others are many feet deep with steep sides. A well in one case was dug twelve feet deep in a mound below the level of the scabrock without striking bottom.

Apparently at the close of the Spokane flood the basaltic lava was left with a decidedly pitted surface, the depressions of which had about the same dimensions in various directions. Sediment accumulated first in such depressions. Vegetation started growing on the sediment and retained the wind-blown material until the entire depression was surrounded and surmounted by a mound. The fine material of the mounds holds moisture better than the scabrock and the depression beneath is a storehouse of moisture which helps to promote a vigorous plant growth. It seems probable that the mounds were chiefly formed soon after the glacial period, although the much more luxuriant growth of grass on them to-day than on the bare basalt would permit additional wind-blown material to be caught and retained. Mounds have been reported outside the channeled scablands on the basalt of the Columbia Plateau but have not been examined by the writer. It would be of interest to learn if these mounds occur above natural depressions in the lava. It also may be that some lens-shaped mounds reported from other sections of the United States may be found to have grown as the result of more luxuriant vegetation in them, catching and holding wind-blown material until the mounds were formed.

The mounds are of economic importance to the inhabitants of the scablands. They provide the best available grazing aside from certain peat swamps. Corn, melons, sweet clover, potatoes and garden truck flourish when planted on the mounds, as the plants draw on the moisture in the soil that fills the depressions. It is difficult, however, to cultivate most of the mounds, due to their small size.

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SOME TOPOGRAPHICAL FEATURES FORMED AT THE TIME OF EARTHQUAKES.....

Hobbs, Wm. H.; *American Journal of Science,* 4:23:245-256, 1907.

About two years ago a symposium seems to have been started upon the origin of the mounds of the Lower Mississippi and the Gulf Plain. To this discussion no less than nine persons have contributed in Science, besides which there have appeared in other journals a number of special articles and references to the subject. The latest contributor, Mr. M. R. Campbell, seems disposed to class together low mounds from whatever district and adopt for all the same explanation. Amid all the variety of ingenious theory, it is a little surprising that of those who have addressed themselves especially to the problem, one only has given weight to a possible birth of the mounds at the time of earthquakes in the district. Mr. A. C. Veatch, the best recent authority upon the geology of the district, has considered the possibility of this origin for certain of the mounds, but believes the dune and ant-hill theories the best supported. Shepard has, however, been able to show conclusively that the low mounds of the "sunk country" are "sand blows"---mounds three or four feet in height with diameters of 20 to 100 feet, frequently slightly hollowed at the center---mounds which came into existence during the earthquake at New Madrid in 1811-12.

Veatch has concisely stated the general characteristics of the so-called "natural mounds" of the Gulf Plain in the following words, the italics being the present author's:

"They (the mounds---*ed.*) occur irregularly throughout the coastal plain in northern Louisiana, northeastern Texas, Arkansas, and southeastern Missouri, except in the present flood plains. They are best developed on the Port Hudson terraces, but extend also over the hill lands. They are not restricted to any geologic formation or any range of elevation. *The material of which they are composed is commonly a very fine loam, which is reported by the agriculturists to be coarser and quite distinct from the surrounding soil, which is commonly clay. Oil-well drillers in southern Louisiana and southeastern Texas report the material in these mounds to be entirely different from the surrounding soil and exactly the* same as the fine sand found beneath the 50 to 100 feet of surface clay. The apparent difference in composition is, however, not so great as it seems at first sight and is in part due to the greater elevation and consequent better drainage of the mounds. Careful mechanical analysis will be necessary to determine the true character and degree of this difference."

Udden has shown that of 59 mounds near Olivia, Texas, the greater number are less than 30 feet in diameter and 7 inches in height, and, further, that it is the larger mounds which show the distinct pittings at the center.

The object of the present article is to draw attention to the fact that the region in question is one of notable seismicity, and to point out that sand and water fountains, as well as mud volcanoes, with their products, "sand" or "mud" cones and "craterlets," are almost universally produced in connection with great earthquakes. The derangement of the ground water at such times results in: (1) local ejection of sand and water (sand blows and mud cones), (2) draining through vertical pipes of swamps or ponds ("funnels" and "craterlets"), (3) in draining following upon an ejection of sand, mud and water (pitted cones), or (4) squeezing out following the sudden draining of the district. The best descriptions of such phenomena have perhaps been given in connection with the earthquakes of Calabria, 1783: New Madrid, 1811-12; Iceland, 1896; India, 1897; and Chemakha, Turkestan, 1902.

The mounds referred to in the above mentioned examples generally consisted of sand mixed with small quantities of various other substances (mica, lignite, etc.) generally foreign to the surface layers of the soil, and it reached the surface borne by large volumes of water which left the material so charged with water as to resemble a quicksand. During the Indian earthquake of 1897 material of this nature spread out from many openings and blanketed large tracts of country with quicksand. In other instances, as near New Madrid, in 1811, the water and sand welled out throughout the length of extended fissures and the arrangement of "sandblows," like the newly developed springs, appears to have been upon fissure lines. During the Chemakha earthquake, and in some other instances, the material ejected was a salty mud, which upon desiccation yielded hard mud cones ranged upon fissure lines. At Chemakha, moreover, a second displacement upon the line of the fissure produced a distinct fault wall a meter in height which cut the dried mud cones.

In Italy, a notable earthquake country, gas and water yield mud volcanoes in the period between earthquakes, but the action in them is usually either more or less vigorous during seismic shocks in the neighborhood. A series of such mud volcanoes runs in a nearly straight line entirely across Sicily from Siculiana upon the south coast to Paterno upon the flanks of Aetna. Mud volcanoes are also numerous in the Apennines, though no attempt has yet been made to determine their arrangement or their relation to structural lines. This is, therefore, a most promising field for future studies in structural geology.

The whole subject of the extensive derangement of the ground water during earthquakes has been difficult of explanation by the centrum theory, and has not received the attention which it deserves or which it is likely in the near future to attract. The introduction of the crustal block or compartment theory of earthquakes affords an explanation, both simple and natural, of these derangements. If the elastic waves which we describe as earthquakes arise from the mutual friction upon the edges of earth blocks, which through an abrupt jolting movement seek to readjust themselves to the stress system, looked for consequences are: (1) the squeezing out of water from the trunk channels of circulation within those districts where blocks are depressed, (2) a sucking down of the water of swamps and ponds wherever blocks are elevated, (3) a sucking down following upon a squeezing out of water (often actually observed with the formation of cratered sand cones) when the slight elevation of a block succeeds to its depression, and (4) a squeezing out of water following a sudden draining of a district when a slight settling follows the elevation of a block. Quite analogous appears to be the forcing of fire damp into the galleries of Belgian coal mines, which, from quite recent studies of Van den Broeck, appears to take place chiefly when the Mistpoeffers are heard and when there are earthquakes in moderately distant districts.

It is a fact of much significance that in the "sunk country" of the Lower Mississippi the springs are often surrounded by little cones of sand admixed with lignite, and that the inhabitants of the district claim that the better quality of water is found by boring in the mounds of the valley. In the words of Shepard:

"Further, we find today that large volumes of water are constantly coming to the surface as springs in this district; that these springs are numerous along the lines of fissure: that deep artesian wells around this region bring up this same variety of sand with lignite, some, as at Memphis, when first sunk, ejecting large chunks of the lignite; that the sand and lignite brought up in the deep wells are similar to the same substances brought up by the innumerable springs that feed the lakes and streams of this district, and that they are apparently the same as that which surrounds the blow holes and fault scraps, and which covers, as with a vast sheet, the considerable areas in the sunken district."

The association of oil with the mounds of the Gulf Plain is further of interest, and especially because it is the low mounds of the spindle-top type in which the petroleum is found. Fenneman states that the chance of finding oil under the elevated spots in the plain is vastly greater than elsewhere. He further says:

"There is some reason for thinking that such structures are ranging along lines of slight crustal deformation or disturbance. If such lines exist they probably trend northeast and southwest. This probability may well be recognized in prospecting for new fields."

The northeast-southwest direction is the one which, according to Lyell, was by far the most common direction of the fissures produced at the time of the New Madrid earthquake. In view of the vast deposits of sulphur which have been found to underlie portions of the Gulf Plain, it is worthy of mention that the earthquake of New Madrid was possibly unique in the respect that the shocks were accompanied by emissions of sulphurous vapors (probably sulphureted hydrogen) causing great discomfort and rendering the river water for days unfit for drinking purposes.

Sand blows, mud volcanoes, craterlets, etc. are clearly closely related phenomena and are to be ascribed to the vertical movement of water, gas, sand, etc. along the widened portions of earth fissures. Their connection with larger tectonic movements as the resulting derangement of the ground water system, is only beginning to be appreciated. Perhaps the most striking and significant single characteristic of the mounds thus produced is that they have a composition essentially different from that of the layers of soil underlying their margins, and that the materials are derived from a lower horizon (see extract from Veatch above). The report of the Naples Academy of Science upon the great earthquake of Calabria (1783) states that some plains, like that of Rosarno, were covered with circular hollows generally filled with sand but sometimes with a concave surface. At other times, the surface was convex. Upon digging down in them it was found that they were funnel-shaped pipes, and that the moist, loose, micaceous sand in the center marked the tube up which the water had spouted. At other places in the same district, cones of sand were built up, and the localization of cones and funnels upon fissure lines was recognized.

According to Veatch and Fenneman, the Gulf mounds differ in composition from the material of the surrounding plain, and they appear, further, to be often pitted at their summits. Attention should therefore be directed more particularly to the composition of the mounds, taking account also of their less common ingredients, and their relation to underlying formations should be discussed. Apparently also there is a possibility of determining the underground structure of such mounds where they have been dissected. Especial interest attaches, in this connection, to the sandstone pipes which occur in the Carboniferous limestone of the eastern coast of Anglesey, for which as yet no explanation has been offered. The surface of the limestone is here pierced by a large number of circular pits opening out in trumpet form and from 1 to 7 feet in diameter. Each can be seen to be, or to have been, filled with a plug of fine white sandstone, descending into the limestone at right angles to its bedding.

"These plugs can be seen in various stages of denudation. Some have been worn flush with the surrounding limestone, and some of the smaller ones have been excavated so as to leave an almost empty pit or pothole with a little sandy matter in the bottom. In one part of the shore, however, the plugs have been left standing, each in its circular pit, some 4 or 5 feet above the level of the surrounding rock; and the foreshore here presents a most extraordinary appearance, great masses suggestive of gigantic fossil corals, or of the Paramoudras of the Chalk, standing up from the rocky ledges, while others, torn out by the sea, lie prostrate in all directions."

The limestone at the locality is overlaid by about two feet of sandstone with which the sandstone material of the pipes is continuous though with no sign of collapse in the bed of sandstone. In fact, in most instances the surface of the sandstone is gently domed upward above the pipes and occasionally has also a domed crack as well. Within the pipe the bedding of the sandstone sags downward and a concentric structure is clearly revealed by the brown weathering. There is, moreover a tendency to radial jointing within the plugs. The enclosing limestone of the plugs is full of cracks at its upper surface and these cracks are filled with sandstone. The pipes belong to three different horizons within the same formation, and with much probability represent fossil sand-blows like those described from near New Madrid. Structures of a similar character, the writer is informed by Professor A. H. Purdue, are found in the Ozark mountains of Arkansas.

Whereas during the New Madrid earthquake certain of the fissures opened spouted the sand and water only locally to build up cones; from others the same materials welled out throughout the entire length of the fissures so as to produce broad blankets of quicksand. Just as the sandstone pipes of Anglesey illustrate the indurated relic of the one phenomenon, so do the sandstone dikes described by Diller, Hay, Crosby, and Case the other. Without exception these authors have explained the dikes by the upward movement of sand in fissures generally at the time of earthquakes.

Any consideration of the mounds found within the Gulf Plain should take account of the "mud lumps" which are constantly forming in the Mississippi delta. These hillocks make their appearance as small isolated cones of mud which often appear above tide and have craters at their summits from which a spring of dirty water issues. Later in their history their conical form is lost and the water issues from their slopes. This water is often loaded with salt, oxide of iron, or lime carbonate, and carries mud and sand. Marsh gas, carbon dioxide, and nitrogen are also given off from them in quantity. Lyell states that the tubular cavities up which the springs rise are about 6 inches in diamter, vertical, and as regular in form as though bored with an auger." A most important contribution to our knowledge of these unique phenomena, in which it has clearly been shown that the material of the mud lumps is of a different nature from that surrounding them, has been very recently made by Hilgard. He has shown that the sticky mud is the "blue delta clay" or "blue clay bottom" derived from a much lower layer of Coast Pliocene, or Port Hudson age, above which the delta deposits are laid down. As the latter are deposited they imprison a thin overlying stratum of very thin mud which results from the clarifying of the river-water when it meets the sea-water outside the bar. The settlement of the delta region under its increasing burden of sediment is the plausible cause to which Hilgard appeals for the forcing up of the mud lump clay, and its associated thinner mud. The lumps are thus in reality true "mud volcanoes." The very stickiness of this blue clay, upon which the river's scour makes little impression, in the opinion of the writer, makes it necessary to assume that a current either of water or of gas, or both, is forced up from beneath the "blue clay bottom." The gas which is emitted from the lumps is, as Hilgard believes, in volume quite insufficient to alone carry on the action. Fissure springs are best suited to explain all the conditions, and the known existence of strong fresh-water springs at numerous off-shore points beneath the Gulf, and especially off the mouth of the Mississippi, indicate the continuation beneath the Gulf of the artesian water stratum characteristic of the lower flood plain.

Moreover, there is other evidence that such fissure springs are in definite alignment. A fact which Lyell considered so important as to print in his rare italics is, "they (the lumps---ed.) were always situated off some one of the mouths of the river. To this Hilgard has given support by a statement, also in italics, "Mudlump formation is at present the normal mode of progression of the visible delta into the gulf." It would thus appear that as the mud lumps become clogged, new ones develop along the extension of the same fissure through a steady migration seaward of the process. The peculiarly straight but divergent channels of the unique "birdfoot" portion of the delta support this hypothesis.

While the mud lumps are perhaps not developed at the time of sensible earthquakes, it is a question whether the settlement of the Mississippi delta takes place gradually or per saltum. The tendency at the present time is to look upon such brady-seismic movements as different in degree rather than in kind from those accompanied by earthquakes---a tendency which the increasing knowledge of subterranean sounds (brontidi) is strengthening.

Many mud volcanoes owe their activity to the high temperature of the subsurface layers of the earth's crust, which supplies steam to raise the mud and eject it with violence. The Minbu mud volcanoes of India are of a different type and have a special interest for the present study because they indicate that the petroleum beneath the mounds of the Gulf Plain may well have played a part in their formation. According to Cadel:

"The Minbu salses, for such they are in reality, are due to the escape of carbureted hydrogen from the oil-bearing strata on the top of the anticline, which rises through the clay beds mixed with a little water and oil and slowly bubbles up at certain spots. As the gas and water rises, it brings up a little gray mud, which, on exposure to the air, dries and hardens while the water evaporates, producing first a low crater basin with a dry rim of mud, then a cone with a crater on the top, in the center of which the gas finds vent."

It will be noted that we have here an evolution of topographic forms identical with those illustrated by the sand phenomena of earthquakes as above outlined. Other petroleum mud cones occur upon the Apennines at Sassuolo and San Venanzio, at Tanan and Baku in the Caucasus, and upon the Island of Trinidad, while Macaluba in Sicily rests upon beds of clay containing gypsum, salt, sulphur, bituminous matter, etc. or much the same mixture as that to be found beneath the gulf mounds. The smell of sulphur which accompanies the eruptions of Macaluba is of interest because it offers a possible explanation of the sulphurous odors with which the air was charged during the great New Madrid earthquake of 1811-12.

The small amount of attention which "mud volcanoes" have attracted we owe perhaps to their name, which classifies them with volcanic phenomena, but with which they have little in common. Generally born at the time of earthquakes, they show a sympathetic response to seismic shocks within their neighborhood, and are properly classed as phenomena consequent upon the derangements of the ground water and gas systems by earthquakes. Our knowledge of the brontidi now makes it possible within a seismic province where mud volcanoes are frequent (Italy, for example), to determine what relation exists between their periods of activity and the perception of subterranean rumbling. It seems certain that where mud or sand cones are now forming, orographic blocks are being depressed, which accounts for their common occurrence within delta regions. The study of bradysisms has clearly shown that nearly all coast lines of the continents are today rising, the marked exceptions being the deltas of the great rivers. The whole Mississippi flood plain, with the exception of Lake County, Tenn., and the opposite shore of the river, would appear to be included within the area which in the isostatic adjustment about the Gulf is being depressed.

Further light is likely to be shed upon the origin of the Gulf Plain mounds through the careful mapping of them within definite districts. If, as seems likely, they have been formed as a result of derangements in the ground water system during earthquakes, they are doubtless aligned upon fissures and located where these fissures are widened---in the majority of cases doubtless at fissure intersections. Such an alignment has already been indicated by Fenneman, but has not been worked out in detail. Their importance as points of segregation of petroleum greatly adds to this interest and places them at once in relation to the famous "mud volcanoes" of Baku, the lineal alignment of which was long since indicated by Daubree. There is thus at least the possibility of gaining some knowledge of the earth's fissure system beneath the Gulf Plain notwithstanding its deep blanket of unconsolidated material.

UNUSUAL EROSION SURFACES

Wind, water, and ice have gouged out some spectacular scenery. But the esthetics of erosion surfaces do not concern us here; it is the anomalous geological process and/or event that we search for---the left-overs that do not seem to fit in the other sections.

Anyone who has ventured into the channeled scablands of Eastern Washington is immediately aware that something unusual has happened to the region in the fairly recent past. The observer feels like an ant on the floor of a dried-up river bed. In a sense he is, but the river was immense and transitory. The debate among geologists about the cause of the channeled scablands was intense. When Bretz proposed an origin involving a catastrophic flood, he was ridiculed much like Wegener was for his pipe dreams about continental drift. Both men were eventually vindicated, and heresy became dogma.

In addition to the channeled scabland there are numerous other peculiar surfacial erosion features smacking of recent terrestrial catastrophism. Only a few can find space here.

• Channeled Scablands

CHANNELED SCABLAND OF WASHINGTON.....

Bretz, J. Harlen, et al; *Geological Society of America, Bulletin,* 67:957-1049, 1956.

Abstract. The existence of four different interpretations of that extraordinary assemblage of erosional and depositional land forms of eastern Washington, the "Channeled Scabland", indicates that rigorously definitive diagnostic characters had not been found. This study, dealing with new data, largely from extensive excavations and detailed topographic maps made by the U.S. Bureau of Reclamation in developing the great Columbia Basin Irrigation Project, returns to the earliest of the four interpretations: that channeled scabland is almost wholly the consequence of catastrophic flooding of glacial water across this part of the Columbia Plateau which remade preglacial valleys into an anastomosing complex of great river channels with huge cataracts, deep rock basins, and bars attaining magnitudes unknown elsewhere on earth.

The new evidence is held to establish firmly the following points:

(1) Some structural basins of the region did not have exterior drainage prior to arrival of glacial water.

(2) The gravel hills called bars by Bretz (1928a) have the shapes, surface markings, structures, and topographic situations possible only for subfluvial constructional deposits. In magnitudes and bouldery composition, they are sui generis.

(3) Several episodes of catastrophic discharge have occurred across this part of the Columbia Plateau.

(4) The Columbia Valley skirting the plateau has had comparable floods in which the scabland complex did not share.

(5) Successive floods have been differentiated only by topographic relations of their records, not by differential weathering and erosion.

(6) Bretz did not overestimate the magnitude of the erosion by glacial waters.

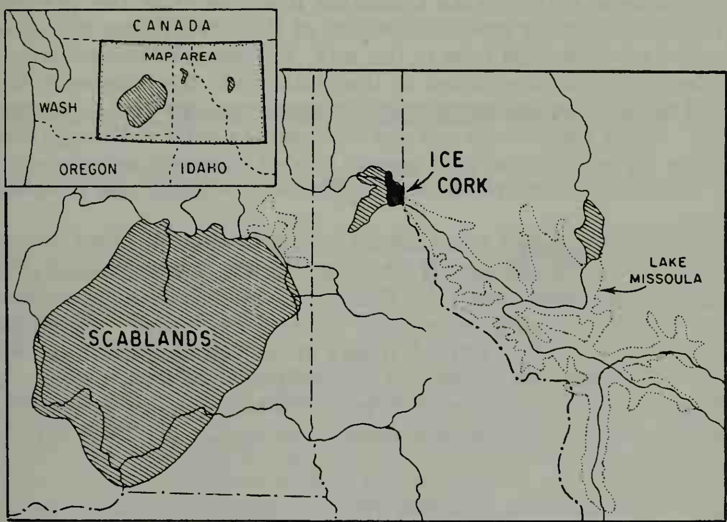
(7) The existing scabland features contradict the three later interpretations.

View of some of the channelled scablands cut during the hypothetical Spokane Flood. (C. Warren Hunt)

THE LAKE MISSOULA FLOODS AND THE CHANNELED SCABLAND

Bretz, J. Harlen; *Journal of Geology,* 77:505-543, 1969.

General Statement. Although paleo-Indians probably were already in North America, no human ear heard the crashing tumult when the Lake Missoula glacial dam (the front of the Pend Oreille lobe of the Cordilleran ice sheet) burst and the nearly 2,000-foot head of impounded water was free to escape from the Clark Fork River valley system of western Montana and across northern Idaho. It catastrophically invaded the loess-covered Columbia Plateau in southeastern Washington and reached Pacific Ocean levels via the Columbia River, 430 miles or more from the glacial dam. So great a flood is unknown at present elsewhere in the world. It has been estimated to have run for 2 weeks. It was 800 feet deep through the Wallula Gap on the Oregon-Washington line.



The area of channelled scablands seemingly created by catastrophic flooding.

On the Columbia Plateau in Washington, it transformed a dendritic preglacial drainage pattern into the amazing plexus of the Channeled Scabland. It flooded across stream divides of the plateau, some of which stood 300-400 feet above today's bounding valley bottoms. Closed basins as deep as 135 feet were bitten out of the underlying basalt. Dozens of short-lived cataracts and cascades were born, the greatest of which left a recessional gorge, Upper Grand Coulee, 25 miles long. The greatest cascade was 9 miles wide. The flood rolled boulders many feet in diameter for miles and, subsiding, left river bars now standing as mid-channel hills more than 100 feet high. Current ripples 10 feet and more in height diversify some bar surfaces. A gravel delta 200 square miles in area was built at the junction of Willamette and Columbia river valleys. Portland, Oregon, and Vancouver, Washington, now cover some of it. Almost 2,000 square miles of the plateau's basaltic bedrock lost its preflood loessial cover which otherwise is on record in the 100 or more "islands" 40 acres to 40 square miles in area---tracts that stood high enough above, or far enough from, main spillways to have escaped the tremendous erosional attack meted out to the plateau's preglacial valleys. Prevailingly, these "islands" have steep marginal slopes and prow points at their upstream ends. Backflooding left deposits for dozens of miles in nonglacial valleys which entered the plateau from Idaho on the east and central Washington on the west.

The above statements are generalized, for there probably were at least seven successive burstings of the dam, each (except the last) repaired by later glacial advances to again impound the valley system of the Clark Fork River in western Montana and make another glacial Lake Missoula. Five of these floods could only cross the plateau, because the westward-leading capacious valley of the Columbia River north of the plateau was then blocked by another lobe (Okanogan) of the Cordilleran ice sheet. Two floods found no Okanogan lobe in the way, and most of their water escaped around the north and west sides of the plateau via the preglacial Columbia valley. The earliest flood outlined the anastromosis of the Channeled Scabland. Later ones deepened and widened its main spillways and thus left earlier high-lying and less deeply eroded channels unrefreshed, to become obscured by interflood weathering, rain wash, and wind-made deposits.

The satellite Nimbus I has confirmed this judgment. One of its pictures, made from an altitude of about 500 miles, encompasses almost the whole plateau in Washington and, despite some atmospheric obscuration, has made possible a comparison with the scabland map. The satellite, which "saw" most of the bedrock floors of the anastomosis clearly, failed to record more than 200 miles of high-lying channelways already known as such from their berg-carried erratic boulders, a few gravel deposits, and some scabby channel-bottom basalt outcrops. (pp. 505-507)

THE SPOKANE FLOOD CONTROVERSY AND THE MARTIAN OUTFLOW CHANNELS

Baker, Victor R.; *Science*, 202:1249-1256, 1978.

Summary. In a series of papers published between 1923 and 1932, J. Harlen Bretz described an enormous plexus of proglacial stream channels eroded into the loess and basalt of the Columbia Plateau, eastern Washington. He argued that this region, which he called the Channeled Scabland, was the product of a cataclysmic flood, which he called the Spokane flood. Considering the nature and vehemence of the opposition to his hypothesis, which was considered outrageous, its eventual scientific verification constitutes one of the most fascinating episodes in the history of modern science. The discovery of probable catastrophic flood channels on Mars has given new relevance to Bretz's insights.

• Miscellaneous

ANOMALOUS EROSIONAL TOPOGRAPHY IN VICTORIA LAND, ANTARCTICA

Smith, H. T. U.; *Science*, 148:941-942, 1965.

Abstract. An area of some 18 square kilometers at the head of Wright Dry Dry Valley displays an erosional terrain of unique characteristics---a labyrinthine complex of erratic, interconnecting channels cut to depths of more than 100 meters in bedrock. It is interpreted as a result of catastrophic fluvial erosion, probably analogous to that which produced the Channeled Scabland of eastern Washington, though on a greatly reduced areal scale.

EROSION SURFACES IN THE CARIBBEAN AND THEIR SIGNIFICANCE

Weaver, John D.; *Nature*, 190:1186-1187, 1961.

Altimetric analysis of a series of topographic maps covering the main Cordillera of Puerto Rico indicates the existence of erosion surfaces, represented largely by concordant summit-levels, at the following average elevations: 760, 620, 470, 330 and 160 m. above present sea-level. Field work at present in progress suggests that these elevations in fact represent mean elevations of groups of stepped surfaces, in some instances bearing sedimentary deposits which have been described previously as residual soils.

At the present time it is not possible to reach any firm conclusion as to the mode of origin of these surfaces; but their distribution, at least in western Puerto Rico, suggests that they probably originated as marine cut surfaces, later modified by sub-aerial processes as they successively emerged from the sea. Whatever conclusion is eventually reached as to their origin, it seems fairly certain that they are related to changing sea-levels, the more widespread surfaces---particularly the 330 and 160 m. ---presumably representing periods of relative standstill.

Examination of these surfaces was originally undertaken in the hope of determining the tectonic movements that had affected the island subsequent to middle Miocene times. However, Choubert has described a series of surfaces in French Guiana with the following mean elevations: 600 (+), 500, 330, 235 and 160 m. These show a remarkable parallelism with the Puerto Rican levels, and this is borne out when the ranges of elevation of each surface are taken into account. In Puerto Rico, the 330- and 160-m. groups of surfaces are perhaps the most conspicuously developed and, from Choubert's map, this seems to be the case in French Guiana, too.

Furthermore, Martin-Kaye has directed attention to the conspicuous concordance of summits in the northern Lesser Antilles at or just above, 1,000 ft. This would seem to correlate with the 330-m. group in Puerto Rico and French Guiana. It seems scarcely likely that such correspondence of levels is a chance one, and I was reluctantly forced to the conclusion that these levels must be related to large eustatic lowering of sea-level and that the stage-by-stage emergence of Puerto Rico was not brought about by tectonic movements as had previously been taken for granted. An overall fall in sea-level since pre-glacial times has already been postulated by Wooldridge and others, at least from 600 ft. above present sea-level, and even greater movements of sea-level have been hinted by Baulig and Hollingworth.

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CLOUD-BURST TRACKS AND WATER GAPS IN ALABAMA

Anonymous; *Science*, 3:276-277, 1896.

A report on the Coosa coal field by A. M. Gibson (Alabama Geol. Survey, 1895) gives a description of two great scars on Coosa mountain, produced by cloud-bursts that accompanied the tornadoes of July, 1872. On the northwest side of the mountain there is a washout sixty feet wide and three or four feet deep, extending down the mountain side. Trees, soil and rocks were all swept down, making great moraine-like heaps at the base of the slope. On the southeast side of the mountain there are several scars of even greater magnitude. From one of these rocks of all sizes were carried down to the low ground and there heaped over 'acres of ground.' One mass, estimated to weigh a hundred tons was carried half a mile.

It is to be regretted that the sanction of State publication should be given a few pages later to an antiquated account of 'Big Narrows' in Double mountain. "Some convulsion of nature must surely have made the break that let the waters enter here, or else it seems impossible that this stream could have cut through such rocky masses by a gorge so narrow, and leaving so little sign of abrasion on the perpendicular cliffs" (p. 32). If there were really reason to regard this gap as the result of a convulsion of nature it would deserve to be carefully described; and such a rarity would become a mecca for geologists and geographers; but as there appears to be no sufficient ground for thinking it different in origin from the hundred other water gaps of the Appalachians, the people of Alabama ought to have a reasonable explanation of its method of production.

FEATURES OF THE CENTRAL ARABIAN DESERT

Anonymous; *Popular Science Monthly*, 17:281-282, 1880.

Mr. W. S. Blunt read a paper, last December, before the Royal Geographical Society, on a journey he had undertaken during the preceding winter from Damascus to the Jebel-Shammar, in the region of Nejo in Central Arabia, in which he passed through a country that no European had visited since the journeys of Mr. Palgrave and Colonel Pelley in 1863 and 1864. On his way he traversed the red, sandy desert of the Nefud. Here he observed a strange phenomenon, which he describes as the only feature of the tract. The whole surface of the plain is pitted with deep horseshoe hollows, called by the Arabs fulj, which are shown to be permanent in site and conformation by the shrubs and bushes which line their sides, and by the tracks which cross and recross each other in such of them as are frequented by sheep. They are absolutely uniform in shape, differing only in size, and are all set with great regularity toward the same point of the compass. In form they exactly reproduce the print of an unshed horse's hoof, the toe pointing westward and being marked by a steep declivity, while the bottom of the hollow slopes gradually upward to the heel, until it reaches the general level of the plain. The frog of the hoof is roughly represented by a number of shallow watercourses converging to the lowest point, the toe. Solid ground sometimes occurs at the bottom of the deepest of the pits. They vary in depth from twenty to two hundred and twenty feet, and in width from fifty yards to half a mile; the appearance of depth is often enhanced by a sand-mound at the western edge of the hole. As seen from the tops of the higher rocks, the fuljes "run in long, sinuous strings with a main direction generally corresponding with their aspect," which gives them still more the appearance of huge horse-tracks.

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THE SAHARA DESERT ICE CAP

Fairbridge, Rhodes W.; *Natural History,* 80:66-73, June-July 1971.

One of the most extraordinary features of the sandstones lying above and to the north of the glacial moraines, was a belt where the sands had been swept by powerful currents into giant ripples ten feet or more from crest to crest, extending in a formation up to 100 feet thick and stretching out for several hundred miles. Giant ripples are formed by tidal currents in certain restricted areas today, such as the southern North Sea, the Celtic Sea, and in the Strait of Malacca. But the ripples in the Sahara are of vast dimensions. Could they represent the decanting of millions of tons of meltwater from the margin of the Ordovician glaciated region during the melt period? At such time, the release of the ice pressure would have permitted the earth's crust to rise rapidly to its former position. A similar spillover occurred in the Baltic after the last glaciation and likewise in Hudson Bay.

Traces of subglacial volcanoes are perhaps the most peculiar of the features not normally associated with sandstones. Eruptions commonly occur under the glaciers of Iceland today, so we have some living models. The lava rises up but is quenched by sudden contact with the ice. In the Sahara, we first saw these circular-shaped structures (about 500 to 3,000 feet across) on air photographs and thought they might be meteorite craters. But at ground level, we found that each had a core of basalt surrounded by a curious belt of fused sand and volcanic rock, like clinker, and all within a ring of the glacial sandstones forced up into a vertical position. In some places the glacial rocks and these intruding volcanic necks are overlapped by beautifully stratified shales of the Silurian age, dating from about 430 million years ago, which show no traces of ice or volcanoes. The Ice Age was definitely past. (p. 71)

UFOS AHOY!

Gregory, Janet; *FSR*, 17:29-30, September/October 1971.

"Commander Jacques-Yves Cousteau, the French underwater explorer, returned home this weekend to report a new mystery of the sea. At his base in Monaco he spoke of strings of puzzling blue holes that he and fellow scientists aboard the research ship Calypso spotted in the sea bed while cruising in the Caribbean.

"The blue holes were first observed, he said, when the Calypso was approaching British Honduras. From the surface they looked like giant tiddleywink counters lying in the depths. There were dozens of holes about 300 yards in diameter, some strung out in lines up to twenty-five miles long. But what surprised the scientists most was the near perfect circularity of the holes.

"Closer inspections showed that the holes were only a few feet deep---just enough to make the cavities show up dark blue against their surroundings. The mystery is how these cavities were formed. Commander Cousteau theorises that they were scooped out of the rocks by pelting rain back in pre-historic times when this part of the ocean floor may have been above the surface." (p. 30)

PLANS OF THE EARTH

It is the nature of scientists to see system in everything and to try and account for it. The jigsaw puzzle pieces of the continents and oceans have entranced geologists, geophysicists, and natural philosophers ever since accurate terrestrial maps became available. The rudely triangular continents and their suggestively conforming coastlines must be that way for some reason.

The modern dogma of Continental Drift and Global Plate Tectonics developed from this basic human urge, fanned by discoveries in geomagnetism and ocean-floor geology. Continental Drift, once anathema and now enshrined, faces scores of technical objections. To illustrate one class of objections, it has been noted that many continents fit together well regardless of where they now "float." Australia, for example, locks well into the U. S. East Coast. Like Evolution, Continental Drift seems to explain too many things too superficially.

Continental Drift was not the first earth-as-a-whole theory. Green's

Tetrahedral Earth is over a century old. Many other polygonal planetary plans have been promoted since---in essence expanding a patterned-ground mechanism to the entire globe. Large-scale catastrophism appears again in this section in the theory that the moon was torn from where the Pacific waves now roll. The idea of an expanding earth has its ups and downs, with today's adherents suggesting that it explains geological and geophysical data better than plate tectonics. The flourishing of so many theories ensures that we still have much to learn.

• Evidence for an Expanding Earth

GEOLOGICAL EVIDENCE FOR A PULSATING GRAVITATION

Machado, F.; *Nature*, 214:1317-1318, 1967.

Dirac suggested in 1937 that the so-called gravitation "constant" $\underline{f}$ could have been decreasing with time. A decrease of $\underline{f}$ has important implications---namely, an expansion of the Earth's volume and a decrease of solar radiation. Expansion will produce regression of the oceans and fracturing of the crust (with apparent migration of continents), and decreasing radiation will make the climate become cooler.

This is the sort of evolution which certainly occurred during some intervals of the Earth's history, and consequently Egyed, Jordan and other authors considered that the geological record confirmed the hypothesis of an expanding (and cooling) Earth.

Expansion, however, is no explanation for thickening of the crust in orogenic belts (as emphasized by Jeffreys), or for the production of oceanic transgressions. Both these phenomena definitely occurred in the past history of the Earth, and fairly warm climates appear to have alternated with the cold ones (even when allowance is made for polar wandering). It is therefore worth reviewing what the geological evidence really suggests for the variation of $\underline{f}$.

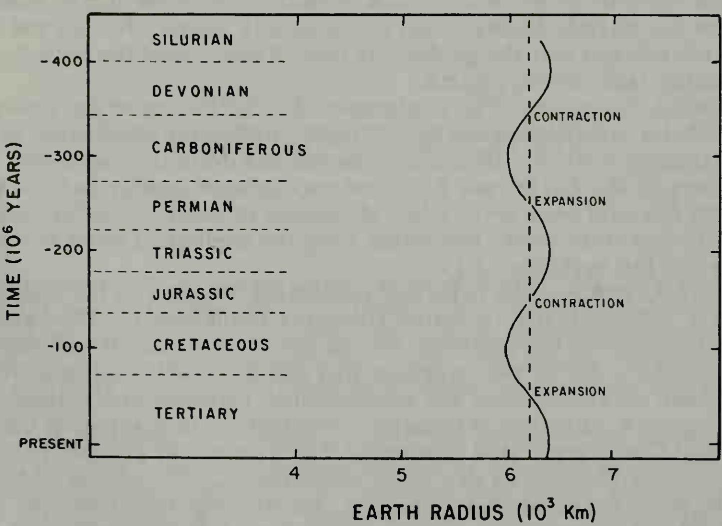
In Table 1, some of the principal geological features of the past 400 x 10^6 yr are schematically indicated (compare Brinkmann). The events which correspond to the intervals (I) and (II) are reasonably repeated, in the same order, during the intervals (III) and (IV), which is quite remarkable. Ocean transgressions and regressions, together with climate variation, suggest a pulsating gravitation "constant" with maxima at Carboniferous and Cretaceous, and minima at Triassic and at present time.

The tectonic phenomena are more complicated. Formation of oceans may have been a discontinuous process, but orogeny is not so easy to understand. It appears that crustal shortening (with corresponding increase of thickness) occurred during the geosyncline phase and produced a root of less dense rocks; folding, however, seems to have been a consequence of the following upheaval, as believed by many writers (see, for example, Beloussov); this latter phase occurred already during the intervals of expansion.

Notwithstanding the possible difficulties of interpretation, the geological record suggests a pulsating variation of f rather than a monotonic decrease.

Table 1. Geological Evolution (Devonian to Present)

Time Interval	Main Tectonic Events	Variation of sea level	Variation of climate
(I) Devonian to Carboniferous	Beginning of Variscan orogeny (geosyncline phase)	Mainly transgressive (rise of sea level	Generally getting warmer (?)
(II) Carboniferous to Triassic	Upheaval and folding of Variscan chains; probable division of Gondwanaland and of Laurasia	Mainly regressive (lowering of sea level)	Generally getting cooler (Permian glaciations)
(III) Triassic to Cretaceous	Beginning of Alpine orogeny (geosyncline phase)	Mainly transgressive	Generally getting warmer (spreading of corals)
(IV) Cretaceous to present	Upheaval and folding of Alpine chains; formation of present mid-oceanic ridges	Mainly regressive	Generally getting cooler (Pleistocene glaciations)



Possible variations of the earth's radius since the Devonian.

AN EXPANDING EARTH?

Harland, W. B.; *Nature,* 278:12-13, 1979.

[Harland begins with a brief review of the history of the Continental Drift Theory, noting that reconstructions of the history of continental positions seem to require more ocean spreading than can be swallowed up in mountain building. Faced with this dilemma, some geophysicists turned to the idea of an expanding earth to account for the apparent physical separation of continents.]

In the intervening years, from magnetic striping, the course of ocean spreading has been delineated with considerable precision so that latterly the problem was to estimate how far this generation of new crust was compensated by the, much more difficult to estimate, subduction in orogenic belts. H. G. Owen (British Museum (Natural History)) has plotted the striping in a series of detailed maps that also require a more modest, but nevertheless significant, expansion of the Earth during the past 200 Ma at least. Owen's expansion is less than Carey's because he recognises the evidence of subduction zones. It might be added that most plate tectonic reconstructions seem to get by with a steady size Earth but they generally do not plot ocean floor spreading details. In this respect Owen's work is so thorough that it cannot be ignored.

....

The palaeomagnetic test compares the palaeolatitudinal spacing on a continent with that on the present Earth. This assumes an inextensible continent, and a continuing geocentric magnetic dipole and would be capable of settling the question if only the errors were not too large. Results would seem to rule out any extreme expansion but might allow up to 5% over the past 200 Ma.

Earth's moment of inertia would change with increasing radius and there would be a marked slowing with expansion. Estimates of the number of days in a year have been made of around 400 days at about 400 Ma. This would not permit the recent rapid expansion hypothesis; but the critical observations on corals on which these figures are based have yet to be repeated more generally.

[In conclusion, Harland states that most geophysicists believe that the earth's rate of expansion cannot be greater than 0.11 cm per year, ruling out theories of rapid expansion.]

TOPOLOGICAL INCONSISTENCY OF CONTINENTAL DRIFT ON THE PRESENT-SIZED EARTH

Meservey, R.; *Science,* 166:609-611, 1969.

Abstract. Certain continents have in the past moved with respect to each other in a manner clearly implied by sea-floor spreading and other data. However, the resulting collective motion of all the continents was apparently not topologically possible on the present-sized earth. An expanding earth might resolve this difficulty.

LIMITS TO THE EXPANSION OF EARTH, MOON, MARS, AND MERCURY.....

McElhinny, M. W., et al; *Nature,* 271:316-321, 1978.

Abstract. New estimates of the palaeoradius of the Earth for the past 400 Myr from palaeomagnetic data limit possible expansion to less than 0.8%, sufficient to exclude any current theory of Earth expansion. The lunar surface has remained static for 4,000 Myr with possible expansion limited to 0.06%, the martian surface suggests a small possible expansion of 0.6% while the surface of Mercury supports a small contraction. Observations of Mercury, together with reasonable assumptions about its internal structure, indicate that G decreases at a rate of less than 8×10^{-12} yr^{-1}, in constant mass cosmologies, and 2.5×10^{-11} yr^{-1} in Dirac's multiplicative creation cosmology.

• Evidence for Earth-Moon Fission

ON THE PHYSICAL CAUSE OF THE OCEAN BASINS

Fisher, O.; *Nature,* 25:243-244, 1882.

Geologists have reason to thank Prof. Ball for directing their attention to the remarkable investigations of Mr. G. H. Darwin upon "The Precession of a Viscous Spheroid, and the Remote History of the Earth," (Phil. Trans. Roy. Soc., Part ii., 1879). Prof. Hull has already been led to point out one result which appeared to him to flow from them, in showing how the ancient tides may have produced the planes of marine denudation, though Mr. Darwin has since expressed doubts as to the legitimacy of this conclusion. I wish to offer another speculation arising from Mr. Darwin's work, which I think may account for the hitherto unexplained distribution of land and water upon the surface of the globe.

Herschel remarked long ago, in his "Physical Geography," that the prevalence of land and water over two opposite hemispheres "proves that the force by which the continents are sustained is one of tumefaction, inasmuch as it indicates a situation of the centre of gravity of the total mass of the earth somewhat eccentric relatively to that of the general figure of the external surface---the eccentricity lying in the direction of our antipodes: and is therefore a proof of the comparative lightness of the materials of the terrestrial hemisphere." In my "Physics of the Earth's Crust," just published, I have shown reasons for thinking that the distribution of the materials of the earth, which gives rise to this condition, is of the following kind. I accept on the whole the theory that the earth is a hot globe, of which the superficial crust is rendered solid by having become cool, and that the central part is solid, either from great pressure, or from whatever other cause may be assigned; an intervening layer beneath the cooled crust still remaining liquid. The layers of which the whole is composed are arranged in order of their density. Now I have given reasons for believing that Herschel's "comparative lightness of the materials of the terrestrial hemisphere" arises from the fact that the cooled crust beneath the continents is intrinsically less dense than that beneath the great oceans. I think that the crust beneath the continents consists of the cooled acid, or granitic, and therefore lighter magma, which ought naturally to have formed originally the entire superficial portion of the globe. But I conclude that the bottoms of the great oceans consist nevertheless of a crust formed out of the cooled basic layer. Beneath the cooled crust the laws of hydrostatic equilibrium would require that, if the substratum is truly liquid, it should be of the same density under both these areas. I also conclude that the upper surface of the basic crust which forms the floor of the oceans is really depressed below the mean surface of figure.

To these conclusions I arrived without being able to suggest any satisfactory explanation of the facts. I saw that they agreed with, and were supported by, the view of those geologists who assert that the great oceanic and continental areas have never changed places; but neither could I any better see the reason for this.

Let us now inquire whether Mr. Darwin's researches throw any light upon the subject. I shall refer chiefly to the summary and discussion of results appended to his paper, for it is small blame to a sexagenarian, not a professed mathematician, to admit that to follow the calculations is beyond the scope of his powers. As I understand Mr. Darwin, he thinks it probable that the moon and the earth were once a single mass, and that at the time when this mass was rotating at the rate of about one revolution in five hours the whole separated into two portions, the smaller of which went to form the moon; and that the moon then began to recede from the earth, until now, after the lapse of fifty-four millions of years or more, it is at its present distance. The ellipticity of the mass when rotating at the above-named speed would be about 1-12th. [This would make the mass very much less compressed than an ordinary orange.] He does not think it probable that this amount of ellipticity would cause the spheroid to break up simply from the centrifugal effect of the rotation; but he suggests, judging from the calculated period of a gravitational oscillation of a fluid spheroid, of uniform density equal to the mean of the earth, viz. 1 hour 34 minutes, that the period of the free oscillation of a spheroid "consisting of a denser nucleus and a rarer surface," but of the same mean density as the earth, might coincide with the period of the bodily solar tide at that time. "It seems to be quite possible that two complete gravitational oscillations of the earth in its primitive state might occupy four or five hours." "Accordingly the solar tides would be of enormous height." He then adds: "Does it not then seem possible that, if the rotation were fast enough to bring the spheroid into anything near the unstable condition, then the large solar tides might rupture the body into two or more parts? In this case one would conjecture that it would not be a ring that would detach itself."

I now proceed to build my speculation upon his. It is obvious that, according to the above theory, the act of fissiparturition by which the moon was born must have been sudden. One of the two solar tidal protuberances broke away from the earth to inchoate a separate existence. A great but shallow hole must consequently have been formed, whose centre would have been on or near the equator. Prof. Ball says: "Not for long would that fragment retain an irregular form; the mutual attraction of the particles would draw the mass together. By the same gentle ministrations the wound on the earth would soon be healed. In the lapse of time the earth would become as whole as ever, and at last it would not retain even a scar to testify to the mighty catastrophe."

I form a less hopeful prognostication. I think the ocean basins are the scar, which still testify to the place of separation.

The density of the moon is 0.56654 times that of the earth. Putting the mean density of the earth at 5.5, this makes the density of the moon 3.1. The density of granite is about 2.68, and that of basalt 2.96. Consequently the density of the moon is a little greater than that of the basic layer of the earth's surface, which I think we may expect to occur at the sea-board at a depth of about 25 miles. The entire mass of the moon is 0.011364 of the mass of the earth.

Accordingly, it would require a layer of about 31 miles thick, of the density of granite, to be taken off the surface of the primitive mass to make a body of the mass of the moon; and if the mean density of the matter removed was the same as that of the moon, a somewhat thinner layer would suffice. But if we reduce the area of the skin removed to the area of the oceans, it would require to be $\frac{197}{146} \times 31$, or about 41 miles deep. Hence a uniform layer rather less than 41 miles thick taken off the oceanic areas would be sufficient to make the moon.

Of course the layer removed would not, in fact, have been of uniform thickness. But the above estimate gives an idea of the size of the cavity which would be produced. What then would happen? This would depend upon whether the surface had already become at all solid. I conceive this would be the case at a very early stage, judging from the manner in which a solid layer forms on the liquid lava of Kilauea. The hole would therefore fill up by the rise of the liquid from below, rather than by the lateral approach of the edges of the wound. When the raw surface again solidified we should have a crust of greater density over the area in question, because formed from a lower and denser layer, which would have risen not quite to the level of the lighter crust. There would, however, have necessarily been a certain amount of flow in the upper fluid layers towards the cavity, and this would have carried the cooled granitic crust which, floating on it, still remained upon the earth along with it. What was left of the granitic crust would therefore be broken up into fragmentary areas, now represented by the continents. This would make the Atlantic a great rent, and explain the rude parallelism which exists between the contours of America and the Old World.

The sudden rupture of so considerable a fragment from the rotating spheroid, would alter its mass, form, and moment of momentum. It appears then that its axis of rotation would be altered, which might account for the fact, that the approximate pole of the oceanic area is not in the equator.

The volcanic surface of the moon, if volcanic it be, would lend considerable support to the view which I maintain, that the water substance emitted by volcanoes is an integral constituent of the fluid substratum. For when the moon broke away from the earth it would carry with it the aqueous constituent of the magma. Owing to the much smaller force of gravity in the moon, the pressure under which this would there be placed would be much less than in the earth. Consequently it would more easily escape, and the signs of volcanic action would be more pronounced. But the difficulties surrounding terrestrial vulcanism are so great, that one is hardly tempted to add the lunar to them.

• Continental Drift Contradicted

CRITIQUE OF HYPOTHESIS OF CONTINENTAL DRIFT

Oppenheim, Victor; *American Association of Petroleum Geologists, Bulletin,* 51:1354-1360, 1967.

Introduction. The controversy concerning the hypothetical drift of continents began with the well-known publications of Wegener (1912, 1924) and DuToit (1927, 1937). The bases for the hypothesis were the similarity or "fit" of the Atlantic coasts of Africa and South America and the assumed geological, paleontological, and paleoclimatic correlations between the two continents. These correlations originally were based on the ideas of Suess (1888) who first called attention to the Permo-Carboniferous Glossopteris-Gangamopteris flora found on the continents of South America, Africa, Antarctica, Australia, and the sub-continent of India. A widespread Permo-Carboniferous glaciation likewise affected large areas on these continents of the Southern Hemisphere which Suess named Gondwanaland. According to Wegener, DuToit, and their followers, the vast continental mass---Gondwanaland---consisting of the five continents or continental areas combined into one, broke into separate continental masses as a result of fragmentation and drifted apart, eventually reaching their present positions. The separation of the individual continents began to take place, presumably, in late Mesozoic time and culminated in Early Cretaceous time. The postulates of continental displacement as presented by Wegener and DuToit ascribed westward movements to South and North America, and required displacement of the South Pole to justify the inferred correlation of paleoclimatic conditions. Thus, continental drift and polar wanderings became part of the hypothesis which is now being vigorously supported by Runcorn (1962) and his followers.

Van Waterschoot van der Gracht and others (1928) have expressed the prevailing trends of thought of the time. Since 1928, a considerable amount of physical, geophysical, and geological material on continents and oceans has been assembled. The relatively thin Earth's crust is, obviously, not unchanging and the continents, as they exist today have not always had their present configuration and composition. Continental margins have been changing and marginal blocks have undergone displacement, yet the acceptance of a notion of random drift of continents over the surface of the Earth would require a far stronger set of convincing geological and geophysical facts than any known to date. Most of the Earth's surface is inaccessible to direct geological observations and, although geophysical measurements and computations have supplied considerable new information on the interior of the Earth, the ultimate knowledge of the structure of the crust and its development can be reached only through the study of the underlying mantle.

The present basic information about the mantle and the Earth's interior is derived from the following sources: (1) extrusive and intrusive rocks; (2) geodetic, gravity, geothermal, geomagnetic, and geochemical observations; (3) seismological observations; and (4) isostatic measurements. However, geophysical considerations or mathematical deductions per se would have to remain subordinate in the interpretation of the crustal development to the tectonic and geological observations.

Geophysical Considerations. Some of the geodetic and geophysical conditions or postulates which radically affect the concept of continental drift are examined here briefly.

The latest and most effective tool in measuring the shape and gravity of the Earth has been provided by the artificial satellites. Combining ground and satellite geodesy, which complement each other, new important information has been obtained. Specifically, the Earth is not uniformly spherical. This information leads to the description of the Earth geoid as a flattened ellipsoid of revolution with four isolated protuberances and corresponding depressions. These were located (Newton, 1964) in (1) the western Mediterranean, (2) near New Guinea, (3) west of South America, and (4) between South Africa and Antarctica. Their counterparts, the depressions, are found (1) near the tip of India, (2) near Bermuda, (3) between Hawaii and Japan, and (4) near the Ross Sea, off Antarctica.

Thus, the irregular ellipticity of the Earth, as shown by gravity measurements from satellites, indicates that it is not in a state of hydrostatic equilibrium which was formerly assumed from ground-level measurements. This evidence that the Earth departs from hydrostatic balance, by a value that could exceed the strength of its materials, raises the question whether convection currents or other random motions within the Earth, capable of exerting excessive outward stresses, are at all possible. The alternative condition could be immobility or symmetrical motion around the Earth's axis, none of which would satisfy the concept of convection currents and its essential application to the hypothesis of continental drift.

Further, gravity measurements both from the surface and from orbiting satellites indicate that, on corresponding levels, the average gravity values over oceans equals the gravity values over continents; thus, only differences in density of deep-seated material within the mantle could compensate for the differences observed on the surface. It is also well known that the heat-producing radioactive elements in the thick continental crust exceed by far those in the thin basaltic, oceanic crust. Nevertheless, because the outward flow of heat in continental areas equals on the average that of the ocean floor, it can be assumed (Jacobs, 1956) that differences in the radioactive composition of the mantle material must extend to depths of hundreds of kilometers. Thus the heat-flow and gravity observations indicate radical differences between the mantle below continents and that below oceans. The above considerations, showing a balance of heat-producing elements and of mass between crust with underlying mantle in both oceanic and continental areas, imply continent-forming conditions that may preclude a mechanism of horizontal displacement and instead point to a process of continent building through vertical segregation of material forming deep continental roots which, through accretion, formed early "proto-continents." The peripheral growth of continents could then have evolved through concentration of thermal stresses at the margins of the young continents, conceivably by a process not unlike the growth and emergence of island arcs (Oppenheim, 1947, 1948b) in unstable and active zones of crustal weakness, by a mechanism of predominantly vertical expansion.

Seismological observations have shown that the velocity of seismic waves changes considerably with depth, which proves that the composition of the material under the Earth's crust is not uniform; this composition changes with depth and probably is distributed in concentric layers. Recordings of deepest earthquake foci were made from 720 kilometers below the surface off the coast of Peru (Benioff, 1955) which implies (1) that continents must have deep-seated roots within the mantle and (2) that their structure below oceans (as well as that of their continental margins) is quite different from their structure below oceans. It would thus appear that, if the mantle consists of concentric layers of heterogeneous material, the displacement of large deep-seated continental masses through convection or other causes is unlikely; the stability of continental masses is implied.

Regarding paleomagnetism, many observers have shown that thermal demagnetization in older rocks which had been subjected to several high-temperature episodes has caused erratic discrepancies in paleomagnetic recordings in many outcrops. This is certainly considered in field observations. Paleomagnetism, on which the revived concepts of continental drift and polar wanderings are now largely based (Runcorn, 1962), has proved that the Earth's magnetic field has resembled an axial depole only since Eocene time. Considering the fact that, during most of Tertiary time, the magnetic poles have been moving at random within about 15° of the present geographic poles, there is no valid reason to assume that, during the preceding several billion years of the Earth's existence, a similar close relation between the geographic and magnetic poles had to prevail. In the present state of knowledge such an assumption for Mesozoic, Paleozoic, and Precambrian ages would be highly conjectural, if based solely on the evidence of Tertiary and Recent pole positions and their relation to the available paleomagnetic observations. Although it has been stated repeatedly that the north and south magnetic poles in Permian and Carboniferous times were located in the northwest Pacific and southeast Atlantic, respectively, and that the geographic poles were in the same areas, there is no evidence for this assumption.

Furthermore, there is no evidence for a dipole-magnetic-field disposition in pre-Cenozoic times. A non-dipole or multi-pole magnetic field for this planet would be quite plausible considering its asymmetrical, ellipsoidal configuration as revealed from the orbiting satellite data. Thus, according to a non-dipole disposition of magnetic fields, the various paleomagnetic poles obviously could not represent the one geographic axis of the Earth; consequently the paleomagnetic recordings in pre-Cenozoic rocks need not be related to the polar axis, a conclusion which implies that the available data may not reflect the Mesozoic and Paleozoic positions of the "wandering poles" and "drifting continents." It can be stated that far more thorough investigations are required before paleomagnetic interpretations can be accepted as a sole valid criterion for continental drift.

<u>Geological Considerations</u>. Factual geological information and inter-

pretation of field observations contradicting the continental drift hypothesis appear to be numerous. This is evidenced from the following structural features of South America, North America, the Arctic basin, and Antarctica, recorded by numerous field geologists during many years of field work. References to their individual contributions would be too extensive to quote here but this geological work is the indispensable basis for any structural interpretation of geological concepts.

South America

Although there exists a broad similarity or "fit" in the outlines of the Atlantic coasts of South America and Africa---a similarity which originated the notion of continental drift---this similarity does not take into account the effect of intense marine erosion of the coasts of these continents since Early Cretaceous time when the breaking up of the continents is supposed to have taken place. DuToit (1927) considered the vast Triassic basalt lava flows of southern Brazil as proof of the catastrophic separation of the two continents and which was preceded by the great outpourings of lava. The writer measured the lava traps of southern Brazil, and observed that they are the largest recorded on the earth (Oppenheim, 1934), covering an area of more than 1,200,000 sq km. However, the basalt lava beds are separated from the Atlantic coast by an extensive range of Archean granite and metamorphic rocks---Serra do Mar---which shows no evidence of regional rifting or thrusting. The Atlantic Coast of South America---the key continent for the concept of continental drift---in no perceptible measure reflects any evidence of such drift. Its structural pattern is everywhere characterized by normal block faulting observable in rocks of all geologic ages from Precambrian to Tertiary. The structure of the vast Parana basin in southern Brazil is unequivocally characterized by block faulting (Oppenheim, 1934; Sanford and Lange, 1960). The bathymetric and seismic observations of the Argentine basin, recently surveyed by the research vessel Vema and the Argentine Navy (Ewing et al., 1964), covering an area of 3,400,000 sq km between 30^{o} and 50^{o} south latitude and the Mid-Atlantic Ridge on the east, reveal the presence of approximately 2,500-3,400 m of horizontally layered sediments with no indication of tectonic disturbance or other structural anomaly. The Falkland Islands form an inseparable part of the South American continent, and the long eastward-trending Falkland Ridge connects the Argentine coast with the Mid-Atlantic Ridge, forming the southern limit of the Argentine basin. Within this seismically surveyed area of thousands of square kilometers, there are no indications of structural disruptions of the ocean floor such as might have been expected.

Regarding the old arguments, i.e., similarity of sedimentary formations on both sides of the Atlantic---eastern South America and Africa---the evident similarity of the paleoclimatic conditions represented by the late Carboniferous glaciation, and the close correlation between the Dwyka tillite of South Africa and the Itarare beds of South America (DuToit, 1927; Oppenheim, 1936), the arguments are impressive but climatic changes leading to widespread Pleistocene glaciations have not yet found an adequate and generally acceptable explanation. Such drastic changes affecting the entire Southern Hemisphere---South America, Africa, India, and Australia---the cause of which is difficult and puzzling to visualize, could have taken place without the concept of Gondwanaland and its disruption by continental drift. Similarly, it can be stated that the widespread association of the Glossopteris-Gangamopteris flora of southern Brazil with

with glacial Permo-Carboniferous sediments in eastern South America, South Africa, and the other glaciated areas of the Southern Hemisphere may imply sudden and drastic climatic changes favoring the distribution of such flora without necessarily justifying continental drift.

Examining the structure of the western coast of South America and the Andean Ranges, it is evident that, to this date, the large volume of geological surface and subsurface observations as well as the available geophysical data have failed to yield any indication of a westward continental drift. The structural pattern of the Andes indicates a westward growth of the Andean Ranges probably through evolution and successive accretion of consolidated volcanic chains, island arcs, and geosynclines as outlined earlier by the writer (Oppenheim, 1947). The geological evolution of the Andean Ranges can be studied along the length of western South America, through Chile, Argentia, Bolivia, Peru, Ecuador, and Colombia (Oppenheim, 1952). The prevailing pattern of faulting is largely normal, indicating the action of vertically directed stresses. Thrusting and low-angle faulting are secondary and of limited extent, mainly in the eastern Andean Ranges, facing the outer geosynclinal borders. Extensive batholithic intrusions of diorites and granodiorites characterize the western Andean Ranges. The continental shelf is narrow and its western termination abrupt, dropping to great depth in the Peruvian and Chilean trenches. It is in this area where the deepest-seated earthquake epicenters have been placed.

Likewise, the outer western edges of the Brazilian and Guiana shields lack any indication of westward thrusting. The contacts of the sedimentary formations of various geological ages, where observed in the numerous outcrops, appear as normal overlaps. Where the older shield rocks are faulted, the contacts with younger sedimentary formations appear to be undisturbed by thrusting. The prevailing structural pattern of the South American shields also is block faulting with no indication of thrusting or drag faulting. These surface and subsurface observations of the structure of South America have this far shown no tangible evidence of a westward drift of the continent. Some observable of physically recordable indication of drift in rocks from Precambrian to Pleistocene ages would have been expected, considering that a distance of more than 4,000 mi separates South America from South Africa.

Antarctica

Although geological information on Antarctica is still fragmentary, considerable progress has been made in recent years. The results of concerted efforts of numerous investigating teams during the International Geophysical Year (1957–1958), as well as the subsequent continuous studies of the U.S. Geological Survey field parties (Ford, 1964) in the Thiel and Pensacola Mountains of Antarctica, have yielded significant findings regarding the structure and tectonic development of that continent. It now appears certain that the vast landmass of eastern Antarctica represents one of the largest shield areas on Earth. Where exposed, it consists of older granite, and gneissic and metamorphic rocks of Precambrian to early Paleozoic age. The Transantarctic Mountains bordering the old shield form a system of ranges that crosses the entire continent, ranking with the world's great chains. This separates the East Antarctic shield from western Antarctica, a structurally younger and tectonically mobile province. According to Hamilton (1963) this structural pattern was caused by "broad epeirogenic up-arching" and upward crustal movements.

Another mountain range forming the backbone of the Antarctic Peninsula continues for more than 1, 500 km from the Drake Passage to Ellsworth Land and, bending around the island arc of the Scotia Sea, connects with the Mesozoic and Cenozic Andean ranges of South America. Hawkes (1962) states that a "relatively eastward movement of the Southern Pacific crust" could have disrupted the continental bond between Antarctica and South America, which should account for the occurrence of continental-crust rock types such as gneiss, schist, and amphibolite on the South Shetland and South Orkney Islands. The Antarctic Peninsula proper appears to have been a marine geosynclinal basin (Adie, 1962), possibly a continuation of the Andean geosyncline of late Paleozoic age. According to the latest radiometric age data, some of the geosynclinal sediments are Cretaceous. Middle Jurassic lacustrine fossils found in the northernmost part of the peninsula suggest normal sedimentation conditions. Orogenic activity, volcanism with outpourings of andesitic and rhyolitic lavas, however, persisted throughout Cenozoic and into historic time in the northern part of the peninsula and on some of the islands of the Scotia Arc.

It can be concluded that the structure of East Antarctica forms part of the framework of borderlands circling the Pacific basin with its young orogenic belts and Tertiary to Recent volcanic activity. The geological and geophysical information gathered to date indicates that the Antarctic continent evolved and grew by accretions to the early Precambrian shield of successively younger geosynclines. Thus, the structural pattern of Antarctica confirms what has long been known, that the circum-Pacific orogen has been part of the Pacific basin since before Mesozoic time. There is no evidence of the effect of a hypothetical continental drift anywhere in this part of the Pacific basin.

North America

It is assumed that North and South America were separated by an ocean till Tertiary time. According to the concept of Wegener (1924) and his followers, Laurasia in the Northern Hemisphere was the counterpart of Gondwana in the Southern Hemisphere. According to DuToit (1937), the folded orogenic belts of the Northern Hemisphere, the Appalachian Ranges of North America and the Caledonian and Hercynian belts of Europe, formed a continuous chain. Carboniferous-age coal measures also are believed to have been continuous before Laurasia broke up. The great gap of the Atlantic Ocean was, according to Wegener, caused by North America breaking away from Europe in late Tertiary time. The westward drift left behind Greenland which was the last area to separate from Europe. The similarities of the opposing coastal outlines on both sides of the Atlantic have been discussed by many authors for many years and they can be made to match. However, simple geographical coastal similarities, which could be accidental or temporary, are totally inadequate to justify the continental drift in the Northern Hemisphere as visualized by Wegener and his followers. There are considerable differences in the ages of the various orogenies which drifters interpret to have been continuous folded ranges (Holmes, 1945) before Europe and North America separated. To justify the presence of vast coal measures on both continents, Wegener conceived polar wanderings which implied radical climatic changes.

The considerable amount of detailed geological information on North America leads to a more plausible concept for the evolution of the North American continent than is assumed by the hypothesis of drift. The continent has evolved through the in situ magmatic differentiation and consolidation of the crustal area, with only secondary continental movements and adjustments. The Pacific coast of North America offers an example of such movements. Comparative studies of the San Andreas fault and its present activity seem to indicate that the coastal strip west of the fault, including possible Baja California, is moving northward at a rate of about 1 cm per year (Gutenberg, 1959). Other major continental faults with known relative movements, such as those in Japan, the Philippines, and New Zealand, demonstrate the known fact that large-scale horizontal movements do take place in certain marginal and local continental areas. This, however, does not justify a generalized concept of continental drift. A mechanism for the drift must support not only the concept of displacement in itself, but also fit with the relative setting of North America, Europe, and South America, before and after the hypothetical displacement and drift.

Although some large strike-slip faults (trans-current) faults are known in the circum-Pacific orogenic belt (Allen, 1962), none of them has been observed and studied as closely as the San Andreas fault. Other great rifts and fracture zones which traverse oceans, like the Mid-Atlantic rift, the Red Sea rift system, the East African rift, or the rift at the crest of the Mid-Indian Ridge (Girdler, 1964), prove that the Earth's crust is not permanently immobile and is subject to internal stresses. However, these rifts generally are oriented north-south and fail to fit the pattern of the hypothetical continental drift as advocated by Wegener and his followers.

The structural evolution of North America appears to have taken place around the old continental granitic core in the areas of Lake Superior, Wyoming, and the Great Slave Lake in Canada, where granite-forming events have been dated at more than 2.5 b.y. Subsequent growth of the continent evolved in cycles around the periphery of this Archean core in a generally arcuate pattern. Thus, it is plausible to assume that North America evolved through continental accretion, along lines first suggested by Dana (1873), the originator of the geosynclinal theory, and not unlike the modern analog of evolving geosynclines in areas of crustal weakness accepted and elaborated by Daly (1912), Stille (1936), Kay (1951), and others.

Arctic Basin

The Arctic basin bordering on North America, Europe, and Asia has in recent years been studied intensively by the United States and Soviet exploratory teams. The latest aeromagnetic and bathymetric data, and the surveys by numerous geophysical means, have revealed considerable information on the structure of the floor of the Arctic Ocean. Thus, the discovery of the Alpha Rise, the new submarine mountain chain---Lomonosov Range---and the adjoining basins was made by the study of submarine profiles and detailed bathymetric surveys. They indicate a pattern of vertical block faulting (Dietz and Shumway, 1961). This appears to be clearly expressed in prevailing truncated surfaces and step-like escarpments which are characteristic of the Arctic Ocean floor. The magnetic anomalies observed in the Central Arctic basin, the Alpha Rise, and the Canadian basin corroborate the block-faulted structural pattern of the ocean floor.

According to the magnetic observations of King et al. (1964), the North American side of the Lomonosov Range is formed of large sunken blocks of probable Precambrian rocks and differs from the Eurasian side of the range in that the magnetic profiles do not resemble oceanic profiles in the Atlantic or Pacific but, instead, shield profiles. The Eurasian side is underlain by material typical of deep-sea areas and, because of the belt of earthquake epicenters in that part of the Arctic, it could be related to the continuation of the Mid-Atlantic Ridge.

Thus, the available data confirming the block-faulted character of the Arctic basin contradict the hypothetical westward or northwestward drift of the North American continent. The tectonic stresses north of North America appear to be directed vertically. If Mesozoic or later drift had occurred, there should be structures indicative of tangential stresses north of the continent. The above considerations do not preclude the possibility that the Arctic basin as such would have been subjected to compressional or tensional stresses because of its position between continental masses and zones of crustal weakness. These factors, however, would have no bearing on the conjectural drift of the continent. If North America had drifted, some indication of large-scale horizontal displacement should have been recorded in the studies of the Arctic basin or reflected in the structure of the ocean floor. To date such evidence of drift is lacking.

Conclusions. The total range of observations recorded by numerous workers of geodetic, geophysical, and geological conditions of continents and ocean doors indicates that the notion of continental drift is an oversimplification of the complex structural conditions of the Earth's crust. This, however, does not imply that the continents are immobile. Fragmentation and partial displacement of fragments of continental blocks in relation to the main continental masses and the adjacent ocean floors could have occurred in numerous places during the past history of the Earth and are also taking place at present, without, however, involving the displacement of continental masses across thousands of miles.

The key to the understanding of the history and evolution of the Earth's crust lies in better knowledge of the mantle underlying the crust and a better understanding of the mechanism compelling motion of high-temperature masses in the mantle.

A more plausible interpretation of the causes of separation of continental masses may be found in the pattern of global crustal fracture zones circling the Earth, across the Atlantic, Pacific, and Indian Ocean floors. This pattern and the pattern of large continental fracture zones to which they apparently are related would suggest that expansion of the Earth's crust has taken place.

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"THE NEW GLOBAL TECTONICS": MAJOR INCONSISTENCIES

Meyerhoff, A. A., and Meyerhoff, Howard A.; *American Association of Petroleum Geologists, Bulletin,* 56:269-336, 1972.

Abstract. Geologic and geophysical data, from the ocean basins and the continents, are now sufficiently abundant to demonstrate that all proposed models for "the new global tectonics" are seriously in error. For example, several sets of paleoclimatic data---specifically, the distribution on the continents and shelves of ancient evaporites, carbonate rocks, coals, and tillites---can be explained only if the present positions of the rotational axis, continents, and ocean basins have been constant for at least 1,600 m.y. The distributions of fossil invertebrate and tetrapod faunas and floras likewise indicate the constancy of position of the rota-

tional axis, continents, and ocean basins for at least 570 m.y. Faunal realm studies are proving to be extremely useful, because they are unambiguous in demonstrating the relations among continents since Proterozoic time.

A truly devastating fact is that the topological requirements for moving the Americas away from Eurafrica eliminate any possibility of such movement unless the earth has expanded greatly during the last 150-200 m.y. Other space requirements for the continents do not permit east-west movements since Archean time of more than 100-200 km in the Northern Hemisphere. North-south movements of individual continents are limited to a few hundred kilometers---on the basis of paleoclimatic and paleontologic data. Movements involving the "opening" and "closing" of Tethys---from present-day Spain to New Guinea---are restricted by detailed field geologic studies to distances of less than 300 km. Geologic mapping during the past 100 years proves that north-south movements since Proterozoic time in the present Mediterranean Sea region of Tethys have involved horizontal translations of less than 200 km. If sea-floor spreading is taking place in the Tethyan belt, lateral movements have been---and are---restricted to mantle movements and the overlying lithosphere has been detached from the mantle.

Ocean-basin studies show that island-arc trench fills, where "subduction" supposedly takes place, are undeformed. The volumes of undeformed sedimentary rocks in layer 1 indicate (1) that sea-floor spreading has not taken place since Mesozoic or earlier time; or (2) that "subduction" must take place seaward from the island-arc trenches; or (3) that there is no such process as "subduction." Detailed studies of the Lesser Antilles and Tonga-New Zealand arcs prove that aseismic island chains seaward from both arcs have been in their same relative positions since mid-Mesozoic and late Paleozoic times, respectively. Preliminary studies of several other island-arc systems lead to similar conclusions.

Sediment fills in fracture zones crossing midocean ridges also are undeformed---a remarkable fact if sea-floor spreading is taking place. Many of these fractures continue onshore into the continents, where the proved senses of movement are the opposite of those predicted by "transform-fault" solutions.

JOIDES drilling results have been hailed as a "remarkable confirmation" of plate tectonics" predictions. The first dating of the "basement" basalts of JOIDES coreholes indicates that the "basement" beneath Mesozoic rocks is late Tertiary or younger. Thus another prop of "the new global tectonics" begins to crumble.

The points listed in the preceding paragraphs have been termed minor details. Are they?

OBJECTIONS TO CONTINENTAL DRIFT AND PLATE TECTONICS

Wesson, Paul S.; *Journal of Geology,* 82:185-197, 1972.

Abstract. This paper collates some problems of the continental drift hypothesis as formulated in its present aspect of plate tectonics. Many of the objections are long standing but apparently unknown to many geo-

physicists, while some are peculiar to the new global tectonics. The conclusions drawn, in order of probability, are (1) the continents have almost certainly not moved with respect to each other; (2) convection is not active throughout the whole mantle; (3) even if convection is active in the upper mantle it cannot account for drift; (4) pole positions derived from paleomagnetism, and results of this method of investigation in its global form generally, are afflicted with an unknown cause of error and are in any case too inexact for drift reconstructions. It is emphasized that this paper considers objections to drift only, except where prodrift data directly affect the antiargument; in these cases both sides of the matter are dealt with to avoid giving a wholly one-sided approach.

GEOPHYSICAL ILLUSIONS OF CONTINENTAL DRIFT

Mantura, Andrew J.; *American Association of Petroleum Geologists, Bulletin,* 56:1552-1556, 1972.

Abstract. The postulated geometric schemes for mobile plates, moving continents, midocean ridges, and convection cells in general are mutually exclusive. Regardless of which scheme of drift, sea-floor spreading, or plate tectonics is adopted, absurd contradictions result. Areas where plate tectonics should be clearly demonstrable---such as Iceland and India---are the very areas where the nonexistence of plate tectonics can be shown clearly and unambiguously. I conclude therefore that the premises of drift are false; that convection does not take place; and that, with so many contradictions and without a mechanism, drift, sea-floor spreading, and plate tectonics are fruitless exercises in nothingness.

GEOPHYSICAL ILLUSIONS OF CONTINENTAL DRIFT: A DISCUSSION

Dietz, Robert S., and Holden, John C.; *American Association of Petroleum Geologists, Bulletin,* 57:2290-2296, 1973.

Abstract. The "illusions of continental drift," as envisioned by Mantura, are not illusions. Continental drift is a necessary consequence of plate tectonics according to which the continents are embedded in a mosaic of even larger rigid lithospheric plates which drift in relative rotation on the earth's spherical surface. The plates are bounded by spreading rifts, subduction zones, and transform faults. Our reply is an attempt to answer the 20 questions posed by Mantura in his open letter to plate tectonicists. Many problems remain unresolved, but plate tectonics remains a strong, viable, and persuasive concept.

HOW CLOSELY DID THE CONTINENTS FIT TOGETHER?

Hallam, A.; *Nature*, 262:94-95, 1976.

[Continental drift is so well-established these days that any contradictory evidence is judged suitable for inclusion in these sourcebooks. One difficulty encountered by this grand synthesis is that the continents do not fit together as well as pieces in a jigsaw puzzle. Owen, rowing against the continental drift, for example, believes that the bad fits help prove the theory that the earth-as-a-whole has been expanding, creating vast cracks in its surface.]

The gist of his argument is geometric, that the celebrated Bullard fit of the Atlantic continents, and its successors such as the Smith and Hallam fit of the Gondwana continents, pose awkward problems of continental overlap and misfit which have not been adequately explained away. For example, many geologists have been worried by the loss of much of Central America in the Bullard fit, despite the fact that extensive areas of old continental rocks occur there, and attempts to get round this problem by seemingly arbitrary ad hoc tectonic displacements and rotations, have lacked plausibility.

Likewise, if one adopts the Smith-Hallam fit, West Antarctica does not run naturally into its obvious geological continuation in Patagonia. More disturbing perhaps, a large gap is left west of Australia, which has led to the suggestion that the Wharton Basin in that region was ancient ocean, now disproved by the Deep Sea Drilling Project which has demonstrated that the basin is underlain by oceanic crust as young as elsewhere. On the other hand, fitting India against Australia, as others have done, leaves a corresponding gap in the western Indian Ocean.

[In looking for missing pieces to the puzzle, some geophysicists have hypothesized the existence of large pieces of thinned and foundered continental crust; viz., the Voring Plateau off Norway, a wide area off Nova Scotia, a region off Angola, and (shades of Atlantis) a sector between Africa and America.]

An important implication is that a sector of subsided and attenuated continent well over 1,000 km wide in places must exist between Africa and America, and that the so-called Quiet Magnetic Zone is not entirely oceanic, as hitherto almost universally accepted by marine geophysicists.

VOLCANO SPACING IN EAST AFRICA

Smith, Peter J.; *Nature*, 265:206, 1977.

The near rectilinear pattern of volcanoes in the Galapagos Islands was first noticed by Darwin (in Geological Observations on Volcanic Islands, London, 1891) and the near-uniform spacing of Hawaiian volcanoes was first observed by Green (in Vestiges of the Molten Globe, Honolulu, 1887). Since then, numerous workers have claimed to detect regularities in volcano siting, and some have pointed out that the spacings of oceanic volcanoes in particular appear to be roughly equal to the thickness of the local crust. More systematic attempts to relate volcano spacing to crustal thickness were doomed to failure, however, because (as we now know) the crust is not the correct unit to consider in this context.

Interest in the problem of volcanic intervals therefore largely died out until in 1974 Vogt (Earth planet. Sci. Lett. 21, 235; 1974) revived it in the light of modern ideas on Earth structure. Vogt found that within oceanic provinces volcano spacings are indeed remarkably uniform. In 'continental' subduction zones volcanoes are typically 70 km apart whereas in island arcs they are 55 km apart. The separations of volcanoes associated with 'hot spots', on the other hand, increase with the age of the surrounding oceanic crust. But what, figuratively speaking, links all these volcanoes is the thickness not of the crust but of the lithosphere. Thus Vogt was able to show that within any given volcanic province the distance between adjacent volcanoes is roughly equal to the thickness of the local lithosphere.

But is this also true for continental volcanism? To find out, Mohr and Wood (Earth planet. Sci. Lett. 33, 126: 1976) have examined volcanoes along the northern section of the East African rift (roughly 15 N–5^{o} S). This is a particularly suitable area because, although data are fewer, lithospheric thicknesses are generally better determined than in oceanic zones and are known to cover a much wider range. In any event, there are sufficient data to allow Mohr and Wood to show convincingly that the volcano spacing lithospheric thickness relationship holds good for East Africa as well and is independent of the type of volcanic rock involved.

[Why the regular spacing holds everywhere is not at all clear.]

• Miscellaneous

RESEARCHES ON THE ORIGIN OF THE PRESENT STATE OF THE TERRESTRIAL GLOBE, OR ITS CRYSTAL-LIKE CLEAVAGE

de Hauslab, M.; *American Journal of Science*, 2:13:268-269, 1852.

This author after discussing the direction of mountains, and of dykes and cleavages among rocks, deduces some general principles with regard to their direction, and then explains his hypothesis that the surface of the globe presents approximately the faces of a great octahedron. In an octahedron there are three axial planes intersecting one another at right angles; and the positions of the circles on the earth's surface which he lays down as the limits of these planes (or their intersection with the surface) are as follows. The first circle is that of Himalaya and Chimborazo, passing from Cape Finisterre to the Himalaya, Borneo, eastern chain of New Holland, (leaving on its sides a parallel line in Malacca, Java and Sumatra,) to New Zealand, thence to South America near Chimborazo, the chain of Carracas, the Azores to Cape Finisterre. The second, passes along the South American coast and the north and south ranges of the Andes, the mountains of Mexico, the Rocky mountains, Behrings' Straits, the eastern Siberian chains, going to the south of Lake Baikal, near Kiatcha, the Altai, Himalaya, the mountains of Bombay in Hindostan, a point in the northeast of Madagascar (where the summits are 12,000 feet high), the mountains of Nieuwefeld, 10,000 feet high, Cape Caffres, Cape Moro de Saint Martha, to Brazil, the rapids of La Plata, Paraguay, Parana, the elevated basin of Titicaca, the Andes, Illimani near Jaen and the defile of Maranova. The third circle cuts the two preceding at right angles, and passes by the Alps, the islands of Corsica and Sardina, along the basin of the Mediterranean, the mountains of Fezzan, Lake Tschan, the Caffre mountains of Nieuwefeld, the Southern Ocean near Kerguelen's Land, the eastern of Blue mountains of New Holland, straits of Behring, Spitzbergen, Scandinavia, Jutland, etc.

These three great circles point out the limits of the faces of the great hypothetical octahedron. Each of the faces may be divided into eight others by means of lines of accidents of minor importance, so as to make in all forty-eight irregular triangles, a form of the diamond. At the intersections, M. de Hauslab observes that there are nodes of dykes, and along the lines or near them, all the mountains of the globe occur. The author gives an extended illustration of his subject and afterwards considers the particular history of the configuration of the earth's surface in accordance with his hypothesis.

M. Boue who adopts similar views adds as a note, that we should remember in this connection that the metals crystallize either in the tesseral or rhombohedral systems, and that native iron, the most common constituent of meteorites, is octahedral in its crystals.---pp. 178-194, Jan. 20, 1851.

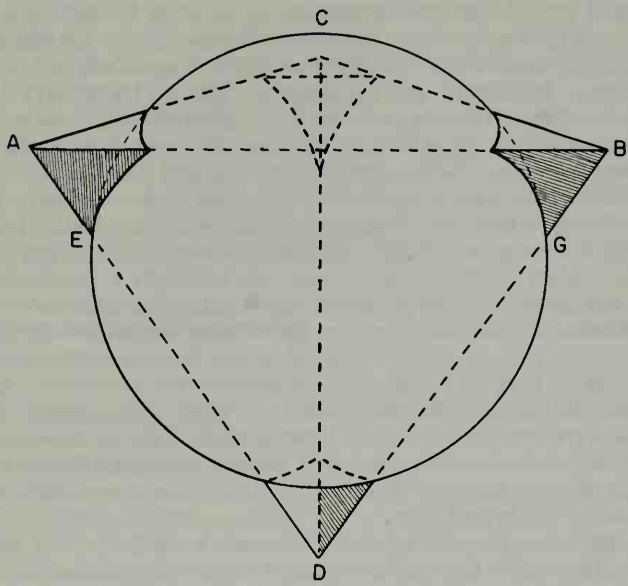
M. Boue afterwards states in a letter addressed to M. Viquesnel, that the hypothesis that the surface of the earth may lead to the idea of the globe's being a polyhedral crystal instead of a sphere was brought out by La Metheric in the Journal de Physique, xvii, 251; xlii, 132; xliii, 355; xlviii, 66; lxxi, 172, 382; lxxviii, 241; lxxxi, 288; and in his Theory of the earth in 1795 and his Lessons on Geology; also by Oken in his Lehrbuch der Naturphilosophie, 1809, pp. 149, 154; by R. Jameson, Mem. Wern. Nat. Hist. Soc. Edinb., 1814, ii, 221---p. 273, March 17, 1851.

THE TETRAHEDRAL EARTH AND ZONE OF THE INTERCONTINENTAL SEAS

Emerson, Benjamin Kendall; *Geological Society of America, Bulletin*, 11:61-99, 1900.

Green's Hypothesis of the Tetrahedral Earth. General statement of the hypothesis.---Attracted by the old Baconian problem of the three triangular continents projecting south, the three triangular oceans projecting north, the Arctic sea and the Antarctic land, Green chose the apparently unpromising tetrahedron as the form toward which the earth has imperfectly tended.

The hypothesis considers the earth to possess a somewhat rigid crust resting on a liquid interior which is shrinking from loss of heat. The law of least action demands that this crust shall keep in contact with the lessening interior with the least possible readjustment of its surface. The sphere of all solids, contains the greatest volume under a given surface, the tetra-



Tetrahedron placed symmetrically within a sphere with four projecting "continents." (After Green)

hedron the least volume under the same surface. The solid spherical crust of the earth, then, collapsing upon its plastic interior, would tend toward the tetrahedral form as the one which would coordinate the greatest diminution of the interior with the least change of the surface. There is a long series of tetrahedroid forms between the tetrahedron and the sphere, and the six-faced tetrahedron with rounded faces---the form so common in the diamond---may nearly approach the sphere, and may be supposed to be the form toward which the earth at first tends.

Four low, equal, and equidistant protuberances (A, B, C, D in figure 1) of rounded triangular boundaries rise equidistant on the surface of the model. Opposite each is a corresponding broad depression. If the body be supposed to be placed like a top on one of these protuberances, the other three would make the top three-shouldered, as they would be placed 120 degrees from each other. (Excerpt)

....

[The projections would form the primitive continents and the depressions, the ocean basins.]

THE ORIGIN OF THE EARTH'S LAND FORMATIONS

Perrine, C. D.; *Science*, 92:210-212, 1940.

The peculiar and very irregular distribution of the land and water areas of the earth's surface as well as their forms and constitutions have attracted attention since man has known of their existence as such. Explanations to account for some of these conditions have been made from time to time, but none has been wholly satisfactory and for some no explanation has been attempted. The object of this note is to put on record the chief points of a general theory which occurred to me some years ago, and which appears to explain satisfactorily a number of observed facts. It is recognized that the difficulties in the way of substantial proofs are very great. For this and other reasons of scientific caution, the hypothesis is presented tentatively for further study and future confirmation or rejection. It is my belief, however, that, in general and radical as it is, it will be confirmed, because some of the evidence is of considerable weight and I have so far found none which is prohibitory.

Several years ago, the principal points known at that time were placed (on a general invitation) at the disposal of a group interested in the progress of science and its dissemination, but as far as I know nothing has yet been published on the subject. These and other details will be given in a full discussion of the hypothesis which it is planned to publish if my impaired health permits.

The theory rests upon the possibility that the earth was bombarded in some past age by a meteoric swarm or swarms which came from a southerly direction. When the explanation first suggested itself, no facts were known which could throw light on this all-important point, the suggestion coming solely from two well-marked peculiarities of continental and mountain formation, viz., the accumulation of land in the higher northern latitudes with a complementary deficiency in the southern hemisphere, and the appearance of the Indian Peninsula and the Himalayan mountain ranges which give the impression of having been thrust northward into the Asiatic Continent. These suggested a force acting from the south. Later, the fact occurred to me that far the larger number of craters on the moon were in its southern hemisphere.

It is now generally accepted that such "craters" could have been formed by the impact of meteors. If, therefore, these "craters" or a considerable number of them, were formed in that way, the assumption is permissible that the earth may have been, and almost certainly was, bombarded in a similar manner. These circumstances provide the possibility of such meteoric action as could bring about the observed conditions.

Briefly, aside from the above, the principal observed facts and their bearing are as follows:

(1) The large land excess in the northern hemisphere and a corresponding deficiency in the south.

(2) The broadening out toward the equator of the continental areas from their pointed southern extremities and still more in the far northern regions where they form an almost continuous ring about the polar ocean.

(3) An open polar ocean and surrounding land mass in the north, and a continental land mass surrounded by water about the south pole.

(4) Generally greater elevations of the land above sealevel near the southern extremities of the continents than in their northern portions.

This is especially noticeable in South America, Africa, Asia and, to some extent, in North America.

(5) Low-lying and frequently marshy or desert areas of great extent in the northern and wider portions of the continental masses.

(6) Carboniferous deposits in these basins, including forests.

(7) As already mentioned, the peculiar appearance of the Indian Peninsula and the Himalaya Mountains to the north. If we look at a contour map of those regions we find the Himalayas folded around the northern and broad part of the Indian Peninsula in just such a manner as is conceivable if the triangular peninsula had been thrust into the Asiatic Continent from the south where we now find the extensive Indian Ocean.

(8) The distances from the South Pole of South America, Africa, India and Greenland all pointed at the southern end, are roughly in the inverse order of their size.

(9) During the Gondwana period the flora (Glossopteris) of India differed greatly from that of Europe but was strikingly similar to the contemporaneous flora of South America, South Africa and Australia.

(10) The southern portions of the South American and African continents are, in general, less temperate than corresponding latitudes in the north.

(11) No secular change in latitude has been established, at least for the continental areas of the northern hemisphere.

(12) Observed earthquake displacements in California, the Philippines and Japan show a relative movement of the continental areas on both sides southward with respect to the Pacific Basin.

(13) It is fairly well established by direct evidence that the earth's crust underneath the great ocean beds is of considerably greater specific gravity than the crust of the continental areas.

(14) The (average) specific gravity of meteorites composing such a swarm may vary from that of stone---say two and one half, to that of iron ---say seven.

(15) If, as is usually assumed, the planetary bodies were originally, like the sun, in a gaseous or liquid state, they should remain more or less homogeneous on solidifying, and the present large differences of specific gravity require explanation.

The above are the observed facts for which an explanation is required.

The following hypothesis outlines the course of events and the results which are conceived to have succeeded an encounter of the earth with a swarm or swarms of meteorites. It is assumed that the meteorites came from a southerly direction---not necessarily exactly in the direction of the pole, that they were numerous and that many of them were of considerable size. A single large meteor is not considered capable of having produced the observed effects.

If any considerable part of these meteors was of the heavy metallic type, we have at once a cause for the greater specific gravity of the earth's crust under the oceans. But such an assumption as to specific gravity is not necessary to the general action of such meteor streams because the ordinary stone meteorites are quite sufficient.

Coming from any direction within, say, 30^{o} or 40^{o} of the South Pole, such streams of meteorites could be expected to exert a pressure upon the earth's crust which would depress it where the pressure was normal to the surface, that is, in the regions more or less adjacent to the pole, and elsewhere to "sweep" the surface layers along toward the equator. The known fact that the earth is not perfectly rigid but slightly elastic, and the observed folding of the rock strata are sufficient evidence that such changes can take place. The indications are that these changes have taken place slowly rather than suddenly.

As a further result of such "sweeping" action we can conceive of the land accumulations in the northern hemisphere as formed in a way similar to the snow or sand drifts in the lee of an obstruction, the equatorial bulge acting as such an obstruction.

An alternative, slightly different conception, but one which is simpler and perhaps more probable, is that instead of heavy meteors being responsible for the greater specific gravity of the crust under the oceans, the "sweeping" process has affected only the lighter layers near the surface, pushing these northward and elevating them above the sea-level, thus exposing heavier layers deeper down. A fact favoring this conception is that the average specific gravity of the entire earth is approximately twice that of the continental masses. It may be that both conceptions are involved.

In a preliminary note it is neither necessary nor feasible to discuss in detail the bearing of the proposed hypothesis on all the different observed peculiarities which have been noted above. In most cases a possible bearing is obvious at a glance, which is enough for the present. That some of these relations are apparent rather than real and that not all will be confirmed, is to be expected. The hypothesis is too radical and too many factors are involved to permit of more than tentative acceptance for careful examination. There appears, however, to be no reason known at present for concluding that some such origin is impossible.

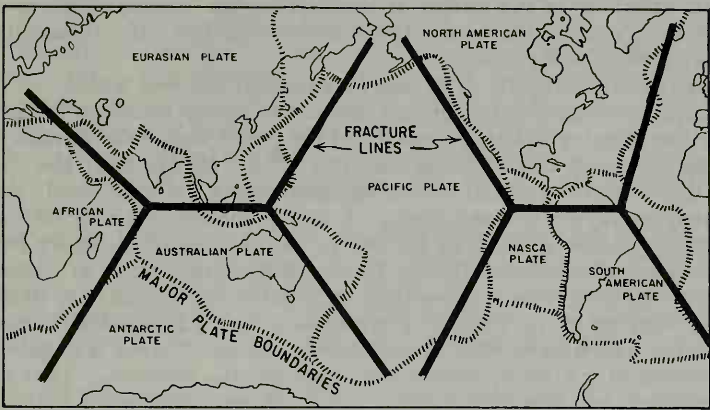
WERE GLOBAL PLATES CRACKED APART BY POLAR WANDERING?

Anonymous; *New Scientist*, 63:445, 1974.

Earlier in this century, geologists used to debate whether past climatic anomalies resulted from continental drift or polar wandering. Today plate tectonic movements satisfactorily account for these observations. However, polar wandering---accurately defined as the movement of the Earth's crust as a whole relative to the underlying mantle (the Earth's axis must remain fixed relative to the stars)---is still invoked to explain a large part of the palaeomagnetic record. Now a researcher at the Goddard Space Flight Center, Greenbelt, Md., suggests that the initial breakup of the Earth's crust into its component plates was caused by stresses resulting from polar wander (Journal of Geophysical Research, vol 79, p 2568).

Polar wandering as described above could itself be due to the slewing round of the rather thin crustal shell of rocks under the action of convection currents in the mantle. Since the Earth is a flattened sphere, however, this movement would force the shell to fit the Earth's equatorial bulge in a different place. The resulting stresses, Liu computes, reach a maximum of 10^9 dyne/sq.cm which is big enough to fracture the crust.

He goes on to deduce the likely pattern of the fracture which would result using a theory of the plastic deformation of shells. If the poles shift through 80° along the meridian of 75°W, the pattern looks like that in his map reproduced here. He points out the remarkable correlation with the boundaries of the six major global plates. Departures from the exact pattern could well be due to inhomogeneities in the crust.



Earth fracture pattern predicted by a theory of plastic deformation of shells.

GEO-ART: TECTONICS AND PLATONIC SOLIDS

Spilhaus, Athelstan; *American Geophysical Union, Transactions,* 56:52-57, 1975.

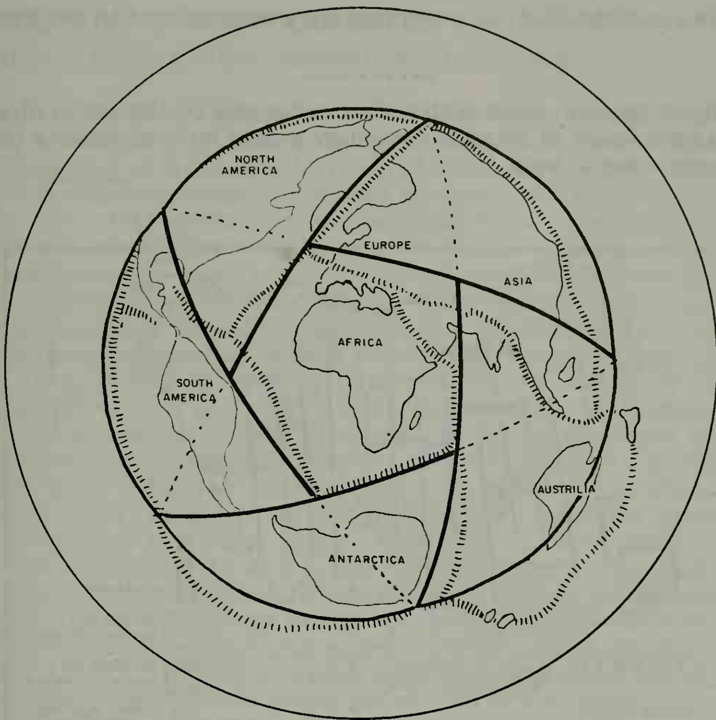
Mantura, in his criticisms of continental drift, argues about the 'curious shapes' of the crustal plates. I, on the other hand, am struck by the extraordinary regularity of the shapes of major plates and their relationship to the systematics of regular solids.

For example, in Figure 8 there is sketched an azimuthal equidistant projection of a regular icosahedron. Fisher and Miller and others have used the icosahedral grid on projections to visualize distortions in area and shape. In Figure 8 the icosahedron is placed in a position so that its vertices most closely coincide with the triple points joining the boundaries that the geophysicists had observed. The resulting picture shows the formal icosahedron in remarkable agreement with the plates as observed in nature. I find reasonable coincidence of the major orogenic foci with vertices of the icosahedron.

Edges join in triple points only in three of the platonic solids. Triple points are found, too, in some of the 13 Archimedean regular polyhedra. The simplest one is the 'icosidode-cahedron'.

Triple points are important, such as the cracks in Pangea, which typify what happens in a homogeneous material that is uniformly stressed.

Could the Platonic solids form the Sculptor's wire framework for the early origins of mechanisms within the earth that led to the regularity of the distribution of continents? (pp. 54-55)



Major tectonic plates of the earth (broken lines) compared with projection of a regular icosahedron (solid lines) on azimuthal equidistant projection. (Fig. 8)

THE WORLD IS A BIT CRACKED

Norman, John, and Chukwu-Ike, Muo; *New Scientist,* 73:320–322, 1977.

Figure 1 shows one of a number of sets of parallel lineaments in Nigeria revealed by the multispectral scanner carried by NASA's Landsat spacecraft. Most geologists will be surprised that there should be such a long, parallel, closely and regularly spaced system, and that all the lineaments should be so uniformly straight over such lengths. The spacing is of the order of the thickness of the Earth's crust. In the field only vertical movements are detectable along these lineaments (fuller details will be published by us in the February 1977 issue of the Transactions of the Institute of Mining and Metallurgy). Two other less continuous sets cross these meridional lineaments at 45°. Unlike the first set these show horizontal shearing, displacing the first set by up to several kilometres in places. These directions show the type of failure pattern that would be caused by a horizontal principle compressive stress in an east-west direction.

But what huge stress could cause such a regular pattern of straight failures, each hundreds of kilometres long? Perhaps the near-meridional orientation is a clue and the force may have been related to the Earth's spin.

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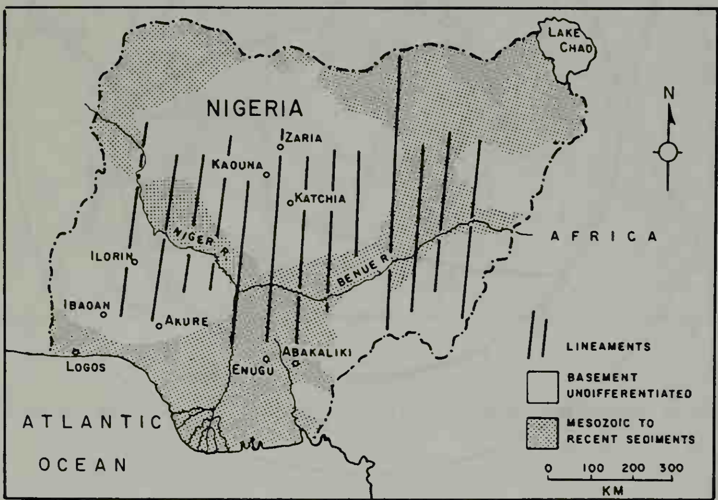
[The authors go on to suggest that the cracks may be the result of a change in the earth's speed of rotation caused by a near miss or oblique impact with a large cosmic body.]



One of the set of long lineaments in Nigeria that may have been created by crustal failures 500 million years ago.

MISCELLANEOUS TOPOGRAPHIC ANOMALIES

-Nieves Penitentes
-Cassia City of Rocks
-Stone piles collected by birds
-Hell's Mouth, Mexico
-Great subterranean cavern under Lancaster
-Natural dams

THE ORIGIN OF "NIEVES PENITENTES"

Anonymous; *Geographical Journal,* 26:91-92, 1905.

In spite of the many attempts, some of them more or less satisfactory, which have been made to explain the mode of origin of the well-known nieves penitentes of South America, the phenomenon continues to exercise the minds of physical geographers, and several new discussions of the question have lately appeared. Some of these contain suggestions which may help towards a fuller elucidation of the details of the problem, though the general principle---put forward independently, a few years back, both by Prof. Hauthal and Sir Martin Conway---that the primary cause is the differential action of the solar radiation, does not seem to be invalidated. In the Sitzunsberichte of the Munich Academy of Sciences (Math. Phys. Klasse, 1904, Heft III.), Prof. S. Gunther calls attention to the close similarity between the penitentes and earth-pyramids, and argues that this must be due to a similarity of origin. He enters somewhat fully into the causes to which earth-pyramids are due, holding that the capping by a stone or rock, though no doubt exercising a protective influence, is by no means of fundamental importance, but that the true cause is the dissection of a deposit of loose material by running water, first into continuous ridges, and afterwards (by an extension of the process) into single pyramids. This, too, he supposes to have been the mode of formation of the penitentes, their arrangement in regular rows being thus accounted for. To explain this regularity of arrangement, Prof. Deecke (Globus, vol. 87 1905, No. 15) has recourse to a supposed wave-formation induced on the surface of the snow by wind, giving an instance of a somewhat similar phenomenon observed by him in Europe in the case of snowdrifts thrown into wave-like forms and subsequently compacted by freezing. But against this is to be set the statement that the penitentes are usually found in spots sheltered from the wind. Perhaps the most ingenious explanation of the whole phenomenon is that suggested by Curt Facilides, in the Mitteilungen des Deutschen und Oesterreichischen Alpenvereins (1904, No. 21). This writer considers especially (1) The regular arrangement in parallel rows, directed in the Andes from north-west to south-east; (2) the limited zone of latitude within which the phenomenon has been observed. As regards the first point, he holds that the true cause is the shadow cast by the irregularities in the surface of the ice during the limited space of time (12 to 3 o'clock) in which the solar radiation is powerful enough to exercise much influence. The larger irregularities will, by their shadow, protect those lying behind them in the direction opposed to the sun, while the smaller will melt the sooner, thus exposing to the effects of radiation those lying behind in a similar direction. (It may be remarked that in any haphazard arrangement of such irregularities, there will always be certain systems running in a given direction, and in the case of these the protective influence of the shadows would, no doubt, be especially operative.) If this explanation is correct, it supplies a reason also for the limitation of the phenomenon to a definite zone of latitude, for not only must the elevation of the sun at noon reach a certain minimum, but there will be also a maximum beyond which the shadows thrown will be too small to have the supposed effect. It is, however, to be remarked that a formation closely resembling the penitentes has lately been observed by Prof. Uhlig on Kilimanjaro (Zeits, Ges. Erdk. Berlin, 1904, p. 632), so that the phenomenon would not seem excluded from the equatorial zone. This observer seems inclined, like Prof. Gunther, to attribute the linear arrangement to the action of the water-runnels, which would follow a direction parallel to the slope. These two writers likewise agree in distinguishing the penitentes from the Karren formed on the surface of glaciers, though while Prof. Gunther says that the former are really formed in ice, not snow, the latter, like Sir Martin Conway, speaks of the substance in question merely as hardened snow.

CASSIA CITY OF ROCKS

Anonymous; *Geographical Review,* 23:488, 1933.

In a basin of the Albion Range of southern Idaho lies the extraordinary assemblage of natural forms known as "Cassia City of Rocks." Turrets and fortresses, towers and spires, mosques and monoliths, human and animal shapes, natural bridges and caves, "bathtub" rocks, hollow boulders, and the like are carved from the granite outcrops. Nothing in North America matches this strange city, and Dr. Alfred L. Anderson, who describes it (Geology and mineral Resources of Eastern Cassia County, Idaho, Idaho Bur. of Mines and Geol. Bull. No. 14, Moscow, Idaho, 1931) suggests that it even surpasses the fantastic Buffalo Rocks of Victoria, Australia. Cassia City of Rocks must have been a familiar sight to pioneer travelers---the old immigrant road to California passes about a mile to the south---and it is well worth the attention of tourists. The Old Oregon Trail (U.S. Highway No. 30), now the main arterial road across southern Idaho, is within 40 miles to the north.

Dr. Anderson ascribes the formation of the rock city to "a complex set of factors involving deep granular disintegration and case-hardening under especially favorable climatic conditions, together with especially favorable structural features, not alone the widely spaced sets of vertical and horizontal joints, but also the protective quartzite capping on the upper side of the basin and the flanking ridge on the lower side which has maintained a proper balance between erosion and weathering by not permitting too rapid removal of the waste products such as would have occurred had erosion not been retarded by the more resistant rocks."

STONES COLLECTED BY EXTINCT BIRDS

Anonymous; *Science,* 60:sup xii, December 19, 1924.

Little heaps of semi-precious stones, scattered over the plains and hills of New Zealand, mark the last resting-places of the moas, gigantic ostrich-like birds only recently extinct. The moa, which was the largest bird that ever existed, carried pebbles in its gizzard, just as ordinary chickens do, to grind up its food. Since it lived largely on tough twigs of bushes, it needed especially hard stones. Where it lay down to die at last, the pebbles endured after even its bones had disappeared. Hence the little heaps of rounded chalcedony, quartz, chert, jasper and quartzite, ranging in size from 2-1/2 inches in length and 2 ounces in weight downward.

Professor W. T. Lee, of the U.S. Geological Survey, who calls attention to this phenomenon, comments on the good judgment of these extinct birds in choosing jewel stones for use in their lapidary mills. "By judicious selection of material, these first families among diamond cutters handed down lasting memorials to admiring posterity," is the way he puts it. Professor Lee also calls attention to the similarity in habit between these ancient birds and the still more ancient dinosaurs, who also swallowed hard semi-precious stones to grind their food. Collections of such stones have been found associated with dinosaur fossils, in approximately the spots where the monster lizards' stomachs found repose. The gizzard-stone habit persists among modern reptiles in the crocodile family who are also rock-eaters.

HELL'S MOUTH IN MEXICO

Leiva, Agustin Aragon; *Science News Letter,* 44:279, 1943.

Ezequiel Ordonez, dean of Mexican geologists, and Ricardo Mongez Lopez, geophysicist and dean of faculty of sciences of the National University of Mexico, will soon explore a mineral-lined pit, believed to be over a mile deep, which is located 80 miles south of Mexico City.

Many legends surround this enormous pit, called Hell's Mouth or Devil's Pit. Tradition says that Indians used the pit to kill enemies and punish criminals. Spaniards threw prisoners into its depths. During Mexico's Independence War and the civil wars which followed, men and women were entombed in the pit.

The rumors are that gangster murders have recently been committed in Hell's Mouth. In hunting for the body of a victim, searchers descended 1,500 feet into the pit. Cold, wind, and lack of air prevented a lower descent. From various measurements taken, it is estimated that the probable depth of the pit is 6,000 feet.

Mayor Bernabe Rios of Tasco, the nearby town, has decided to close the entrance to Hell's Mouth by dynamiting it or by otherwise barring access to the entrance. In this way he feels that he can remove from Tasco the notoriety connected with the pit.

Ordonez and Mongez will survey Hell's Mouth with the assistance of American miners working in Tasco. If it is found that it is not of geological interest, the pit will be sealed; if, however, the survey shows the pit may have geological value, further exploration will probably be made.

It is expected that the survey will also answer the question of whether or not Hell's Mouth is an entrance to the famous Cacahuamilpa Caves, located in the same region. Mineral formations clearly indicate that this pit has an origin similar to or common with the caves.

PROBABLE EXISTENCE OF A GREAT CAVERN UNDER LANCASTER, PA.

Anonymous; *Scientific American,* 14:228, 1866.

It is a well settled belief among many of our most intelligent residents, that underneath the city of Lancaster and vicinity their exists a vast cavern. Many facts are recited giving extreme plausibility to this theory, the most important of which may be briefly stated, as follows:

The city is located within the great limestone belt extending across the south-eastern part of the State, and of all the geological formations limestone the most abounds in caverns, many of which are known to be of vast extent. In sinking wells in certain parts of the city, the bottom crust breaks through before reaching water, and the pump is suspended from above by chains.

There have been several well authenticated cases in the vicinity of the city, of the crust of the earth breaking and engulfing farm animals. In two instances men engaged in plowing, saw their teams disappear beneath the surface and only a funnel-shaped cavity remained to mark the spot.

The earthquake of Sept. 29, as well as several lighter shocks, may be very reasonably accounted for by this theory. Huge masses of rock breaking from the roof of the cavern and falling into the depths beneath may cause such a quaking of the upper crust and dull rumbling noise as that which astonished the inhabitants on that day.

One of the most convincing proofs of the existence of this subterranean cavity is the discovery of an eyeless catfish in the waters of the Conestoga, a stream flowing past the city and supposed to connect with the hidden waters beneath. This fish is entirely destitute of organs of sight, having only small spots in place thereof.

In a celebrated grotto of Italy eyeless fish have been found, and it is inferred that the eyeless catfish of the Conestoga must originate in a similar underground locality and escape through the fissures of the rocks. I have endeavored to present as concisely as possible the principal facts bearing on the theory, and leave it for others to elaborate.

NATURAL DAMS OF HAVASU CANYON, SUPAI, ARIZONA

Black, Donald M.; *Science,* 121:611-612, 1955.

Inaccessible except on foot or on horseback, Havasu Canyon is a deep-sided canyon in the southwestern part of Grand Canyon National Park. It is reached only by steep winding trails.

Emerging from the Supai formation, some 2700 feet below the rim of the Grand Canyon, are a series of fresh water springs whose overflows join and flow down through Havasu Canyon. This creek, bearing the same name as the canyon, once had beautiful blue-green water. Hence, the Indians living there are called the Havasupais, which, translated, means "the blue-green water people."

In addition to its phenomenally colored water, Havasu Creek deposits spectacular mineral dams across parts of its course north of the Supai village. These dams sometimes build upward as much as 2 feet a year.

The local Indians give little thought to this until the water levels at the fords become so deep that their feet get wet when they are crossing them on horseback. When this annoying height is reached, the dams are breached with explosives until the water levels return to a convenient fording height.

Although they readily encrust any submerged twig or root, the minerals never seem to impregnate porous, dead bits of wood. Other than arching downstream, there is little consistency in the method of mineral deposition or in the structure of the dams. Anything resisting the flow of the creek tends to become encrusted with minerals and to initiate a dam. Analyses of mineral samples indicate that the subaqueous deposits are primarily calcite with some admixed clay. Remnants of older and higher deposits of minerals now visible along the lateral areas of Havasu Canyon contain layers of crystalline calcite, aragonite, and clay, as well as manganese oxide stains, on their weathered surfaces. Both old and recent deposits are rich sources of impressions of past and present vegetation in this region.

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Chapter 3
UNUSUAL ROCKS

INTRODUCTION

Macroscopic geology deals with stratigraphy and topography---the big picture. After these large-scale anomalies and enigmas have been ticked off, one is left with a host of microscopic puzzles. Individual rocks, fields of rocks, sands, and even muds pose their own mysteries; some perhaps trivial, others dogma-shaking. A tektite the size of a button may contain the seeds of a revolution in geology. A dune of musical sand engenders only a delightful legend of a buried monastery. Then there are fitting boulders, Libyan Desert glass, the moving rocks of western playas, and curious rock impressions called dinosaur leather. Obviously this is a catch-all chapter. The reader must be prepared for anything.

COLORS AND SYSTEMATIC SURFACE MARKINGS

Natural forces may alter the surface appearances of rocks in unexpected though not particularly mysterious ways. For reasons not entirely clear, some rock surfaces crack in regular geometric patterns. The polygonal symmetry of these designs is doubtless closely associated with polygonal cracking in soils and the tendency of some rocks to fracture into prisms and other regular shapes. Other organized surface markings seem to be the fossilizedtracks of animals orlife-associated imprints of some kind; viz., the so-called "dinosaur leather." Although life forms are usually blamed for these extensive displays of regular marks, details are not offered. The idiosyncracies of erosion also produce strange rock engravings, such as the "sunflowers" on rocks in the American Southwest. Finally, Nature frequently applies varnishes and other coatings to rocks. Desert varnish, for example, decorates rocks in a variety of climes and undoubtedly has a variety of chemical/environmental origins.

• Rock Colors, Films, and Varnishes

THE BLACKENED ROCKS OF THE NILE CATARACTS

Anonymous; *Geographical Journal,* 27:197–198, 1906.

The cause of the black surface film found on many of the rocks of the Nile cataracts is once more discussed in a paper by Mr. A. Lucas, chief chemist at the Survey Department Laboratory in Cairo (Cairo: National Printing Department, 1905). As is well known, such rocks occur, not only on the Nile, but at the cataracts of many great rivers, including the Orinoco, Congo, and Niger. An investigation of the subject by MM. Lortet and Hougounenq, the results of which were published in the Comptes Rendus of the Paris Academy of Sciences in 1902, was referred to in the Journal for December of that year (vol. 20, p. 655). Mr. Lucas has gone into the matter with unusual thoroughness, and has brought to light some new facts. He first discusses the question of the similar discoloration observed in the rocks of desert regions, and previously studied by Walther and others. A careful analysis of the film found on desert rocks was effected with the aid of strong hydrochloric acid, in which it is readily soluble, and this showed that, besides the oxides of iron and manganese, the film contained phosphoric acid and other ingredients not hitherto recognized. Doubt has been expressed by some observers whether all the rocks on which the film is found contain iron and manganese, but Mr. Lucas ascertained, on examining hundreds of different samples, that there was not a single instance of anything occurring in the film that was not also present in the rock below. All the constituents of the film, therefore, seem to be derived from the rock itself, the conditions necessary being a hot climate, coupled with occasional rainfall (or dew) by which the soluble compounds are dissolved, being afterwards brought to the surface by capillary attraction, and there forming insoluble oxides. In the case of the Nile rocks (granite, etc.) the film was again found to contain other ingredients than iron and manganese, but all these were likewise present in the rock itself, as also in the Nile water (both in suspension and solution). It is not easy to determine whether or not they are derived solely from the former source. All the conditions for the formation of the film from the rock in a manner analogous to that suggested for the desert film actually exist, as the rocks are almost always, if not universally, situated between the high and low water line. On the other hand, there seems to be evidence that the film may occur on permanently submerged rocks, while the fact that the rock is polished below the film, and certain indications of the occurrence of Nile mud also beneath it, would seem to favour the idea that it is a deposit from the water, as would also the similarity of composition of the film on the most diverse rocks. Lortet and Hougounenq considered the absence of the film from rocks below the cataract to indicate that it was not derived from the water, but Mr. Lucas shows that such absence is not quite certain, while the fact that the geological formations are naturally more resistant in the region of the cataracts would explain the prevalence of the blackened rocks in such localities. On the whole, however, he is inclined to consider the source of the film to be the rock itself, in the river no less than in the desert.

DESERT VARNISH

Hunt, Charles B.; *Science*, 120:183-184, 1954.

Desert varnish is a blackish or brownish stain of iron and manganese oxides on rock surfaces. As the name implies, desert varnish is best developed, or at least most conspicuous, in arid or semiarid regions; but similar staining also occurs in humid regions---in northeastern United States, in tropical rain forests, at high altitudes in the Alps, and on tunnel walls in the southeastern United States. Glacial and periglacial boulders at alpine levels in the Rocky Mountains commonly are stained.

The stain occurs on nearly all kinds of rocks---glassy, volcanic, and granular plutonic rocks ranging in composition from granitic to basaltic, sandstone, dense chert, and, more rarely, bull quartz. It is less common on limestone than on the less calcareous rocks.

The varnish may coat isolated bodies or the exposed and now dry surfaces of pebbles or cobbles forming a desert pavement. It may coat vertical or overhanging cliffs, or rock surfaces that are splashed by rivers or wetted by springs or seeps. It may develop on surfaces that are dark or poorly lighted, such as tunnel walls or joint planes. The coatings on joint surfaces or other slightly opened planes of parting in the rocks grade into vein deposits.

Although the stain appears to be composed largely of iron and manganese oxides, the proportions of these must vary greatly from place to place. Certainly the color and luster vary, although they are controlled in part by the fineness of the grain of the rock that is coated and in part by wind polish.

Such widespread deposits in such heterogeneous environments assuredly have heterogeneous origins. At some places, the stain appears to have been transported a considerable distance to the surface that is coated; at other places the coating seems to have been derived from weathering of minerals in the rock beneath it. Some stain assuredly was deposited by physical-chemical processes, but other staining appears to have been deposited biochemically. Either process, however, requires active moisture. In southwestern United States, the desert varnish seems to be in large part the product of past pluvial climates.

The conspicuous deposits of desert varnish on the Colorado Plateaus today are being eroded. On the cliffs, the varnish is preserved on smooth flat cliff faces or beneath overhanging ledges, but it has been largely removed from the rounded edges of joint blocks and from the more exposed upward-facing parts of the sandstone cliffs or buttes. Recent rock falls from the cliffs leave bright scars on surfaces otherwise darkened with varnish. Varnish still coats protected parts of isolated boulders, but it has been removed from their weathered rounded edges. Moreover, the conspicuous and extensive deposits are associated with a topographic unconformity that reflects a past climatic change. It seems clear that the conspicuous deposits of varnish in the Colorado Plateaus have a respectable antiquity and are the product of a past epoch.

The deposits of varnish that are forming today are restricted to places that are wetted frequently. Boulders lying between the high- and low-water stages of the Colorado River, for example, are stained; so are the sandstone cliffs where they are moistened by seeps. Such deposits suggest that the moisture requirements for deposition of desert varnish are considerable.

Archeological evidence indicates that the principal deposits of varnish on the Colorado Plateaus were formed prior to introduction of pottery. The masonry dwellings of the pottery-making Anasazai and related peoples are stained but little. Their petroglyphs were pecked into deeply stained rock surfaces, but the pecked figures, for the most part, remain fresh.

Locally, however, two generations of petroglyphs occur on the same cliff face, and the older may be stained. In southeastern Utah, the older set of petroglyphs commonly includes the square-shouldered conventionalized human figure of geometric outline that is believed to date from pre-pottery or earliest pottery times.

At such places, the exact dates remain uncertain, but the chronology is clear. First, there occurred extensive deposition of desert varnish, and this predated an occupation that may predate pottery. This occupation was followed by deposition of more varnish, and this deposition was followed by the occupation known as Developmental Pueblo---A. D. 500 to 900.

The younger varnish that formed during the interval between the occupations was deposited about the same time as one of the alluvial formations in the Colorado Plateaus. Presumably this was a pluvial period more or less at the beginning of the Christian Era. The older varnish may be as old as late Wisconsin in age.

It is suggested, therefore, that the principal deposits of varnish on the Colorado Plateaus were formed during the wet periods, and as such they can be useful in deciphering the stratigraphy of late Pleistocene and Recent deposits and events.

• Crack Patterns

POLYGONAL CRACKING IN GRANITE

Leonard, R. J.; *American Journal of Science*, 218:487-492, 1929.

Polygonal jointing or cracking of rocks has heretofore been largely attributed in geologic literature to shrinking and tensional cracking of rock material, either in the form of cooling lava or that of drying sediments. Recently, however, Johnston has shown that weathering agencies are now producing cracks of this pattern in a thoroughly consolidated arkosic sandstone of Newark age (Triassic), near Chapel Hill, North Carolina. He further discusses the occurrence of similar cracks in granite bowlders and concludes that these cracks also may have been formed as a result of weathering.

Exceptionally well-developed cracking of this polygonal type occurs in the granite of Cochise Stronghold, an embayment or pocket-like erosional excavation in the eastern slope, near the northern end of the Dragoon Mountains, in southeastern Arizona. The granite of this area is part of a large stock which forms the main mass of these mountains. It is a medium-grained rock of white color, but usually stained yellowish to reddish-brown on the surface. The granite mass is more or less intensely jointed. Weathering has produced a confusion of tumbled, rudely cubic or rhomboidal blocks, and prominent rough blocky and castellated outcrops characteristic of a much-jointed granite in an arid region. There is some rounding of the edges and corners of blocks, to be sure, but it is not pronounced and the aspect is blocky rather than bouldery. The faces of many large blocks and outcrops are wholly or partly cracked into polygons of varying size and irregular shape.

The faces of the joint-blocks displaying cracks are relatively plane surfaces, and the surfaces of the individual polygons are smoothly flat, are prevailingly of a light reddish-brown color, and appear to be glazed or varnished or case-hardened. The cracks separating the polygons are of various widths and depths, averaging probably between one and two inches in both depth and width, and commonly having nearly vertical walls. Occasionally, however, a crack may be several times as deep as wide and much narrower at the top; one such crack observed was six inches deep, one-half inch wide at top, and one inch wide near bottom. The walls of the cracks are always rough, are never smooth, and are somewhat iron-stained. As weathering advances, the less resistant material behind the polygons disintegrates and eventually the polygonal plates or slabs fall away from the rock mass, allowing more rapid and varied disintegration of the surfaces thus openly exposed to weathering activities.

....

Regarding the origin of the polygonal cracks, field evidence and theoretical considerations prompt the opinion that they were originally small fractures which were developed in the joint-block faces at the time of major jointing or afterwards and as a consequence of it. Later, upon exposure to atmospheric conditions, various processes of weathering have been active in widening and deepening the fractures so formed to produce the peculiar system of larger cracks now developed. The following observed facts seem adequate proof of this mode of origin: (1) the polygonal cracking occurs only in flat, smoothly hardened surfaces, quite evidently the faces of joint-blocks; (2) on blocks that are in place (outcrops), the cracks occur only in vertical faces; (3) recently-exposed portions of joint surfaces, as illustrated in Fig. 4, contain many small cracks which appear to have been formed long before the surfaces were uncovered to weathering attack. From a theoretical standpoint also, this interpretation seems equally adequate. It is generally accepted that most joints in massive igneous rocks are probably tension cracks resulting from the cooling and contraction of an originally fluid mass. It is logical to suppose that incipient fracturing within joint-blocks may occur more or less at the same time and by the same cause. Or the minor cracks might develop because of the absence of compressive stress on certain sides of blocks, as is common along the faces of cliffs. Again, cracks of this nature might be produced as the result of torsional strains induced by settling of the blocks after jointing. That granite does frequently contain small fractures of this kind, is shown by Ries and Watson in their discussions of building stones, where they state that certain intensely jointed granites which appear to be fresh interiorly, "are not infrequently traversed by minute cracks, which do not become noticeable until the stone is put in use." (Figs. omitted.)

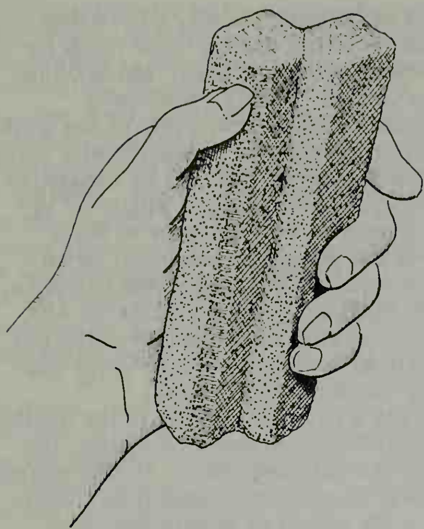
To ascribe the origin of these polygonal cracks exclusively to the work of weathering would demand an explanation difficult to reconcile with many of the observed facts. If the original fracturing was caused by expansive chemical changes, frost action, or temperature variation, singly or in combination, the effect of such forces should be evidenced by at least slight warping---bulging or curling---of the polygonal faces and by an uneven or pillowy structure of the block surfaces containing the polygons. It has already been pointed out that both block and polygon surfaces are notably flat and smooth. Furthermore, cracking should occur in the top or horizontal surfaces as well as in vertical surfaces of joint-block outcrops, if caused by eathering agencies. Such is not the case.

Although weathering apparently was not a principal factor in the origin of the cracks, it is fully evident that a particular process of weathering, granular disintegration, has been and is the dominant factor in the enlargement of the cracks since their exposure to atmospheric agencies. Their roughened walls, with mineral grains in all stages of separation from them, are convincing proof of this process. Whether the crumbling of the rock is primarily due to diurnal temperature changes, to the formation of frost or of secondary salts between mineral grains, or to solution and removal of mineral matter between grains, must be left for future observation and study to determine.

PRISMATIC SANDSTONE FROM MISSOURI

Haworth, Erasmus; *Science,* 19:34, 1892.

On the right bank of the St. Francois River, in S. 31; T. 33, N.; R. 6 E., about 200 yards south-west of the St. Louis Granite Company's quarry, near Knob Lick, in Madison County, Mo., is a little sandstone ridge, trending north-west and south-east, nearly 200 yards long, 10 yards wide, and not more than 8 to 10 feet high above the nearly level ground on either side. The country rock here is the Cambrian sandstone, which overlies the granite, as is beautifully illustrated at the quarry near by. This little ridge is interesting on account of the peculiar form of the sandstone composing it. In places where the soil has been somewhat worn away, instead of revealing flat layers of sandstone, as can be found near by in any direction, the surface is covered with fragments of sandstone of a prismatic form, resembling in shape the basaltic columns so well known in different parts of the world. In size the prisms range from about three-fourths of an inch to one and a half inches in diameter, and from three to eight inches in length. They are not uniform in geometrical outline, some having four sides, some five, and a few six. Quite often two and occasionally three prisms adhere together, side by side, but generally so loosely that they can easily be broken apart. In such cases the boundary between them is usually a single plane, but sometimes two new planes are exposed by the breaking, forming a re entrant angle on one prism. Fig. 1 fairly represents a combination of two of these prisms.



Prismatic sandstone from Missouri. Prisms are about an inch wide.

The nature of the rock was studied quite carefully, both macroscopically and microscopically, and it was found to be nothing but an ordinary, somewhat irregularly indurated, fine-grained sandstone. The grains of quartz are waterworn, as is usual. The induration is produced by the interstitial spaces being more or less filled with silica, but the thin sections examined showed no instance of secondary growth of the quartz crystals.

The existence of the ridge is probably due to the induration of the sandstone. Why this limited area should be thus indurated, and the surrounding country should not be, there seemed to be no obtainable evidence. However, this of itself is of little importance. But the prismatic form of the sandstone is much more interesting. The specimens gathered were on or near the surface, and were not seen in situ; but from their great abundance it must be argued that they extend downwards for a considerable distance. It was first thought that possibly a dike rock had once existed here, which had assumed the prismatic character, and that in some way by surface decay it had left moulds into which the sand had been carried. But a careful examination revealed no indication whatever of there ever having been a dike here, although they are quite common in the surrounding country. The granite close by is older than the sandstone, and could not therefore have played any part in the matter by metamorphosing the sandstone in any way.

If any of the readers of Science know of any other occurrence similar to this, or can suggest any cause likely to have produced this peculiar formation, it is hoped they will give the information through the columns of Science.

CRACK PROPAGATION IN SEA ICE . . . . .

Mukherji, B., *EOS*, 53:1009, 1972.

Abstract. Long cracks spaced at reasonably regular intervals have been observed in thick ice sheets in the Arctic. To help explain this natural phenomena within the framework of the established theories of mechanics of materials, an analytical modeling has been attempted. Analytical methods for fracture prone materials, such as ice, often take the critical stress intensity factor as a criterion for failure. Based on the Energy approach, involving computation of strain energy of a system in two adjacent cracked configurations, stress intensity factors have been computed for ice sheets with finite rectangular geometry. For a fixed thermal gradient across the depth, variation of the stress intensity factor for several levels of crack penetration and different logitudinal spacings have been studied treating the ice sheet as a two dimensional continum under plane strain condition and resting on an elastic foundation. Solution to the problem has been attempted by making use of an existing finite element computer code with some modifications to comply with particular requirements.

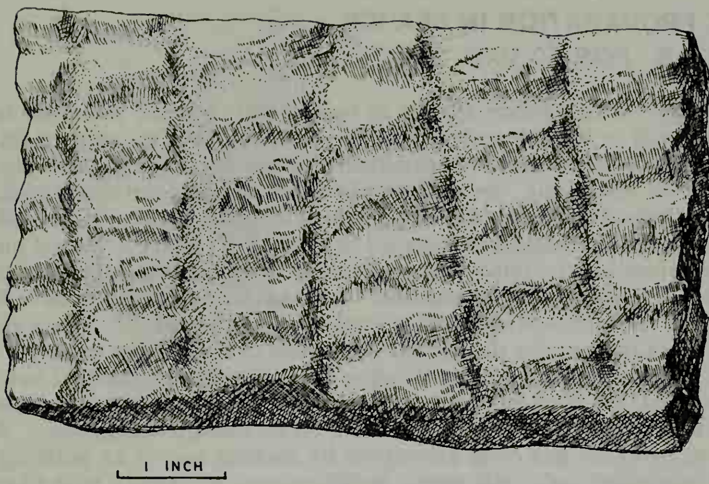
• Strange Patterns and Markings on Rocks

SOME UNUSUAL RIPPLE MARKS FROM THE TRIASSIC OF UTAH

Stokes, Wm. Lee; *Journal of Geology*, 58:153-155, 1950.

Ripple mark is one of the most commonly observed primary features of sedimentary rocks. It has been noted in rocks of practically all ages, and its various paleogeographical implications have been clarified by comparison with modern occurrences. Several detailed papers dealing with ripple marks have been written, and numerous writers have published illustrations and incidental comments in connection with broader investigations.

The purpose of the present paper is to place on record some unusual forms of ripple mark observed in the red silty facies of the Moenkopi formation near Temple Mountain, in the southeastern portion of the San Rafael Swell, Emery County, Utah. Conditions during Moenkopi time were evidently especially favorable for the production and preservation of ripple mark, since this feature is present over very wide areas and through a vertical interval of several hundred feet. All lines of evidence indicate that the red-bed facies of the Moenkopi were laid down in very shallow water or on mud flats marginal to and only slightly above the general level of the early Triassic sea in which highly fossiliferous marine beds were laid down farther northwest in Utah and Idaho. The



Unusual interference ripple marks from Utah.

present examples of ripple mark were obtained about 150 feet below the upper contact of the Moenkopi formation.

Plate 1, A, illustrates a commonly occurring type which corresponds with what Bucher has termed "hexagonal interference-ripple mark." The cross-bars are slightly oblique to the main ridges and have a staggered arrangement. A modification of the above type is illustrated by plate 1, B. It was produced by planing off the crests of ridges and cross-bars so as to leave a series of kidney-shaped depressions which mark the deepest parts of the troughs. The depressions are arranged in regular rows but vary in depth and distinctness. Examples of the rock were excavated from a bedrock exposure, and other similarly marked specimens were found scattered below the outcrop, so it is evident that the truncation of the ridges did not occur through recent erosion. The markings occur in a layer of sandy siltstone about 1/2 inch thick, which is underlain by soft red shale. Above the ripple-marked layer is another shale lamina which is about 1/3 inch in thickness and is followed by a sandstone layer with ordinary ripple mark about 3 inches thick. The markings suggest some sort of organic imprints but the evidence of production from and gradation into other types of ripple mark is clearly evident.

The specimen shown in plate 2 is the most complex example of ripple mark seen in the Moenkopi formation. Three components are evident: (1) prominent parallel ridges, (2) secondary lower parallel ridges, and (3) cross-bars. Kindle has published an illustration of a specimen showing the low intermediate ridge but makes no explanation as to origin. The cross-bars in the present example are low and broad with distinctly rounded crests, whereas the indentations or furrows between them are relatively sharp and narrow. The secondary ridges seem to be made up of a series of separate, poorly defined coalescing segments and are, on the whole, much less sharp than the other features.

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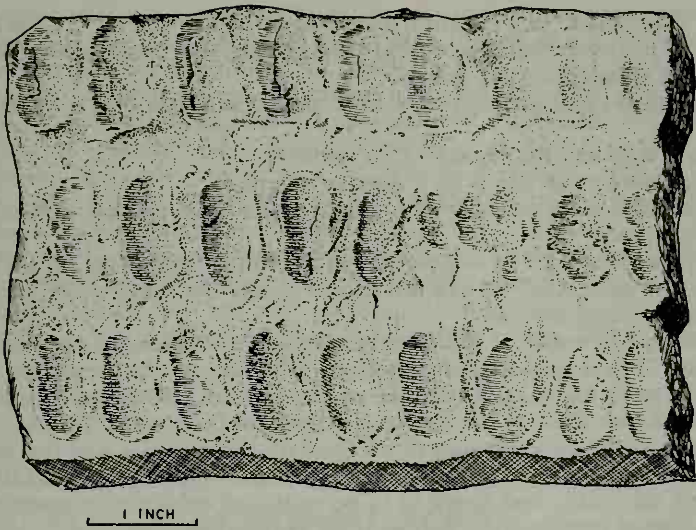


Truncated interference ripple marks from Utah.

FOSSIL IMPRINTS OF UNKNOWN ORIGIN

Vokes, H. E.; *American Journal of Science,* 239:451-453, 1941.

Among the multitude of fossils and pseudo-fossils constantly being sent to the Department of Paleontology at The American Museum of Natural History there occur specimens that at times baffle all the members of the staff. Recently one such specimen was received from Mr. Oscar T. Lewis of Billings, Montana, and is here illustrated in the hope that some one may be able to enlighten us as to its origin.

According to Mr. Lewis the fossils occur "in a lower member of the Colorado Shale' at the top of a sand formation, possibly the Nowry (?)." They consist of series of stellate imprints ranging from two and three-eighths to three and one-quarter inches (60 to 80 mm.) in diameter, composed of eight sharp grooves which appear to have been made by pointed "toes" which were contracted toward the center resulting in the development of an uplifted pile of sand at the inside end of each groove. The central circular area within the ends of the grooves is from one and one-quarter to one and one-half inches (32 to 38 mm.) in diameter. The grooves on an imprint 64 mm. in diameter are each 16 mm. long, 2 to 3 mm. wide and 1 to 4 mm. deep.

Mr. Lewis states that these imprints occur in series and generally center from three and one-half to five and one-half inches (90 to 140 mm.) apart. One imprint occurs which is partially superimposed on another. They are known from two localities, three miles apart, which occur southwest of Billings, Montana.

The matrix on which they are found is a fine grained, light gray sandstone or "siltstone" in a stratum about three inches thick. The stratum is finely to coarsely laminated, the laminae showing marked evidence of cross-bedding and current action.

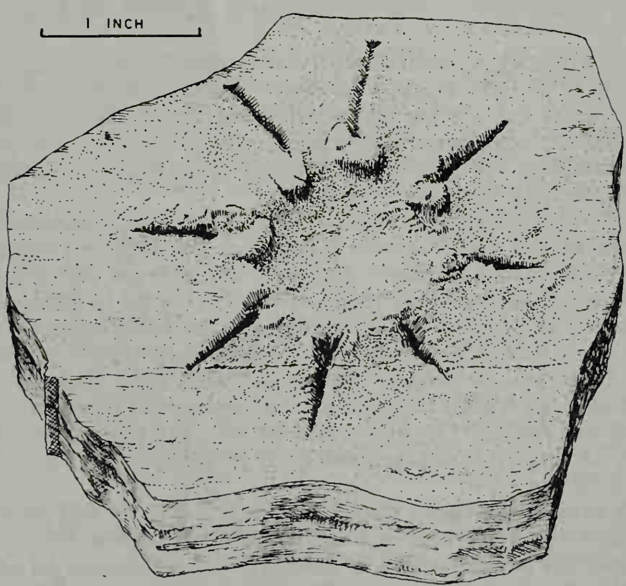
Three types of suggestion have been made as to the origin of these imprints:

(a) That they are the tracks of an animal;
(b) That they were made by a marine worm;
(c) That they were made by the mouth parts of some bottom feeding organism.

Objections to all three suggestions are readily apparent. If they are the tracks of an animal we are not aware of any type that would produce such eight pronged prints.

Dr. Walter Granger of the Department of Paleontology, and Mr. Junius Bird of the Department of Anthropology, who visited the localities where the fossils were found, say that one of the remarkable features of the imprints is the fact that, if the grooves represent the contraction of "toes" or "spines" in the progression of an animal, the grooves and the matrix pulled inward at the time of the groove formation are always equally developed on all sides, and there is in no case any evidence suggestive of the direction of progression unless it be vertical.

Dr. Walter Bucher, of Columbia University, to whom the imprints were described, but who has not seen the specimen, mentioned that he had observed somewhat similar markings made by marine worms, the circular central area being the site of the burrow, the surrounding markings being made by the tentacles. Objections to such a suggestion as to the origin of the present fossil seem to be (1) that no known marine worms have tenta-



Eight-rayed fossil imprints of unknown origin.

cles equipped with organs of sufficient hardness to permit the scraping of the distinct grooves noted, and (2) an examination of one broken print indicates that the laminae of the "siltstone" matrix are not disturbed and are apparently continuous across the entire area below the print.

The third suggestion, that they were made by the mouth parts of some bottom feeding organisms has been offered by a number of people, who have seen the specimen. A number of objections remain to be answered, however. The presence of eight, rather than five grooves would seem to eliminate the echinoderms from consideration while the nature of the radial grooves does not conform to anything that would be developed by any of the known cephalopods or bottom-feeding fishes. Furthermore, it would be expected that any such method of formation would tend to leave raised areas of mud in the center of the imprint rather than at the ends of the grooves.

....

A PECULIARLY MARKED SEDIMENTARY ROCK

Talmage, J. E.; *Journal of Geology,* 4:653-654, 1896.

The author describes and illustrates a fine-grained argillaceous sandstone, bearing peculiar surface markings consisting mostly of straight lines intersecting at right angles with almost mathematical precision. The deposit was examined by the writer in place, and an extensive collection of specimens was made under his direction by the "Utah University and Deseret Museum Expedition of 1895." The formation consists of undisturbed sedimentary deposit, referred to Trias or Jura-Trias age, and occupies a relatively low table land between the Kaiparowitz and the Paria plateaus on the north of the Colorado River near Glen Canyon, Arizona. The bed of marked rock is almost two feet thick, and lies conformably between deposits of coarser sandstone, which show none of the rectilinear markings. While the most regular arrangement of the marks appears on slabs with perfectly flat surfaces, yet the rectilinear intersections are plainly shown on warped and ripple-marked surfaces. The lines are so regular as to suggest the possibility of human instrumentality when hand specimens only are examined.

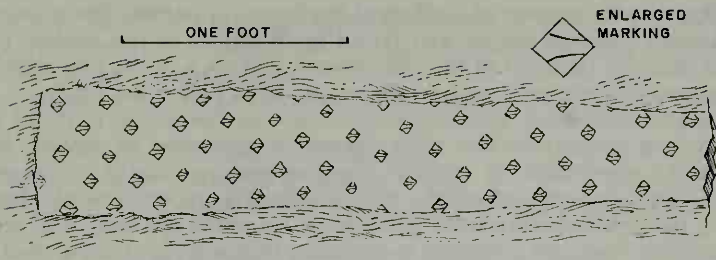
....

NOTICE OF A SINGULAR IMPRESSION IN SANDSTONE

Lea, Isaac; *American Journal of Science,* 1:1:155, 1822.

On looking over my portfolio a few days since, I found a drawing of some reliquia which I made a few years since, when I observed them about a quarter of a mile above Pittsburgh, and on the same side of the Monongahela.

With this I send you a copy of the drawing, which you will please to insert in the Journal of Science, if you think it worthy of a place in that useful work. I am more anxious to see this figure in a permanent place, as



An unusual impression in sandstone from Pennsylvania.

on a late visit to it I found the dilapidating hammer of the quarry-man, to be likely to remove from its native bed, and destroy one of the most singular specimens of the kind which I have ever seen, and respecting which, the learned find so much difficulty in deciding whether it belongs to the animal or vegetable kingdom.

The impression is very perfect on a sand stone rock, and entirely flat. The base is perfectly terminated in the rock and is about six inches across; its length three feet, and terminated by a fracture of the rock, which leaves it doubtful how long it may have been in its pristine state; at this fracture it is four inches broad. The two lines are distinct in both lozenge shaped impressions, which are represented of the natural size in fig. 2d.

The hill in which it exists is not sufficiently high to take in the bed of coal pervading the neighbouring hills in a horizontal stratum about two hundred and fifty feet above this locality. In fragments of the same rock, are found many impressions resembling culmiferous plants, the joints of which are perfect. Some of them are now in my own collection, others I deposited, particularly a large one, in the "Academy of Natural Science."

ORDOVICIAN "DINOSAUR-LEATHER" MARKINGS

Chadwick, George Halcott; *Geological Society of America, Bulletin,* 59:1315, 1948.

Abstract. Photographs will be exhibited of astounding current marks covering a space 2 by 10 yards on the under surface of vertically upturned Normanskill graywacke grit and shale beds (Austin's Glen member, approximately Black River age) along the west side of U.S. highway 9-W 3 miles north of West Coxsackie (N.Y.) traffic light.

The purpose is to direct attention to a phenomenon of most unusual character, likely soon to be destroyed by weathering, in the hope that its mode of formation may be explained or at least some reasonable theories suggested.

The pattern consists of a repetition of units each about 1-1/2 by 3 feet in size, and each containing an overall similarity but not perfect duplication 100 or so minor elements that make the whole suggestive of reptilian

skin on a gigantic scale. There is, however, no indication of organic origin given in these or in totally different markings on slightly different bedding planes in the same road cut, all of which need explanation.

CURIOUS IMPRESSIONS IN CAMBRIAN SANDSTONE NEAR LOCH MAREE

Anonymous; *Nature,* 25:93-94, 1880.

In course of the short excursion to Loch Maree and its neighbourhood, Mr. Walter Carruthers, of the Inverness Courier, happened, on June 13, to light upon an interesting portion of the Cambrian or Torridon Red Sandstone of the district, forming part of the bed of the burn, near Loch Maree Hotel, on which occur what have been called the Victoria Falls, so named from the fact that the Queen visited them. There an exposed surface of the rock about sixteen feet in length, nearly as much in breadth, and almost perfectly level, is marked by several double grooves quite discernible, and each divided by a very thin raised line. These traverse the whole length of the rock in a perfectly straight line, and on both sides of them are roughnesses which, if we could entertain the idea that the grooving had been caused by some living creatures, might be produced by footprints which have been to a great extent obliterated. The impressions were so striking that they immediately suggested a recollection of the footprints discovered in the sandstones of Morayshire and Tarbatness, though there was no other resemblance than their marked character on the broad, flat rock. Having heard that Mr. William Jolly, H.M. Inspector of Schools, was in the neighbourhood, Mr. Carruthers called his attention to the subject, and indicated where he should find the markings. Mr. Jolly was not slow to examine the spot, and he writes to Mr. Carruthers as follows, as given in the Inverness Courier of July 1:

"I found your curious lines without difficulty, guided by your accurate description of their locality. They are assuredly no 'mare's nest,' but bona fide ancient impressions of some kind, which should receive the attention of geologists, both on their own account and as existing in the second oldest geological formation in Britain, in which, as yet in Scotland, no evidences whatever of organic life have been discovered.

"The lines or bands in question occur in the chocolate-coloured Torridon sandstone, the Cambrian of Murchison and Geikie, which is so well developed around Loch Maree, and rises into the great dome of the Slioch, or the Spear Head, that guards its waters. The most distinct of the impressions consists of two continuous flat bands side by side, 1-1/4 to 1-1/2 inch broad, and about a quarter of an inch deep, running quite straight across the flat layers of sandstone in situ, and perfectly distinct for sixteen feet, disappearing on the west side under the superincumbent rock, and broken only where portions of the sandstone have been weathered out. In some places a third line runs alongside the two, but this is much less distinct and persistent. The double band resembles nothing more nearly than the hollow impression that would be left by double bars of iron placed closely together and neatly inserted in the rock for clasping some structure on it, if the iron were subsequently removed; or, as you suggest, the marks of a gouge driven by a carpenter across a board. The bands, when looked narrowly into, consist of very fine close hair-like lines, continuous and parallel to their sides, resembling very minute striae left by glaciation, and look as if caused by some object drawn along the original red sand, before it became the present indurated rock.

"A similar double line runs parallel to this one, about two feet lower down, seven feet long, and a third parallel double line on the other or upper side, three feet long, both of the same breadth as the first. Besides those pointed out by you, which occur on the same flat of sandstone, other lines exist farther down, on the other side of the pool below this rocky flat, on a similar bed of sandstone, part of the same layer---one three feet in length, another six feet, running more or less parallel to those above. Indications of others may also be seen, and, no doubt, several more may be discovered on more careful examination.

"What they are I can scarcely even surmise, having seen nothing of the same kind elsewhere. They do suggest the possibility of their being the indentations of the caudal appendage of some huge creature, similar to the hollow tail-lines between the footprints on the sandstone at Tarbatness and along the shores of Morayshire---a suggestion strengthened by the fact of the existence, on both sides of the line, of numerous rounded hollow marks, very like the footprints on these repitiliferous rocks, occurring, as in them, at intervals. But the continuous even breadth and square section of the bands would seem to render this impossible. Then they might be the depressions left on the soft sand by the hinder portions of the shell of some large crustacean---a more likely cause, rendered more probable by the existence of very good ripple-marks on the same sandstone, in the same and neighbouring layers. The striae-like lines of which the grooves consist would seem to point to some moving agent, organic or physical. They may, however, be the casts or impressions of some great land reed or sea fucoid, the hair-lines being the marks of the fine structure of its stem or the parallel veins of its leaves. It would be desirable to have the superincumbent layer of rock carefully removed where the bands in question disappear under the upper rock, which might shed some light on the nature of the strange marks. I was sorry I could not spend more time on their examination."

The impressions occur about 300 or 400 yards above the Victoria Falls, and immediately beside the last of three lesser waterfalls on the west side of the stream.

NATURAL SUNFLOWER PICTURES ON ROCKS

Anonymous; *Science*, 85:sup 9, May 21, 1937.

The origin of giant sunflower pictures on southwestern rocks has been explained as a process of erosion by Walter B. Lang, of the U.S. Geological Survey. Mr. Lang solved the puzzle by chemical tests of a typical "sunflower" specimen in the Smithsonian Institution. The giant sunflowers range from about one to two feet in diameter, and are formed on hard sandstone rock. Showers tend to dissolve the binding cement and mineral salts in the sandstone, and in arid climate a small depression in the rock may soon grow into a deep pocket. Such a pocket resembles the disk of a giant sunflower. Rills of rainwater flow in troughs from the pocket outward, forming the rays or petals of the flower.

RILLED LIMESTONE

Laudermilk, J. D., and Woodford, A. O.; *Geological Society of America, Bulletin*, 43:227, 1932.

Abstract. In arid regions loose pieces or outcrops of limestone sometimes develop rather fine, meandering, often radiating systems of grooves. Such rocks have been named Rillensteine by the Germans. They have been explained in several ways, some recent writers favoring wind erosion and others etching by various processes of solution. As a result of field studies in Southern California, supplemented by experiments, the authors suggest the probability that most, if not all, such rills originate by solution, with later polishing of some occurrences by silt-laden winds.

METEORITES, TEKTITES, AND GLASSES

Despite what scientists vigorously maintained less than 200 years ago, stones do fall from the sky. In flight, they are usually termed meteors. Anomalies during this aerial phase are treated in the companion handbook MYSTERIOUS UNIVERSE. When a meteor strikes the earth it is taxonomically transformed into a meteorite and enters the realm of the present volume. This class of alleged fallen objects must also include tektites, some controversial terrestrial glasses, and those tiny magnetic spherules that apparently form a sort of cosmic rain. No one has seen these objects actually fall from the sky, and their compositions differ substantially from bona fide meteorites; nevertheless, they all seem to have undergone one or more meteor-like baptisms of fire in the crucible of the atmosphere. One must be careful here because volcanism and human-operated smelters can produce slags and cinders emulating the tektites, glasses, and spherules.

Only the geological conundrums posed by meteorites need be considered here: (1) the apparent rarity of meteorites in young and old sediments; and (2) the amazingly high concentrations of meteorites discovered in the polar regions. It seems that meteorites survive easily under polar conditions but soon dissolve away in most terrestrial sediments.

The several species of tektites have been described frequently, although some compositional and geographic anomalies remain to be reported here. The great volume of tektite literature focusses on their origin(s) with many an intemperate remark along the way. Do tektites have a terrestrial, lunar, cometary, or some other origin? The issue has not been clearly resolved despite assertions to the contrary.

Tektites are important in geological history because their falls are age-correlated with some magnetic reversals and periods of intense geological activity. The evolution of life, in particular, seems punctuated by tektite falls.

Tektites have also stirred up a fascinating confrontation in geological dating. Competent Australian geologists firmly maintain that the Australites are found in situ only in very young sediments, but geophysicists dogmatically peg Australite ages at two orders of magnitude greater through radiometric and fission-track dating.

The several small areas of glassy surface deposits are even more enigmatic than the tektites. The Darwin (Australia) and Libyan Desert glasses are most notable. Like the tektites they seem to have had fiery births---but were the midwives comets, huge meteorites, or simply terrestrial volcanoes? Unfortunately, most scientists are distracted by the tektite controversy.

• Remarkable Meteorites

METEORITES IN SEDIMENTARY ROCKS?

Tarr, W. A.; *Science,* 75:17-18, 1932.

For many years I have searched for meteorites or meteoritic material in sedimentary rocks. About fifteen years ago, one of my students found a meteorite in a bed of gypsum in western Oklahoma. At first, it was thought that the occurrence represented a fall at the time of the deposition of the gypsum, which is Permian in age. A careful study of the occurrence of the meteorite, however, proved that it was evidently recent. I have interviewed the late Dr. G. P. Merrill, of the U.S. National Museum, and Dr. G. T. Prior, of the British National History Museum, both well-known students of meteorites, and neither man knew of a single occurrence of a meteorite in sedimentary rocks. Dr. Prior knew of a meteorite that was found in recent stream gravels but of none occurring in sediments of past geologic periods.

This letter is a petition for any information indicating that meteorites do occur in the sediments. Dr. Merrill was of the opinion that we should not expect to find them in the sediments because they would decompose before they could be buried. Although we may admit that the iron-nickel meteorites might undergo rapid oxidation under the conditions of weathering on the land surface and the stony meteorites at a slower pace, if a meteorite of any type fell in a sea in which muds or limestones were accumulating, why should it not be buried in these sediments? We know that many of the minerals of the stony meteorites are similar to those of the terrestrial rocks and that the minerals of the latter may be buried without undergoing decomposition. We find arkosic rocks and graywackes (which contain minerals that under normal weathering conditions decompose entirely) that have been buried and constitute integral parts of sedimentary rocks.

An iron meteorite falling in sea water would be rapidly attacked (unless quickly buried) and the exterior converted into iron oxides which would protect the inner portion, in some degree at least, from complete alteration. Even if such a meteorite were completely altered to iron oxides, these should remain as a type of pseudomorph of the original meteorite. Unless the nickel which normally occurs in iron meteorites were all removed during the oxidation, its presence in the resulting ferruginous mass might be taken as evidence of the meteoritic origin of the mass. I have never found any material which suggested that it was of this origin or which seemed to merit being tested for nickel. It is equally difficult to believe that a stony meteorite, falling in a soft mud or calcareous ooze would not be buried before decomposition took place.

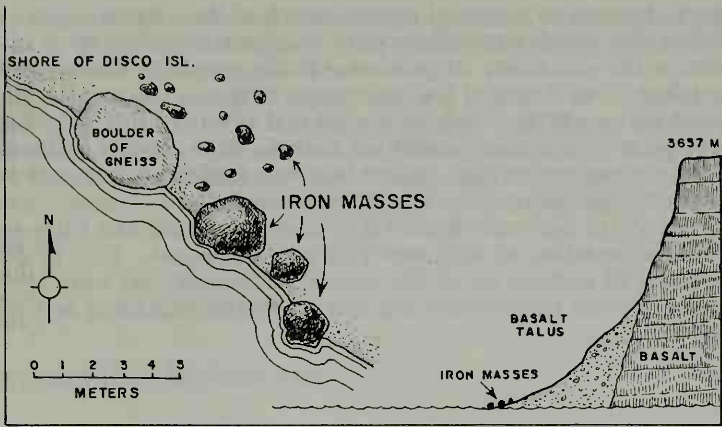
The presence of meteoric material in deep-sea muds has little real bearing on the question, as this material may be recent. It is in the possible occurrence of meteorites in the ancient sediments that I am interested. I will appreciate any information any one may have regarding this interesting quest.

HUGE METEORITES FROM GREENLAND

Anonymous; *Scientific American Supplement,* 2:510, 1876.

In 1870 Professor Nordenskjold discovered at Ovifak, Disco Island, on the western coast of Greenland, a number of masses of metallic iron, consisting in three huge blocks, respectively 44,000, 20,000 and 10,000 pounds in weight, accompanied by numerous smaller pieces. Impressed with the scientific interest attaching to these specimens, M. Nordenskjold succeeded in inducing the Swedish Government to send a couple of vessels to secure them, and by dint of great exertion they were loosened from their resting-place on the beach. The location of the masses is shown in Fig. 2, from which it will be seen that they were grouped quite closely together. Behind them rose a declivity of basalt fragments, and then a steep precipitous basalt cliff over a thousand feet in height. By means of huge rafts the blocks were after some months labor transported to the ships, and by the latter brought to Sweden. There an analysis was made of the metal, the presence of nickel and cobalt was recognized, and the chemists pronounced the masses to be of extra-terrestrial origin.

From time to time, as our readers are aware, masses of mineral matter fall upon the earth, accompanied with brilliant manifestations of light and great noise. Some of these masses have hitherto been recognized as composed of metallic iron. In addition to the fact that such large quantities of pure metal are not found on earth, the meteoric metal is distinguished from that industrially produced by the presence of nickel and cobalt; so that when these metals were detected in the Greenland blocks, as already stated, the chemists were inclined to ascribe to them an origin in stellar space: still, celestial origin was not to be predicated without more certain proof. According to the analyses of M. Daubree, the rocks containing native iron at Onfak belong to three types. The first consists in a blackish rock, resembling certain graphitic cast iron, and susceptible of polish. Its fracture is lamellar, though the faces of the cleavage do not show any regular disposition or crystalline system. The second type also has a color and brilliancy resembling ordinary wrought iron, but when the rock is pulverized it separates into two distinct portions, one of which becomes reduced into fine powder, while the other remains always in fine scales. Finally, in the third type, the metallic



Unusual concentration of large meteorites in Greenland.

substance instead of being continuous appears in grains in a stony mass; the latter is silicious, and of a dark green color.

These rocks are equally distinguishable by their aspect and by their composition from the types of meteorites hitherto known. On the other hand they offer many points of similarity among themselves. Their crystalline state and the presence of oxidulated iron seem to ally them to basalts and dolerites. Even the existence of native iron, which at first sight seems to constitute a profound distinction, may be considered as a connecting link. In fact, if it is true to say that meteoritic iron is not counted as a species among terrestrial rocks, it must likewise be admitted that it is found in the nodules in many of the latter.

It will be observed from our map that the Onfak shore is shut in by a high range of basaltic rocks. These contain meteoric iron in extraordinary quantity, which presents itself under the form of rounded grains of all sizes, possessing the same chemical composition as the large detached blocks. Moreover, it has been noted that fragments of the same basaltic rock were still adherent to the exterior, and even embedded in the interior of the isolated masses.

To explain this on a hypothesis of extra-terrestrial origin it would be necessary to suppose that the fall of the meteorites occurred while the basalt was in a state of pasty eruption. But this the form of the iron nodules negatives.

In the interior of the globe, it is believed that there exists a nucleus in which iron predominates. Now, asks La Nature, may we not consider these supposed meteoric masses, which hitherto have caused such excitement in the scientific world, to be but portions of that internal nucleus? In other words, it is suggested that they are merely of volcanic origin. If this hypothesis be substantiated it becomes of importance in that it indicates the existence in the earth of vast quantities of nickeliferous iron.

METEORITICS AT CAMBRIDGE

Hindley, Keith; *New Scientist*, 75:353, 1977.

A total of over 1050 meteorite specimens has now been recovered by Japanese and American searchers in blue ice areas of the Antarctic coastal regions. They include three irons, a stony iron, and hundreds of stones including several carbonacious chondrites and achondrites.

Preliminary dating of some of the meteorites has startled scientists. Normally, weathered meteorites have terrestrial ages of up to 10,000 years, implying that meteorites weather down to unrecognisable form quite quickly. However, one meteorite recovered by the Americans has been dated at over one million years, while several of the Japanese stones exceed this and one reaches four million years. Antarctic recoveries therefore offer an opportunity of studying meteorite populations as they were in the distant past. In addition, the exceptional freshness and preservation of the specimens may mean the recovery of normally very friable and readily weathered types. (Excerpt)

ROCKS ON THE ICE

Sears, Derek; *New Scientist*, 81:959-961, 1979.

Scientists who work on meteorites have been amazed, over the past few years, by the number of meteorites being found in Antarctica---more than 1300 specimens have been discovered. Meteorite falls are very rare, and this figure may be compared with the 2000 or so pieces which the museums of the world can boast. The museum collections have been painstakingly assembled for over 200 years, incorporating meteorites from all four corners of the Earth. Why then, are there so many meteorites in Antarctica? How were they discovered, and what will be the consequences of this sudden growth in the size of our collections?

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By the early 1960s, the amount of research being carried out in Antarctica had considerably increased. As a result, three new meteorite finds were made; at Lazarev in 1961, Thiel Mountains in 1962 and Neptune Mountains in 1964. However, it is the tenth Japanese Antarctic Research Expedition which can probably claim the major share of credit for our new attitude towards Antarctica as a source of meteorites. In 1969 a Japanese team was working 300 km south-west of the base at Syowa Station. At this location they discovered nine pieces of stony meteorite, all within 10 km of each other. It was four years before their next expedition to Antarctica, and on this they recovered a further 12 fragments.

It clearly looked as if the Japanese had stumbled across a major source of meteorites. However, the next expedition caught everyone by surprise. The 1974-75 Antarctic season yielded 663 pieces of meteorite to the Japanese, and a further 307 the following year. As the meteorites were all found within a relatively small area, about 4000 sq. km, it seems most probable that the site of a major meteorite shower had been discovered.

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This high meteorite density is not unique to the Yamato Mountains. Prompted by the Japanese discoveries, a joint United States/Japanese expedition was despatched to the Allan Hills and Mount Baldr regions of the Trans-Antarctic Mountains for the 1976-77 season. It resulted in the recovery of 11 more meteorites, one of which was a massive 408 kg. The following year a joint expedition was again organised and more than 300 specimens were returned.

....

Even if we assume nine out of ten Yamato meteorites belong to a single shower, we are still faced with the fact that Antarctica is providing more meteorites per unit area than the rest of the world. The surface density of meteorites in Antarctica is something like one or two per 10 sq. km, compared with about one per 100 sq. km for the Prairie States in the US---the world's previous "best bet" for finding a meteorite. Meteorites are falling at the rate of one per million sq. km each year. This means that either the ice at the Yamato Mountains and Allan Hills sites is extremely old, in fact several hundred million years old, or that the meteorites are somehow being concentrated at preferred sites.

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The workers who discovered the first Yamato meteorites realised that their discoveries were always made on what they termed "blue ice". This refers to regions where snow has been swept from the ice sheet by fierce winds, and where evaporation is very efficient. They are regions where the ice sheet encounters a mountain range, such as the Yamato Mountains or the Trans-Antarctic Mountains, and rises, bringing any meteorites trapped in it to the surface. After a while the meteorites will be revealed, when evaporation and wind erosion have removed the overlying snow and ice.

....

(See the handbook MYSTERIOUS UNIVERSE for discussions of meteorite composition and, in particular, "sedimentary" meteorites! WRC)

• Tektites

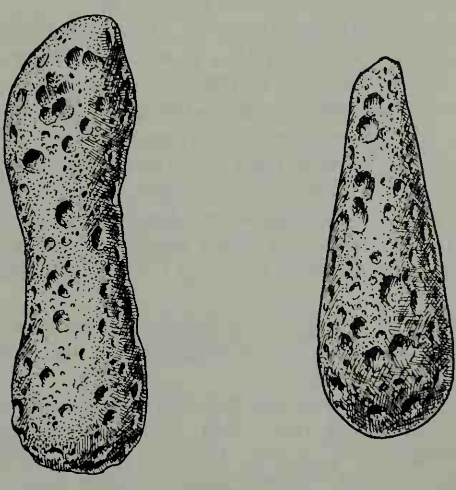
PHILIPPINE TEKTITES AND THE TEKTITE PROBLEM IN GENERAL

Beyer, H. Otley; *Popular Astronomy*, 48:43-48, 1940.

One of several things for which the Philippines are remarkable is the presence in the Islands of the world's largest known deposit of tektites. The term tektite was adopted in 1900 by Professor Franz E. Suess of

Vienna as a general name for a curious group of natural glasses which have come to be widely regarded as of cosmic or extra-earthly origin. In recent times, it has become apparent that these bodies did not fall singly or sporadically, but that great showers of them fell upon certain parts of the earth at widely separated geologic periods. A small deposit has been found in the Ivory-Coast region of West Africa that is believed to date as far back as Mesozoic times; the Moldavites, or European tektites, date from the Helvetian strata of the mid-Miocene; the whole group of Far Eastern tektites, or Indo-malaysianites, are undoubtedly mid-Pleistocene; while the Australites, or tektites of Australia and Tasmania, are believed to be post-Pleistocene or recent. These four major geologic groups of tektites all differ from one another to some extent in physical appearance, chemical composition, and specific gravity, but all possess certain common differences from other earthly rocks which have led them to be classed together as genuine tektites, of unknown but probably cosmic origin.

Most if not all true tektites appear to have been originally of the natural shapes that would be assumed by molten glass revolving in the atmosphere or any similar gaseous medium, i.e., spheroids, disks, or oval, cylindrical, dumb-bell-shaped, and pointed, drop-shaped bodies, some later broken or exploded into fragments of various sizes. This fact, together with their anomalous chemical composition, and the further fact of their being found frequently in wholly non-volcanic regions, have been the chief reasons for adopting the cosmic hypothesis in seeking a reasonable explanation of their origin. The Australite group of tektites adds still further probability to the cosmic theory by showing a partial re-fusing of the original glass sphere, a part of which has flowed backward and solidified into a more or less flattened ring or band, giving to the whole specimen a peculiar button-like appearance, in the typical forms. In many other cases, the re-fused material has been completely swept away in flight, leaving



Sketches of dumbbell and teardrop tektites from Indochina.

only a small sharp-edged or lens-shaped remnant of the original tektite sphere.

The Philippine tektites all belong to the general Indo-malaysianite group, of mid-Pleistocene origin; this group contains also the tektites found in Indo-China, Borneo, and the Island of Java. While presenting great uniformity in composition, and in color, specific gravity, and other properties of the glass itself, the Indo-malaysianites of different geographic areas present certain characteristic differences in shape, surface markings, flow-lines, and the degree of viscosity of the original material, which have led to their being divided into four major and several minor subgroups of more or less distinctive and well-defined character. The four major subgroups are:

(1) Indochinites (originally most viscous, with stretched-bubble sections, and with both straight and curved pointed drops, and irregular fragments as the most characteristic forms, spheroids being rare);
(2) Rizalites (pitted spheroids, ovals, and cylindrical forms being most characteristic, showing intermediate viscosity);
(3) Billitonites and Malaysianites (with deeply-etched spheroids, cylinders, and irregular pieces, showing worm-track grooves and navels as the characteristic forms; medium fiscosity); and
(4) Java Tektites (least viscous ?, with highly complicated flow-lines mildly but clearly etched out on relatively smooth surfaces, and with spheroidal and irregular or fragmentary forms as the most characteristic).

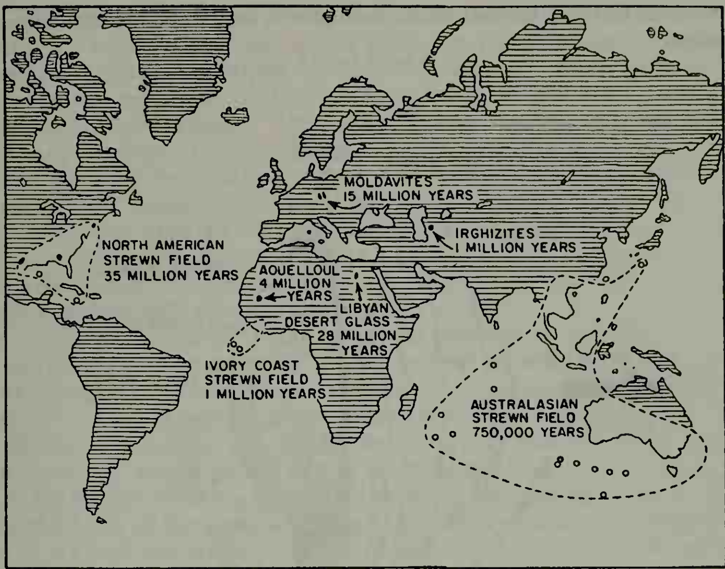
The most typical Indochinite specimens occur in South China and northern and central Indo-China, although they are found also, sparsely, in Luzon (particularly in the Rizal-Bulakan area, where they are mixed with much larger numbers of Rizalites and a few Billitonite and Malaysianite types).

The most typical Rizalites occur only in Luzon, although a few similar, pitted specimens are known from Borneo and Java.

The Billitonite and Malaysianite types, although least in number, cover the greatest area, being found in parts of southwestern Luzon, the Island of Busuanga in the west-central Philippines, Borneo, the Natuna archipelago, southern Indo-China (especially Cambodia), the Malay Peninsula, and the Island of Billiton. The original Billitonites (first found in the tin mines of Billiton Island) show characteristic worm-track grooves and navels, with relatively smooth surfaces between such markings, while the true Malaysianites tend to show irregular and heavily-etched surfaces with the irregular pits and other markings often running together more or less continuously, as seen most typically in many Cambodian and Busuanga tektites.

The most typical Java tektites are found only in central Java, but a few very similar specimens occur in the Philippines (particularly in the Santa Mesa district of Rizal Province).

The largest known whole tektites occur in southeastern Luzon, in the Paracale district of the Bikol Peninsula, while those of Indo-China rank next, and the Malaysianites probably third. The great Bikol tektites may be truly called "super-sized," since most of them are large, and small specimens comparatively scarce. The largest found so far weighs 1070 g., and is an almost perfect sphere a little over 4 inches in diameter, but



Tektites are concentrated in strew fields, some of which have been linked to specific meteor craters. The Australites, however, seem unrelated to any known crater.

more than a hundred Bikol specimens running from 200 to 700 g. each have so far been found. The largest recorded whole Indo-China specimen is from Cambodia, and weighs 630 g., while the largest known Malaysianite is believed to have come from Pahang and weighs 464 g. Only a few other specimens weighing 300 g. or more are known, all of them having come from the Indo-malaysianite region, most of them being from Indo-China and the Philippines, with one each from Java and the Malay Peninsula. The average for this region, however, is between only 15 and 20 g. The largest Australite has the exceptional weight of 218 g., since the Australites are the smallest of all tektites, averaging only about 1 g. each or less. Tektites from other regions are intermediate, but no recorded specimen reaches 150 g. in weight.

However, what was originally probably the most gigantic of all tektites is again recorded from Indo-China. This is the famous specimen of Lower Laos, of which several thousand irregular fragments have so far been gathered within a relatively small area. The largest piece weighs more than 3 kg., while many of the smaller ones weigh only a few grams each. The evidence to date seems to indicate that all of these pieces are parts of a single huge tektite, perhaps half a meter in diameter, and weighing nearly 100 kg. One of the most interesting things about these finds is that no other small whole tektites have been found anywhere near the same region; this fact lends force to the cosmic theory, since any shower of smaller bodies accompanying this great cosmic bomb would have tended to fall far behind in the course of its flight through the earth's atmosphere.

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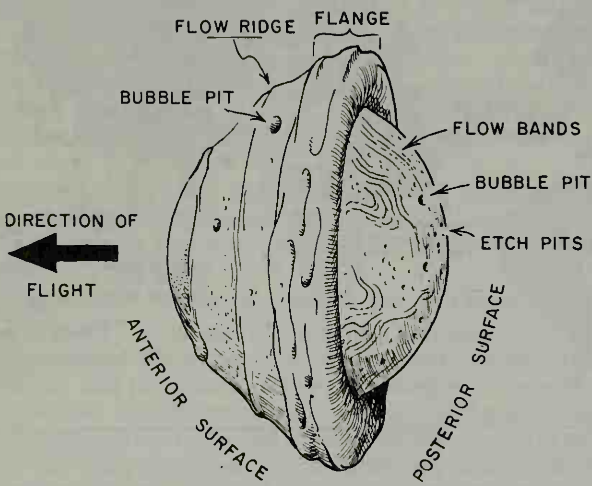

A flanged, button-type Australite supposedly shaped by high-temperature flight through the atmosphere.

THE ORIGIN OF TEKTITES: A BRIEF REVIEW

King, Elbert A.; *American Scientist*, 65:212-218, 1977.

During the past forty or so years, few topics have been characterized by such disagreement and acrimonious debate in the scientific community as the origin of a group of curious, natural glassy objects called tektites. The answer is now clear---tektites are produced from terrestrial rocks melted by hypervelocity impacts of large, extraterrestrial objects. Now that we have resolved the question of origin, it seems in order to review the steps that have led most of us to this conclusion (a few diehards still tout an extraterrestrial origin), as well as to point out some of the remaining uncertainties.

[Tektite description and analysis omitted.]

Extraterrestrial Evidence and Final Questions. The elegant aspect of the last ten years of the tektite debate is that all workers in this field knew that the Space Program would surely provide a conclusive answer---and it did! The Surveyor Program made the first in situ chemical analyses of the lunar surface by means of an alpha particle backscattering device. The results showed that the lunar surface rocks did not resemble tektites in composition; there was, nevertheless, some uncertainty about the accuracy of remote analyses performed under adverse conditions. The lunar samples returned by the Apollo Program provided definitive results and demonstrated that the alpha backscatter analyses were quite accurate! No lunar sample returned by the Apollo or Luna missions is a suitable parent material for tektites. Although O'Keefe claimed that tektite glass had been discovered in the Apollo 12 samples, this was quickly refuted. The fact is that the chemistry of lunar samples differs in a number of fundamental ways from terrestrial rocks and tektites. These differences include distinctive rare Earth element distribution patterns, chromium contents, potassium to uranium ratios, aluminum and silicon contents, and lead and oxygen isotopic ratios. These and other chemical differences have been convincingly summarized by Taylor.

Thus the major problem of the origin of tektites is solved---it is the Earth. Nevertheless, a number of unanswered or only partially answered questions remain. We have a source crater (Bosumtwi) for the Ivory Coast tektites, and at least a possible source (Ries Crater) for the moldavites. The source crater for the North American tektites is no particular problem because, owing to the age of the tektites, we would expect the source to be buried under a great thickness of sedimentary rocks somewhere in the area of the coastal plain of the Gulf of Mexico. However, the lack of a candidate crater for the source of the largest and most recent tektite group, the Australasian tektites, is particularly annoying. Various possibilities have been suggested, including a possible large crater under the ice in Wilkes Land, but none can be strongly supported with the evidence at hand. Urey suggested that tektites might be formed by the impact of a comet and that, because of the diffuse, low-density nature of the impacting comet, a large crater might not be formed. However, our knowledge of possible cometary impacts is poor indeed, and the validity of this mechanism to produce the layered tektites described by Barnes who also supports a cometary impact origin for at least some tektites, is difficult to evaluate.

Another group of remaining problems involves the mechanics and time sequence of events that can accelerate fused droplets to the velocities required to distribute tektites hundreds to thousands of kilometers from the source crater. The velocities, which should range from approximately 2.4 km/sec to as much as 6 km/sec, do not appear to be such a serious problem themselves because large meteorites, asteroids, and comets impact the Earth at velocities ranging from 11 to 72 km/sec, and it has been well established from experimental impact mechanics that some of the target material may be accelerated to a velocity that equals or even exceeds the velocity of the impacting projectile. The problem for tektites is that molten droplets, or even solid bodies, cannot be propelled through the atmosphere at velocities that could account for the observed geographic distributions. They must escape the Earth's atmosphere into near-Earth space. But even here there are still uncertainties, because the mechanics and sequence of events by which the atmosphere is blown aside, or otherwise permits the ejection of tektites into near-Earth space, is not well understood.

Tektites have, in retrospect, probably received much more attention than they deserve. They should now be relegated to a rather minor topic within shock metamorphism. It is apparent that more than a little confusion was caused by an overly restrictive application of the term tektite. Many later workers assumed that true tektites should have all of the properties of the moldavites as described by Suess. L. J. Spencer saw the problem and the solution clearly, but because of the primitive state of knowledge of shock metamorphism and cratering mechanics at that time, his prescient conclusions were not widely accepted. It remained for us to reach the same conclusions, after very much more work, in only slightly more quantitative terms.

THE TEKTITE PROBLEM

O'Keefe, John A.; *Scientific American,* 239:116-125, August 1978.

If tektites are terrestrial, it means that some process exists by which soil or common rocks can be converted in an instant into homogeneous, water-free, bubble-free glass and be propelled thousands of miles above the atmosphere. If tektites come from the moon, it seems to follow that there is at least one powerful volcano somewhere on the moon that has erupted at least as recently as 750,000 years ago. Neither possibility is easy to accept. Yet one of them must be accepted, and I believe it is feasible to pick the more reasonable one by rejecting the more unlikely. (p. 116)

The key to solving the tektite problem is an insistence on a physically reasonable hypothesis and a resolute refusal to be impressed by mere numerical coincidences such as the similarity of terrestrial sediments to tektite material. I believe that the lunar-volcanism hypothesis is the only one physically possible, and that we have to accept it. If it leads to unexpected but not impossible conclusions, that is precisely its utility.

To cite just one example of the utility, the lunar origin of tektites strongly supports the idea that the moon was formed by fission of the earth. Tektites are indeed much more like terrestrial rocks than one would expect of a chance assemblage. If tektites come from a lunar magma, then deep inside the moon there must be material that is very much like the mantle of the earth---more like the mantle than it is like the shallower parts of the moon from which the lunar surface basalts have originated. If the moon was formed by fission of the earth, the object that became the moon would have been heated intensely, and from the outside, and would have lost most of its original mass, and in particular the more volatile elements. The lavas constituting most of the moon's present surface were erupted early in the moon's history, when its heat was concentrated in the shallow depleted zone quite near the surface. During the recent periods represented by tektite falls the sources of lunar volcanism have necessarily been much deeper, so that any volcanoes responsible for tektites have drawn on the lunar material that suffered least during the period of ablation and is therefore most like unaltered terrestrial mantle material. Ironically, that would explain why tektites are in some ways more like terrestrial rocks than they are like the rocks of the lunar surface. (p. 125)

AGE OF AUSTRALITE FALL

Gill, Edmund D.; *Journal of Geophysical Research,* 75:996-1002, 1970.

Abstract. Australites occur at Port Campbell in the A2 horizon of a humus podsol. Charcoal accompanying them in situ dated 4830 to 5700 years B.P., whereas underlying humified stems in the top of the hardpan dated 7380 years. Humic material from the middle of the hardpan dated 14,600 years. The minimal date for the australite fall is 4830 years. If the australites fell on the podsol, the maximal date for the fall is 14,600 years B.P. However, this is open to doubt because buckshot gravel (formed in a different kind of soil) accompanies the australites. If they were derived together from another soil, they could not have traveled far because of the fine translucent sharp edges and the good general preservation of many australites. Such a buckshot soil has not been found nearby. The formations underlying this humic podsol with australites (including the 0.7-m.y. zone) have been searched, but none has been discovered there even though it is so plentiful above. A new line of investigation was followed by collecting australites from the calcrete surface (stripped soil) of a Last Interglacial coastal calcarenite dune, where the tektites either fell or were carried by aborigines. Good reasons for not accepting the latter theory are given. If these observations are correct, then the australite fall was later than the soil on the Last Interglacial dune. Consideration has also been given to the chemical solution of australites in relation to the very varied environments in which they are found. This investigation also suggests a young age. These results seem to be in sharp contradiction to indications arrived at by other methods, but the evidence must not be explained away. The author prefers to keep an open mind on the age of the australite fall until further knowledge is available.

AUSTRALASIAN MICROTEKTITES AND THE STRATIGRAPHIC AGE OF THE AUSTRALITES

Glass, B. P.; *Geological Society of America, Bulletin,* 89:1455-1458, 1978.

Abstract. The study of age relations among the Australian tektites (australites) has led to a paradox. On the one hand, K-Ar and fission-track studies give an age of 700,000 yr. On the other hand, stratigraphic studies in Australia indicate that the australites fell between 7,000 and 20,000 yr ago. Age, chemical, petrographic, morphological, and geographical studies link the australites to tektites found in Indonesia, Southeast Asia, and the Philippines. These tektites have stratigraphic ages consistent with their K-Ar and fission-track ages of 700,000 yr. The discovery of microtektites in deep-sea sediments adjacent to Australia that have a stratigraphic age of 700,000 (based on their association with the Brunhes-Matuyama reversal boundary) indicates that the australites also fell 700,000 yr ago. However, Chalmers and others (1976) have recently questioned the relationship between the microtektites and australites and have reaffirmed the low stratigraphic age of the australites. This paper reviews the evidence and concludes that the microtektites are indeed part of the Australasian strewn field and that the occurrence of australites

in what are apparently late Pleistocene to post-Pleistocene deposits indicates that they were probably eroded and redeposited at this time.

AUSTRALASIAN MICROTEKTITES AND THE STRATIGRAPHIC AGE OF THE AUSTRALITES

Chalmers, R. O., et al; *Geological Society of America, Bulletin,* 90:508-512, 1979.

In a paper presenting the results of many years of work on the occurrence, distribution, and age of Australian tektites, we said, "Unsolved problems include: (1) the inconsistency between the geological age (7000-20,000 years B.P.) and K-Ar and fission track ages (700,000-860,000 years); (2) the relationship, if any, between australites and the 'microtektites' in Indian Ocean sediments; and (3) the source region of the australite material." Glass has discussed the first two statements and taken strong exception to them, but unfortunately he avoided the third; a reasonable answer for the source region would probably resolve the dilemma posed by the preceding statements.

....

To resolve the difference between this geologic age and the K-Ar and fission-track age, Glass asserted that all these investigators were mistaken when they decided they were finding australites at or near the place of fall, and that all the occurrences in upper Pleistocene to post-Pleistocene deposits are eroded and transported specimens from an unidentified 700,000-yr-old stratum. We re-emphasize the critical evidence against this hypothesis, as follows.

1. In nearly all the locations we collected, both in the Lake Torrens-Lake Eyre region and on the Nullarbor Plain, australites are the only exotic objects. At locations to which australites have clearly been transported, they are a sparse component of a varied assemblage of pebbles. Can Glass envisage a transporting mechanism that would select only australites?
2. In all areas known to us, australites are associated with upper Pleistocene to Holocene deposits. Stratified Tertiary and Pleistocene sediments occur around the shores of Lake Eyre and Lake Frome, but no australite-bearing horizon at around 700,000 B.P. has been found in them.
3. In the Lake Torrens region the nearest extensive rock outcrops and erosion surfaces older than latest Pleistocene are at least 15 to 25 km mountainward (eastward) from the Motpena-Myrtle Springs strewn field. It is inconceivable that the many delicate australite forms collected in these strewn fields could have been transported at least 15 to 25 km by vigorous piedmont streamfloods without suffering any abrasion.

....

In summary, we admit the dilemma posed by the inconsistency between the physical (K-Ar and fission-track) and stratigraphic ages of australites; Glass denies the existence of the dilemma. In doing so, he denies the validity of not only our observations, but also those of all other geologists who have actually studied the field occurrence of australites---that is, that in most places they are found at or close to where they fell, in a stratigraphic horizon near the Pleistocene-Holocene boundary.

THE MICROTEKTITE DATA—IMPLICATIONS FOR THE HYPOTHESIS OF THE LUNAR ORIGIN OF TEKTITES

O'Keefe John, A.; *Journal of Geophysical Research,* 74:6795-6804, 1969.

Abstract. The distribution of microtektites provides more definite boundaries for the Australasian strewn field. It is found that this field does not encompass the earth. It encompasses so much of the earth, however, that, if it is the result of terrestrial impact, the initial velocity must have been more than 6 km/sec for much of the material and almost none could have reached 7 km/sec. No trace is found of accompanying unmelted soil particles. The microtektites probably cannot be ablation droplets from larger tektites because there are too many and they do not resemble australite flange material; the bottle-green microtektites cannot be explained by processes of volatilization; and there is evidence that, in fact, the Muong Nong tektites are the result of the welding of microtektites. It follows that the microtektites must come directly from the moon, as postulated by Chapman, if they are extraterrestrial at all; the parent-body hypothesis will not work. Presumably tektites which miss the earth on the first encounter are destroyed by the Radzievsky-Paddack effect (rotational bursting induced by asymmetric radiation pressure). The chemical constitution is not decisively different from that indicated by the analyses of Turkevich except in calcium; this can perhaps be explained. Microtektites may represent the unwelded component of a lunar ash flow, of which the Muong Nong tektites are the welded component.

IVORY COAST TEKTITE SITE

Anonymous; *Science News,* 112:408, 1977.

The region over which the Ivory Coast microtektites are strewn has been found to be nearly four times as large as previously thought. It also appears to be associated, like the Australasian tektites, with a magnetic-reversal event.

Billy P. Glass of the University of Delaware reports the discovery of microtektites in three additional sedimentary cores from the equatorial Atlantic Ocean off Africa. These now show the area of distribution to be equal to about half the area of the United States. He calculates that there may be as much as 10 billion kilograms of microtektites in the Ivory Coast site.

Microtektites and tektites are small glass beads found in restricted areas of the earth's surface. Many scientists believe they are formed from the impact of a meteorite on earth (although a second view is that tektites are from the moon). The largest tektite site, the Australasian, is closely associated with the last major reversal of the earth's magnetic field, 700,000 years ago. The Ivory Coast microtektites appear to be in a layer associated with the beginning of the Jaramillo magnetic event. This event is a time about 0.95 to 0.9 million years ago when the earth's magnetic field reversed polarity and then about 50,000 years later changed back. The latest discoveries lend support to Glass's long-held hypothesis that there may be a relationship between reversals of the earth's magnetic field and tektite falls.

WATER CONTENT OF RUSSIAN TEKTITES

King, Elbert A., and Arndt, Jory; *Nature*, 269:48-49, 1977.

The first occurrence of tektites in Russia was reported recently by Florensky, who named them irgizites, and concluded that they were produced by fusion of terrestrial rocks at the Zhamanshin impact structure where they are found. The Zhamanshin impact structure is approximately 10 km in diameter and is 200 km north of the Aral Sea ($\sim 49^{\circ}$N, $\sim 59^{\circ}$E). The irgizites have the splash forms that are commonly found among other tektites and impactites, for example, indochinites and Wabar glass. Although Florensky clearly describes the field occurrence, shapes, general petrography, major element chemistry and origin of the irgizites, the reported bulk chemical analysis of the major elements includes neither ferrous/ferric iron nor water. Thus, data for two of the most widely accepted chemical criteria for the identification of tektites have not previously been available for irgizites. This note reports investigations into their water content. [Analysis omitted]

The piece of irgizite glass we examined seems to be a typical tektite glass in all respects except for the greater water content and possibly the, as yet undetermined, ferrous/ferric iron ratio. Whether or not the irgizites should be classified as tektites is a moot question. Perhaps they should be termed wet tektites, but regardless of their name, they are extremely similar to, and have originated by, the same basic process as true tektites.

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COMETARY COLLISIONS AND GEOLOGICAL PERIODS

Urey, Harold C.; *Nature*, 242:32-33, 1973.

Some fifteen years ago, I suggested that tektites were produced by collisions of comets with the Earth. Many detailed investigations of these objects have added much to our knowledge, and these, together with the lunar investigations, have proved this hypothesis to be very probably correct. I have also suggested that the geological periods were terminated by such collisions, but this was published in the Saturday Review of Literature, and no scientist except me, so far as I know, reads that magazine. The energy of such collisions and their frequency was roughly estimated at that time, and the number of these collisions has been reviewed again by Durrani.

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Were the ages of Tertiary times determined by the fall of comets which produced the tektite fields? Table 2 lists the ages of these recent geologic periods and the ages of tektites Rough agreement exists. Errors are probably present in both the geological estimates and the physical measurements of the tektite ages which are my averages of recent measurements. Probable errors in the Moldavites, Libyan Desert Glass and the Bediasites are about 2 m.y. The agreement is satisfactory. I wonder if tektites might not be found at some other boundaries between the Eocene, Palaeocene and Cretaceous periods? Lin required nearly as great an energy as calculated here in order to account for the Indochina and Australian tektites, and this produced only a minor discontinuity in geologic strata, so it seems probable that the energy required for the termination of the Cretaceous was much greater than that estimated here:

Table 2. Ages of Geologic Periods and of Tektites

Geologic period	Ages (m.y.)	Ages (m.y.)	Tektites
Pleistocene		0.71 ± 0.10	Australites
	1	1.2 ± 0.2	Ivory Coast
Pliocene			
	13	14.7 ± 0.7	Moldavites
Miocene			
	25	28.6 ± 2	Libyan Desert Glass
Oligocene			
	36	34.7 ± 2	Bediasites
Eocene			
	58	?	?
Palaeocene			
	63	?	?
Cretaceous			

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METALLIC SPHERULES IN TEKTITES.....

Chao, E. C. T., et al; *Science*, 135:97-98, 1962.

Abstract. Iron-nickel spherules, as much as 0.5 mm in diameter, have been found completely embedded in some philippinites. The spherules consist mainly of kamacite with unidentified pink inclusions. The meteoritic origin of these spherules seems reasonable, suggesting that the tektites containing them were formed by asteroidal or meteoritic impact.

A NEW GLASS OF POSSIBLY EXTRATERRESTRIAL ORIGIN

Cross, Frank C.; *Popular Astronomy*, 56:549-552, 1948.

Abstract. This paper records the discovery, in Val Verde County, on the Rio Grande in Texas, of 350 remarkably symmetrical specimens of natural glass resembling certain forms of tektites---particularly austra-

lites. The distribution of the specimens in a small elliptical area far removed from any evidence of volcanic action, as well as certain features of the specimens themselves, suggests for them a possibly extraterrestrial origin, tho they exhibit certain features which set them definitely apart from other specimens ordinarily accepted as belonging in the category of tektites.

Early in 1941, Mr. Orville Lee, of Del Rio, Texas, reported to me his discovery of several hundred small specimens of natural glass, of unusual form and appearance, in Val Verde County, about 4 miles northwest of Del Rio. He described the locality where the specimens were found as follows:

"The area happens to be on top of a limestone formation---low hills or a divide. There is no certain place in this area to find the specimens. There is some gravel and a little sand on top of the lime, but you find some in the sand or gravel, and some in places where there is no soil, and where there is just lime rock, you find some; so the formation or the soil has nothing to do with them. They are just in a certain area, which happens to be on top of a mesa or divide, and not in a valley.

"I do not think, or I am positive, they do not weather out of any formation, and they appear to be only on top of the soil or formation. There are no wind blow-outs, and the soil is subject only to the average erosion of the weathering agents."

In another report, Mr. Lee stated that all the specimens had come from an elliptical area, about 2 miles long and 3/4ths of a mile wide, extending from southeast to northwest, and that most of the specimens, including the larger ones, had been found at the northwest end. This distribution is noted because of the manner in which it parallels the distribution of meteoritic showers. Del Rio is in a region of Cretaceous and Eocene formations, on the Rio Grande, about 120 miles east of the Big Bend area. The nearest volcanic rocks of Quaternary times are more than 300 miles away---in northern Chihuahua, near El Paso, and in central Tamaulipas. The nearest volcanic rocks of older age are more than 100 miles directly west of Del Rio. There are 350 specimens, ranging in weight from 1/4 gm. to 32 gm., in the collection which Mr. Lee submitted for my examination. Remarkably symmetrical in form, they are predominately lenses, either circular or elongated, resembling one of the common forms of australites. Some of the lenses are widely elliptical when viewed edgewise; others are much flattened. A few ellipsoids and capsular shapes occur, as do also a very few quasispatulate forms and almost perfect spheres. These specimens, which I shall call <u>valverdites</u>, exhibit various features which set them definitely apart from other specimens commonly accepted as belonging in the category of tektites. As determined by Dr. Lincoln La Paz, they fuse readily into a frothy mass under a blow-pipe flame; they have an index of refraction which averages about 1.48; and they have a density which averages 2.30. Even more notable from the standpoint of differences is the fact that they contain many crystals, ranging in size from microscopic trichites to megascopic crystals almost 2 mm. in diameter. These qualities indicate that valverdites are composed of a rather high-silica glass, closely resembling the glass in obsidian.

Suess defined tektites as "bodies which, in contrast to other meteorites, are completely melted materials." In all probability, he intended that the term should be applied to any glass of extraterrestrial origin, regardless of its physical and chemical properties. As now commonly used, however, the term applies to specimens of natural glass which in composition associate themselves with certain sedimentary rocks, whereas obsidian is related to magmatic rocks. Tektites are widely assumed to be of extraterrestrial origin, for no other reason than that no better explanation has been found to account for them! There is a tendency, however, to ignore the fact that in various parts of the world other varieties of glass have been found which also are difficult to explain. Libyan Desert glass and Darwin glass are two of them, tho La Paz holds that Darwin glass should be classified with impactites, such as Wabar glass. Another specimen which differs widely has been found in southern Sweden. More significant in the present discussion are the specimens of natural glass found in Colombia and Peru, to which Martin has given the name of americanites. These specimens occur over many hundreds of square miles, mainly on the tops of hills, in a region devoid of volcanoes and bedrock obsidian. In chemical composition they correspond closely to obsidian, but in gas content they differ widely therefrom. They contain mainly CO_2, CO, and H_2, which are strongly present also in tektites. No chlorine or sulfur gases, which characterize obsidian, are present. Like the valverdites, they contain crystals. In certain localities in the Philippines, typical tektites and specimens of obsidian-type glass are found together, according to Koomans, who states that they bear a very close resemblance to one another in color and in surface sculpturing. That they have different origins is assumed, because they have different compositions. There is a likelihood that valverdites are rather closely related to americanites. In external appearance, however, they differ very noticeably. While the americanites are rounded, they lack the symmetry and common conformity of valverdites and also the lacquer-like surfaces.

A series of valverdites may be easily selected which shows progressive stages of corrosion, from glossy-black specimens that appear almost wholly untouched by any corrosive agent, to dull-black specimens deeply invaded by pits and linear etchings. The greater number, however, are merely roughened on the surface, with very few markings large enough to be discerned easily without a magnifying glass. U-shaped and bow-shaped furrows are very plentiful, but long, deep furrows of the kind that appear on many moldavites and billitonites are entirely missing, as they are also on australites. One specimen, which shows the highest gloss of any specimen in the collection, has what appears to be a thin secondary fusion overlying its surface, tho the evidence is not conclusive. Under the microscope, one spray of trichites may be seen on its surface which looks like a bunch of white hairs caught beneath a coat of black paint, with only the tip ends exposed. A larger white crystal, still microscopic, resembles a match stick trapped by a finger of black tar across its middle. There has been only one discovery, to the best of my knowledge, of a specimen of natural glass which has been described as having a clearly definable secondary fusion on its surface. This specimen, discovered in southern Sweden, is said to have a crust which in thin section is distinguishable from the compact interior glass. I have been unable to confirm the presence of a secondary surface fusion on the valverdites by examining a specimen in thin section. This fact may, or may not, be significant. Wahl, in his description of the Swedish specimen, comments on the difficulty that was encountered in lighting the crust in a manner to make it clearly visible. The glossy lacquer-like surface which still appears on many valverdites is plainly what remains of the original surface. There is no evidence at all of desert polish, or of any natural or artificial agent other than heat, which could put a gloss on the surface of a rough obsidian pebble. All the evidence indicates a gradual deterioration of the surface, which is first dulled as if it had been treated with hydrofluoric acid. In the next stage, the characteristic minute, overlapping pits on the original surface are corroded away; then bow-shaped furrows and numerous parallel corrosion lines begin to appear on some specimens, and in the final stage the effects of the corrosion are such as to make the surface unsuited to a polish of any kind. It is impossible to interpret the varying surface features of valverdites as indicating a movement in the other direction; i.e., from a rough obsidian pebble to a glossy symmetrical specimen. Many obsidian or perlite specimens from Arizona exhibit a high degree of desert polish, but very few of them have even a semblance of symmetry. None of the polished specimens has the minutely pitted surfaces that characterize valverdites; on the contrary, they are very smooth; they look polished, not lacquered. The progress of corrosion is shown clearly on one valverdite, which exhibits a considerable area of glossiness on a surface that is otherwise dull and featureless. It has the appearance of a specimen that has been partially immersed in hydrofluoric acid. Obviously, the original surface has been corroded away where the glossiness is missing. Spalled and broken surfaces of valverdites never show any tendency to develop markings that resemble the characteristic surface markings of the glossier specimens; on the other hand, these surfaces show the same stages of deterioration as the normal surfaces. All surfaces which have resulted from fractures, with one exception, are bounded by edges that show virtually no evidence of abrasion or rounding by any agency; they have been little affected by any factor other than a mild degree of corrosion since they were broken. One broken specimen is, however, well rounded along all the edges of its fractured surface. This appearance might be explained by assuming that the specimen was broken before, or during, its flight thru the atmosphere.

About half of the specimens are opaque. The rest are translucent, and several are sufficiently transparent to permit indistinct discernment of typewritten letters thru them. They are smoky-amethyst in color. A considerable number of the translucent specimens are crossed by agate-like bands of darker material. These bands, as well as the parallel etchings on some specimens that have undergone corrosion, show an internal structure that could not have resulted from the same process that shaped the valverdites. It is obvious that the glass was formed before the shaping process occurred. This same feature appears in the specimen found in Sweden, which also is banded like rhyolite.

I believe that the features exhibited by valverdites indicate that they may have been subjected to a secondary surface fusion which can be readily explained only by assuming that they have undergone the rigors of a violent flight thru the atmosphere. To eliminate them from consideration among glasses of possibly extraterrestrial origin, solely because they resemble the igneous glass exuded by volcanoes, is no more defensible in logic than to eliminate a stone from consideration as a possible meteorite for no other reason than that it resembles some terrestrial sedimentary formation. This procedure is a priori reasoning.

All the evidence pertaining to valverdites, including the circumstances under which they are found, seems to me to suggest that they may have arrived on the Earth at a relatively recent date as compared with the bediasites of Grimes County, Texas, and other known tektites; certainly, the proof is not final.

THE VALVERDITES: A WEATHERED OBSIDIAN FORM.....

La Paz, Lincoln; *Popular Astronomy,* 56:552-558, 1948.

Abstract. This paper is devoted to a critical study of the natural glasses recently found in Val Verde County, Texas. On the basis of the behavior of these so-called valverdites under the blowpipe flame; of their low densities and indices of refraction; of the crystallites and megascopic crystals contained in them; and of their other peculiarities, the conclusion is reached that they are not tektites, but are weathered pebbles of obsidian.

• Enigmatic Terrestrial Glasses

DATING THE LIBYAN DESERT SILICA-GLASS

Oakley, Kenneth P.; *Nature,* 170:447-449, 1952.

Pieces of natural silica-glass up to 16 lb. in weight occur scattered sparsely in an oval area measuring 130 km. north to south and 53 km. from east to west, in the Sand Sea of the Libyan Desert. This remarkable material, which is almost pure (97 per cent SiO_2), relatively light (sp. gr. 2.21), clear and yellowish-green in colour, has the qualities of a gemstone. It was discovered by the Egyptian Survey Expedition under Mr. P. A. Clayton in 1932, and was thoroughly investigated by Dr. L. J. Spencer, who joined a special expedition of the Survey for this purpose in 1934.

The pieces are found in sand-free corridors between north-south dune ridges, about 100 m. high and 2-5 km. apart. These corridors or 'streets' have a rubbly surface, rather like that of a 'speedway' track, formed by angular gravel and red loamy weathering debris overlying Nubian Sandstone. The pieces of glass lie on this surface or partly embedded in it. Only a few small fragments were found below the surface, and none deeper than about 1 metre. All the pieces on the surface have been pitted or smoothed by sand-blast. The distribution of the glass is patchy. It was found to lie most thickly around the expedition's Camp 7 (lat. 25° 17' 54" N., long. 25° 34' 0" E.). At several places there were groups of flakings, evidently where large lumps had been broken up by man. Only two small fragments were found upon the dune ridges. They occurred in company with an implement of quartzite and had evidently been carried there. One piece of silica-glass was found 240 km. south by east of the main area of distribution, and another piece 225 km. to the east-south-east. These, too, had probably been transported by man.

While undoubtedly natural, the origin of the Libyan silica-glass is uncertain. In its constitution it resembles the tektites of supposed cosmic origin, but these are much smaller. Tektites are usually black, although one variety found in Bohemia and Moravia and known as moldavite is clear deep green. The Libyan silica-glass has also been compared with the glass formed by the fusion of sand in the heat generated by the fall of a great meteorite, for example, at Wabar in Arabia and at Henbury in Central Australia. Reporting the findings of his expedition, Dr. Spencer said that he had not been able to trace the Libyan glass to any source; no fragments of meteorites or indications of meteorite craters could be found in the area of its distribution. He said: "It seemed easier to assume that it had simply fallen from the sky".

It would be of considerable interest if the time of origin or arrival of the silica-glass in the Sand Sea could be determined geologically or archaeologically. Its restriction to the surface or top layer of a superficial deposit suggests that it is not of great antiquity from the geological point of view. On the other hand, it has clearly been there since prehistoric times. Some of the flakes were submitted to Egyptologists in Cairo, who regarded them as "late Neolithic or pre-dynastic." In spite of a careful search by Dr. Spencer and the late Mr. A. Lucas, no objects of silica-glass could be found in the collections from Tut-ankh-Amun's tomb or from any of the other dynastic tombs. No potsherds were encountered in the silica-glass area, but in the neighbourhood of the flakings some "crude spear-points of glass" were found, also some quartzite implements, "quernstones" and ostrich-shell fragments.

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ORIGIN OF LIBYAN DESERT SILICA-GLASS

Cohen, Alvin J.; *Nature,* 183:1548-1549, 1959.

Since first reading of Libyan Desert glass, I have been intrigued concerning its origin. In the course of investigation of impurities in the glassy state, the role of trace germanium in fused silica was studied. All fused silica produced artificially from natural quartz contains trace germanium impurity. Two different fused silicas investigated contained 0.9 p.p.m. of germanium. It occurred to me that the trace germanium content of Libyan Desert glass might offer a clue to its origin, as no trace germanium would be expected to volatilize selectively (as germanium (II) oxide) during sudden melting and quenching of a high silica-content glass. [Analysis omitted]

I conclude from the chemical and mineralogical content that Libyan Desert silica-glass is terrestrial in origin, being formed from Libyan Desert materials, most likely by impact of some cosmic body. In this regard the area around 22° 18' N. and 25° 30' E., containing explosion craters (as well as volcanic evidence), should be more thoroughly investigated. Ehmann and Kohman indicate a cosmic origin for Libyan Desert silica-glass based on the apparent presence of aluminium-26 and beryllium-10. However, the level of activity of aluminium-26, for which the measurement was the more reliable, is lower than that in chondrites and in australite, and may be due to some other cause than free-space cosmic radiation.

Analyses				
Element (oxide)	Libyan Desert silica-glass	Aouelloul: Sandstone	Aouelloul: Glass	Ivory Coast tektite
SiO_2	98.20	95.30	86.10	76.56
TiO_2	0.23	0.55	0.60	0.60
Al_2O_2	0.70	1.85	5.05	11.54
Fe_2O_2	0.53	0.45	1.45	0.17
FeO	0.24	0.05	1.45	3.99
NiO	0.02	Nil	0.025	--
MnO	--	0.02	0.05	0.08
MgO	0.01	0.40	1.50	3.60
CaO	0.30	0.80	0.90	1.62
Na_2O	0.33	0.20	0.05	1.32
K_2O	0.02	0.10	2.05	0.82
H_2O	0.064		0.02	0.0047

GEOCHEMICAL AND GEOLOGICAL EVIDENCE FOR THE ORIGIN OF DARWIN GLASS

Taylor, S. R., and Solomon, M.; *Nature,* 196:124-126, 1962.

The occurrence of a frothy siliceous glass, from the eastern slopes of Mt. Darwin, Western Tasmania, was brought to scientific attention in 1910 by M. Donoghue. It was first mistaken for slag from an abandoned copper smelter. In 1913, H. Conder, State mining engineer, informed the Geological Survey of Tasmania of the occurrence, and a survey was undertaken by Loftus Hills. Samples were sent to Prof. F. E. Suess in Vienna, who named it 'Queenstownite' after the nearby town, and compared it with the moldavites. Later workers have preferred the name 'Darwin glass'. Hills fully described the details of the discovery and location, gave a description of the glass by Suess, and two chemical analyses by Ludwig.

A further description of the occurrence, with two new analyses by Ampt, is given by David et al. All these workers have agreed on the natural origin of the glass, and placed it with the tektites, although recognizing that it was an aberrant type.

Later workers, notably Conder, Suess and Spencer, classified Darwin glass as an impactite, formed by fusion of siliceous sediments by meteorite impact. Preuss reported a single determination of 240 p.p.m. chromium, 314 p.p.m. nickel, 1.80 per cent iron, with a nickel-iron ratio of 170×10^{-4}. Ehmann found 162 p.p.m. nickel and 1.60 per cent iron, giving a nickel-iron ratio of 100×10^{-4}, and he placed Darwin glass among the impact glasses without comment. Baker and Gaskin and Baker considered the glass to be of uncertain origin (no meteorite crater has yet been discovered in the vicinity) and Baker has suggested an origin by fusion of silica in burning peat horizons. Doubt has also been cast on the authenticity of some specimens, and it seems possible that some of the smelter slag and also some Tertiary tachylyte have been accidentally distributed as Darwin glass. We therefore decided to undertake a geological and chemical examination of the occurrence, and report here the preliminary findings. One of us (M. S.) is responsible for the collection and geological description, and the other (S. R. T.) for the chemical data and their interpretation.

The glass is very irregular, slaggy, with twisted stalactitic forms, and with rare teardrop and disklike shapes. Numerous bubble pits are present, and the pieces are consequently of very low density (sp. gr., 1.7 - 2.2) and have a frothy appearance, well described by the prospectors' term, 'petrified kelp'. The largest specimen weighed 21 g and measured 6 cm by 2.3 cm. The average weight of 330 specimens described by Fenner was 0.57 g; the average of 41 pieces in the University of Queensland collection was 1.61 g. The density of the powdered glass varies from 2.275 to 2.296 g cm^{-3} and the refractive index from 1.474 to 1.479. Twisted and bent particles of fused silica (lechatelierite) are present, but later investigators have failed to confirm the presence of metallic spherules reported by Conder.

The glass is abundant on the east slopes of Ten Mile Hill, which lies 12 miles south-south-east of Queenstown, and occurs sparsely in scattered areas within a zone 1/2 - 1 mile wide that extends north from Ten Mile Hill for about 6 miles. Glass probably occurs to the south also but dense vegetation prohibits further observations. The largest (up to 6 cm long) pieces are found at Ten Mile Hill; the average size decreases northwards and eastwards and at the northern limit of the zone of occurrence all the pieces are less than 1 cm long. The glass fragments are scattered in the peaty soil cover, which varies from a few inches to 18 in. in thickness. Many pieces appear broken but there is little evidence of stream-rounding. The shallow depth of occurrence and the lack of abrasion indicate that the glass is no more than a few thousand years old and formed or fell on a surface that has since been only slightly modified. [Analysis omitted]

The comparison with australites is interesting. Potassium, rubidium, copper, titanium and zirconium have about the same concentration. Iron and barium are about half as abundant, and lithium, sodium, strontium, vanadium, manganese and scandium are depleted by larger factors in Darwin glass. These are the sort of changes to be expected with an increase in silica content of about ten per cent. Nickel, chromium, and, in group I, cobalt, are markedly more abundant in Darwin glass compared with the australites.

The relationships of iron, nickel and chromium in Darwin glass, in australites, meteorites, and a variety of terrestrial rocks are shown in Figs. 1 and 2. These diagrams clearly indicate the distinctive composition of the glass for these elements. The iron-nickel diagram illustrates the similarity with the undoubted impact glasses from Henbury and Wabar, and the probable impact glass from Aouelloul. Data on chromium and other trace elements are not yet available for these samples.

DARWIN GLASS RELATED TO TEKTITE FALL?

Anonymous; *Nature,* 248:101-102, 1974.

The material that has come to be known as Darwin glass was first recognised and described just 60 years ago by Suess who found large quantities of it along a north-south track some 3 km to the east of Mount Darwin in Tasmania. About 50 years later, geochemical studies and the discovery that the glass contains coesite led to the view that the Darwin glass must have been formed by impact---a conclusion which was strikingly confirmed two years ago when Ford (Earth Planet. Sci. Lett., 16, 228; 1972) discovered Darwin Crater, a circular depression with a diameter of about 1 km lying some 4 km or so to the east of the most southerly of Suess's deposits.

It is now known that there are far more examples of glass in the vicinity of Mount Darwin than Suess had realised; and with the aim of confirming the genetic relationship between the original occurrences and the more recently discovered crater glasses, Gentner et al. (Earth Planet. Sci. Lett., 20, 204; 1973) have used both potassium-argon and fission track methods to date glass samples from the interior and rim of the crater and from areas up to 2 km away from the rim. The mean potassium-argon and fission track ages are 0.70 ± 0.08 and 0.74 ± 0.04 million years, respectively, giving a combined age of 0.73 0.04 Myr. This compares with the fission track age of 0.72 ± 0.02. Myr for the longer-known glasses, obtained previously by Gentner et al. (Geochim. cosmochim. Acta, 33, 1075; 1969).

Gentner and his colleagues thus conclude that all the known Darwin glasses were produced at the time of the impact that formed Darwin Crater 0.73 Myr ago. But there may be more in this than simply a study of the relations between glass deposits. That the Darwin glasses occur geographically close to the Australasian tektites has been obvious for some time; and what Gentner et al. have now done is to show that the glasses and the tektites have the same age. This is apparently the first evidence obtained that an impact crater was formed at the time of the Australasian tektites. It seems hardly likely that this is a coincidence; and yet it is unlikely that an impact forming a crater as small as the Darwin Crater could be responsible for the large Australasian tektite field. One reconciling conclusion is that the meteorite or comet fall (if such there was) leading to the formation of the Australasian tektites produced a number of craters, of which the Darwin Crater is but one. If so, a careful search in the area should reveal them in time.

NATURAL GLASSES FROM MACEDON, VICTORIA.....

Baker, George, and Gaskin, Arthur J.; *Journal of Geology,* 54:88-104, 1946.

Abstract. A small quantity of natural glass from Macedon, Victoria, is shown to be like Darwin glass from Tasmania. The glasses from both localities are compared and contrasted with natural glass from other parts of the world.

The results of secondary fusion of rocks under special circumstances during the fierce burning of tree trunks at two localities in Victoria suggest that these glasses may have developed during forest fires. This casts further doubt on the belief that Darwin glass is of tektitic (extraterrestrial) origin.

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Conclusions. Examination of the nature, mode of occurrence, and chemical composition of various types of natural glass has not led to any finality regarding the origin of the Macedon glass from Victoria and the Darwin glass from Tasmania. Nevertheless, it has been shown that theories of origin suggested earlier are unlikely, whereas the discovery of soils and rock fragments fused under special conditions indicates the possibility that natural glass can develop during bush fires.

Macedon and Darwin glass are not glass meteorites (tektites) as australites, moldavites, bediasites, billitonites, etc., are believed to be. They do not show the form or surface features characteristic of the true tektites, many pieces having shapes like those resulting from the dripping, twisting, and drawing-out of solidifying glass. Moreover, they are far more vesicular and richer in silica than tektites, as well as showing other minor differences.

The glasses from Macedon and Darwin differ from fulgurites sufficiently to show that it is unlikely that they resulted from the fusion of sands by lightning. Whereas the glasses from Henbury, Wabar, and Meteor Crater show indisputable evidence of being true "impacttites," there is little that is suggestive of Macedon and Darwin glass having been formed by the fusion of sedimentary material by meteoritic impact.

There is nothing to indicate that Darwin glass originated from the fusion of rocks or their disintegration products caught up in burning tree trunks, although from the chemical evidence there is a strong suggestion that this glass (and hence probably Macedon glass also) represents fused sedimentary material of terrestrial origin.

The distribution of the Darwin glass in Tasmania might be readily explained by assuming that the pieces represent residues from silica-bearing plants burned during a bush fire. Such a mode of origin, however, is partially discounted by a comparison of the chemical compositions of Darwin glass and of glass from wood ash. The potash content of Darwin glass is much too low, compared with that of "straw silica glass"; but the discrepancy is not nearly so great when compared with a slag produced from boxwood charcoal in the suction gas plant. In this comparison, however, it is seen that silica, alumina, and titania occur in greater quantities in the Darwin glass than in that from boxwood ash, while lime and magnesia are much lower.

The fact that lechatelierite particles occur in the various types of artificial and natural glasses is no criterion for determining the mode of origin of any particular glass. They can be formed in a variety of ways. All that the lechatelierite particles indicate is that quartz was a constituent of the source materials, that fusion was rapid, that the heat was very intense, and that cooling was rapid.

The evidence accrued therefore leads to the conclusion that each particular occurrence of natural glass has to be considered individually. The presence of lechatelierite particles, comparisons of chemical and spectrographic analyses or physical properties for each glass, are, taken alone, insufficient to establish a specific theory of origin. Mode of occurrence and associated features have gone further toward establishing the mode of origin of certain of the glasses than any other type of evidence. This applies especially to Henbury, Wabar, and Meteor Crater glasses, for which, from the very nature of their occurrence alone, the meteorite-splash theory of formation can scarcely be disputed, and it is definitely known that fulgurites are formed by the fusion of sand by lightning. A definite mode of origin, however, cannot be conclusively assigned to Libyan glass, Macedon glass, or Darwin glass from either their manner of occurrence, their associated features, or their chemical composition, whether ascertained chemically or spectrographically. All that can be said of Darwin glass and Macedon glass with any certainty is that they represent sedimentary material that has been rapidly fused at high temperatures lasting for relatively short periods and that cooling was rapid. The heating agency, however, cannot be specifically stated. The evidence is against heating in the way that tektites were heated and against heating by electrical discharge, while there is little, if anything, to support the idea of heating by meteoritic impact. Some of the evidence points to the possibility of the heat of bush fires being sufficient under set conditions, to form natural glass, not so much, perhaps, by the fusion and collection of the silica contained in silica-bearing plants as, more probably (as the chemical composition indicates), by the melting of silica-rich material caught up under special circumstances in burning tree trunks.

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• Magnetic Spherules

MAGNETIC ROCK FROM SKY

Anonymous; *Science News Letter,* 67:279-1955.

Roughly 7,000,000,000 mysterious particles from outer space bombard the earth each year. This was revealed from studies made of the ocean bottom.

More than 300 of the odd magnetic particles were swept from 45,000 square miles of ocean floor by a home-made magnetic rake during the Danish Deep-Sea Expedition in 1950-52. They have been named caudaites to distinguish them from meteorites and cosmic dust.

The particles are believed to originate from the tails of the larger cosmic bodies that enter the earth's atmosphere.

Varying in color from grayish-brown to shining black, the caudaites are nearly all spheres. They measure less than one-half millimeter in diameter. Upon examination, scientists found that some of them consist wholly of magnetite.

Others have a silicate groundmass loaded with magnetite crystals. They also found that nearly all the particles had spherical cavities. Altogether, seven metallic particles were found in the material studied.

Support of the theory that the particles come from outer space involves several factors.

The structure and composition of the metallic particles indicate that their formation requires high heat and rapid cooling.

No comparable particle formation has been found to occur naturally on land.

A comparison of the particles with iron meteorites was made from similar particles found in an 1872-76 expedition and showed that all the material found in the particles is also found in stony meteorites.

Other particles found by a Swedish expedition from deep borings into the sea bottom rule out artificial origins.

The scientists reporting the cosmic particles estimated that the total weight of the 7,000,000,000 particles falling on the earth each year would be about 30 tons.

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COSMIC SPHERULES

Parkin, D. W.; *Nature,* 276:323-324, 1978.

Most scientists will not have heard of cosmic spherules, yet Murray and Renard found and named them long ago ("Challenger" Reports 4, 1891). About a dozen of these extraterrestrial spherules, $\sim$100 μm diameter, can be magnetically extracted from a cupful of deep oceanic red-clay, which slowly deposits at a few metres per 10^6 years. They are black and quite spherical. Two types occur: the 'stones' and the 'irons', although a few might be called 'stony-irons'. The stones are olivine $(Mg, Fe)_2SiO_4$ and magnetic Fe_3O_4; a little glass may be present but not as a noticeable phase. The irons are magnetite and wustite FeO; often a globule of Fe/Ni alloy is present, eccentrically placed in the oxide shell. There are other rounded magnetite forms in the red-clay which are not extraterrestrial. These occur especially in the less than 30 μm-sized range. Probably these faceted and very shiny black forms are growths on the sea bed or may come from volcanoes. Care is needed not to confuse these small particles with cosmic spherules. Above 50 μm there is little chance of contaminating a collection. The fact that the ratio of stones to irons is the same in any surface sample of red-clay provides a strong argument for an extraterrestrial source for both types of spherules.

Most meteorite experts would accept the extraterrestrial origin; but they have tended to ignore cosmic spherules, believing that they are merely droplets sprayed from a meteorite as it ablates in the atmosphere. On the other hand, Öpik (Irish Astr. Jour. 1, 145; 1951; 4, 84; 1956) proposed a more interesting origin: cosmic spherules are formed in the atmosphere by the melting of similarly sized fragments coming directly from the zodiacal cloud.

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Now, as a result of a few recent papers, interest in cosmic spherules is likely to be renewed. Brownlee et al. (Interplanetary Dust and Zodiacal Light, Eds. H. Elsasser and H. Fechtig, Springer-Verlag, 279, 1976) have painstakingly identified extraterrestrial dust by using aircraft in the stratosphere. Amongst these μm-sized crumbs, most of which are like carbonaceous meteoritic material, similar sized spherules have been found at about 10% frequency. It could be that both crumbs and spherules are coming directly from the zodiacal cloud.

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CONDENSATION GLOBULES AT METEOR CRATER

Nininger, H. H.; *Science*, 113:755-756, 1951.

The American Meteorite Museum, located on U.S. 66, 5 miles from Arizona's meteorite crater, has been making extensive and intensive studies of the adjacent soil. These studies have brought to light minute metallic globules that are believed to have been formed as condensation products from metallic vapors generated by the explosion of the colliding meteorite or meteorites.

Chemical analysis of these particles by F. G. Hawley shows them to be about 17% nickel, and metallographic studies by A. W. Herbenar prove the presence of cohenite, steadite, and schreibersite, as well as troilite. The percentage of nickel is about double that of the meteorite fragments found in the same area. The reason for this nickel-enrichment is still problematical.

Although these little objects have eluded fieldworkers for nearly 60 years, we have now proved that they exist in concentrations as high as 100 g/cu feet of topsoil. Such a concentration would amount to 3,000 tons/sq mi. Over how large an area this high concentration extends is not known, but it is thought to be rather limited. However, at least a sparse sprinkling of the material has been detected over 100 sq mi around the crater. Quantitative studies are now in progress.

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RINGING ROCKS

Ringing rocks abound the world over. There is no real mystery in this because many solid substances resonate naturally at audio frequencies. Modern men and probably prehistoric peoples as well appreciated the novelty of ringing rocks, fashioning gongs and crude xylophones from them. Beyond mere curiosity value is the fact that some rocks ring while their neighbors, ostensibly of the same species, have no respect-able voices at all. The Upper Black Eddy (Pennsylvania) field of ringing rocks has engendered the most speculation. Here, various environmental forces seem to affect the rocks' ringing properties in ways still poorly understood.

THE SOUNDING ROCKS OF GUILDO

Anonymous; *English Mechanic,* 49:191-192, 1889.

Not far from Dinan, on the banks of the Arguenon, one of those small torrential rivers which, in emptying into the sea, carve the coast of Brittany into capricious festoons, there is shown to the tourist a heap of greyish rocks known in the country under the name of the "sounding stones of Guildo."

In the crystalline texture of these rocks and their slaty colour we at once recognise that variety of stone known in mineralogy by the name of amphibole (complex silicate of iron, manganese, and lime). These stones, which, aside from their musical properties, possess no novelty, are situated in the midst of wonderful scenery. They occupy a small cove, that at rising tide is entirely covered, and which is overlooked by a high bank, upon which stands the little village of Guildo, formerly the centre of a celebrated pilgrimage.

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The stones of Guildo are not erratic blocks derived from the upper part of the valley. It is clearly seen that they have been detached from the bank itself, the strata of which are of rock of the same formation. They are huge boulders rolled and polished by the sea. When, at the rising of the tide, the Norouet wind blows in a tempest, the waves break over the points of Saint Jacut and ascend the river bed with irresistible force. Now, the sounding rocks stand at the very point where, in consequence of a slight bend in the course of the Arguenon, the fresh descending water comes into contact with the salt-ascending stream. Under the repeated stresses of these two opposite currents, the huge rocks clash against each other, wear away, and gradually become polished.

The sounding-stones are three in number. They are long prismatic blocks, lying side by side, at right angles with the shore, and because of their form, the inhabitants sometimes call them "the horses in the stable." The central stone more particularly exhibits the phenomenon. It is about 20 ft. in length and 23 ft. in circumference, thus giving it an approximate weight of 165,000 lb. On the river side it ends in a sort of truncated spur. It is at this part that it is necessary to strike it with an iron instrument, or, better, with a stone of the same nature. Near this spur there are observed three or four points that are well marked by the wear produced by the repeated blows of visitors. These are the points at which the maximum of sonorousness is obtained.

Under a blow the stone emits a very clear, silvery sound, similar to that which would be obtained by striking a large bell with a mallet of softwood. The sound, as far as a hurried examination allowed us to judge, corresponds to mi_2. The more one approaches the other end, in continuing the blows, the deader the sound becomes. Near the top the totality seems to increase a little. Finally, at certain points, which must be nodes of vibration, merely a dull sound is obtained. If, while striking, one presses his ear against the other extremity of the rock, the sound heard is extraordinarily intense, and, in measure as it dies out, the various harmonics are distinctly perceived. The two other stones emit nothing more than a muffled sound. It is asserted that this is due to the fact that they have been disturbed by the action of the sea. In fact, it is to be noted that the musical stone rests through a few points only upon the pebbles that support it, while the two others are now partially sunk in the subjacent earth.

We examined all the surrounding stones and found several that gave very varied sounds, without there seeming to be any relation between their size and the height of the pitch. At the end of the cove we more particularly remarked a horizontal stratum partially buried in the shore and divided into fragments, forming, as it were, something like the gigantic keys of a prehistoric piano. Three of these stones gave clearly the perfect major chord. While watching our researches with curiosity, a boy of the locality exclaimed now and then, previous to our experiments: "Will sound!" "Won't sound!" and, accustomed to make the singular stones speak, he soon showed us how, at the first glance, it was possible to recognise the musical stones. The rocks, in fact, exhibit two very different aspects.

Those of a silvery grey, with a very fine texture, all render, even when broken, a very pure sound. Those of a darker colour and blotched with brown, through an excess of iron, are as if exfoliated, and emit no sound. The bank of diorite must have been traversed by a ferruginous vein, for at more than one point we found large rubble stones composed of the two kinds of rock.

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SOUNDING STONES AT CH'UFU, SHANTUNG

Tingle, Alfred; *Nature,* 73:222-223, 1906.

Last July I happened to pass through Ch'ufu, the birth- and burial-place of Confucius. In 'seeing the sights' of the town I found three very fine examples of "sounding stones," or "stone gongs" as they are sometimes called. These particular examples do not seem to be very well known except by Chinese; none of my foreign acquaintances who have been in Ch'ufu had noticed them. Photo No. 1 shows the tomb of the grandson of Confucius. The cover of the incense dish (on which my servant is resting his hand) is made from stone, but when struck with a stick, or even with the knuckles, it rings as though it were bronze. In fact, my man in the photograph refused to believe that it was anything but painted bronze until I myself assured him to the contrary. Photo. No. 2 shows two pillars (marked with crosses) of the balustrade in front of the principal hall of the great Confucian temple at Ch'ufu. Struck at any point with a piece of wood, they give a distinct musical note.

Inside the temple is a large tablet, about 5 x 3 x 1/2 feet, of the same stone. In this case the note produced varies according to the point at which the stone is struck. The stone from which all these bodies is made is a greyish oolitic limestone. I was informed that it came from a quarry at Kwan Ko Shan, about seventeen miles south-east of Ch'ufu. Most of the stone from this place has no musical quality, but from time to time veins of it are found, and when found it is usually abundant. "Stone gongs" of this kind are found in all parts of the country, and some are in the possession of foreigners. So far as I can find out, they all come from this one locality. They have been known for many centuries, and it is recorded that the district from which they come paid its share of a certain special Imperial tax in "sounding stones." I should be pleased if any reader could give the cause of this very remarkable property, and if it is not understood I would gladly give what help I can towards elucidating it. During this journey I was pressed for time, and as my route lay directly east from Ch'ufu I was not able to visit the quarry. Should there be any object in doing so, however, I will take the first opportunity of returning and making any observations that I may be asked to make. Such an opportunity may occur at any time, and, in fact, could be easily made to occur, as the journey would only take four days each way. I am afraid, however, that it might prove very difficult to secure any sample of this stone for transportation to Europe.

SOUNDING STONES

Carus-Wilson, Cecil; *Nature,* 73:246, 1906.

Many hard and compact varieties of rock are sonorous when struck. Flint nodules often possess this property. The purity of the tone appears dependent upon the length, calibre, and homogeneity of the nodule, the best results being obtained from the long and slender forms. At studland Bay I have collected many of these "musical" flints, and obtained one from a chalk pit near Faversham which can be used as a gong when suspended. This particular specimen is nearly 2 feet in length (it was once longer), and is scarcely as thick as a rolling-pin!

Many years ago I saw a "rock harmonicon" in the museum at Keswick. It was formed of strips of rock (known as "clinkstones") arranged on the principle of the dulcimer, upon which various tunes could be played.

The phonolite of the Wolf Rock, nine miles south of the Land's End, possesses sonorous properties, and Sir Wyville Thomson has described St. Michael's Mount, an island near Fernando Noronha, as being entirely formed of phonolite which "literally rings like a bell" on being struck.

In quarrying the rock from the Whit Bed, at Portland, the workmen profess to be able to judge of the quality of the limestone by the clearness of the metallic ring emitted from the blocks on being struck.

SOUNDING STONES

Crossland, Cyril; *Nature*, 73:297, 1906.

It may be of interest to add to the list of musical stones provided by your correspondents another limestone, viz. the very hard, crystallised, coral rock of the coasts of British East Africa. Among the bizarre forms assumed by these rocks under the erosion of the sea, isolated pillars with projecting arm at the top, like a gallows or an inverted capital "L," are common in places. This horizontal arm in many cases gives a clear musical note when struck with a stone or hammer, being thus a ready suspended natural gong.

ROCK MUSIC

Gibbons, John, and Schlossman, Steven; *Natural History*, 79:36-41, December 1970.

On a June day in 1890, Dr. J. J. Ott played several musical selections for the Buckwampum Historical Society in Bucks County, Pennsylvania. He was accompanied by a brass band, but, in the words of one who was there, "the clear, bell-like tones" he was playing "could be heard above the notes of the horns." What made the concert different was that Dr. Ott was making music by hitting boulders with a hammer.

Dr. Ott had put together an octave of ringing rocks from a boulder field in Bridgeton, one of many dotting eastern Pennsylvania and western New Jersey. The peculiar ability of the rocks in some of the fields to ring like a bell had been known long before, but not until 1965 was a serious attempt made to find out why.

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The ringing rocks fields are not very different from the other boulder fields in the area. Irregular clearings of ten to fifteen acres in the predominantly hardwood forest, the fields are floored by loosely piled boulders varying in size from one to fifteen feet in diameter. The boulders are made up of a dark igneous rock called diabase that is about 180 million years old. There is no soil between the boulders in the field, and they lie on a sloping bedrock surface of the same rock type. Some worts and lichens are the only plants to be found there. The absence of soil to retain rainfall makes the presence of rooted plants impossible. The microclimate of the area has been aptly described as desertlike.

The boulders themselves are usually flat, and their exposed surfaces are often stained reddish by iron oxides. Weathering has sculptured the upper surfaces into a pitted and grooved pattern. The surrounding forest floor contains boulders similar in size and composition to those in the boulder fields. Outside the fields, however, the boulders do not ring, have no reddish stain, and display a peculiar "crazed," or cracked, pattern on their surfaces. One of the persistent observations about the boulders is that they cease to ring if they are removed from the fields.

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The boulders in the fields are not buried in soil or shaded by overhanging trees. They are wet only for a short period following a rain or snowfall. This makes the chemical alteration of the minerals and the stresses produced by those alterations accumulate at a very slow rate. Frost action, the breaking of rock by expanding ice, is probably also minimized by the short time water stays in the system. Long periods of time for the establishment of a state of stress equilibrium are thus provided.

Those boulders outside the fields exist in a different environment:

they are shaded and usually lie on or in water-retaining soil and forest litter. Weathering and frost action proceed much more quickly. Time for adjustment of the stresses in the rock to an equilibrium state is insufficient, and the boulders "crack up."

This conclusion explains why boulders removed from the field stop ringing. If left outside in a rock garden or other shaded spot the boulders are soon overstressed and break up. Ringing rocks kept dry in geologic collections continue to ring indefinitely.

The delicacy of environmental controls on the ringing effect can be illustrated by examining the edges of the boulder fields: the zone separating boulders that ring from those that do not is relatively sharp. The boundary usually lies several feet within the field. The position of the boundary was a puzzle until a botanist friend accompanied us to the site one day. His chance comment about the plants growing along the shade line from the bordering trees struck home. The boundary of the ringing boulders area corresponds roughly to the average position of the shade produced by the larger trees about the edges of the field. More shade means less evaporation and thus more moisture retained. Enough apparently, to disrupt the balanced processes that cause the boulders to ring.

We therefore propose that the answer to the ringing rocks lies, not in witchcraft or ancient ruins, but in a very subtle and delicate interaction between earth materials and environment over very long periods of time. These are things that cannot be observed in terms of man's unaided senses. The concept of the immensity of geologic time is peculiar enough to most people. The measurements necessary to detect and measure the data presented here are impossible without complex instruments. Faced with phenomena for which there are no observable causes, it is completely logical that supernatural explanations should be proposed. Such proposals are the product of the same curiosity that has produced all sciences, especially the natural sciences.

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WHY THE ROCKS RING

Anonymous; *Pursuit,* 4:38-41, 1971.

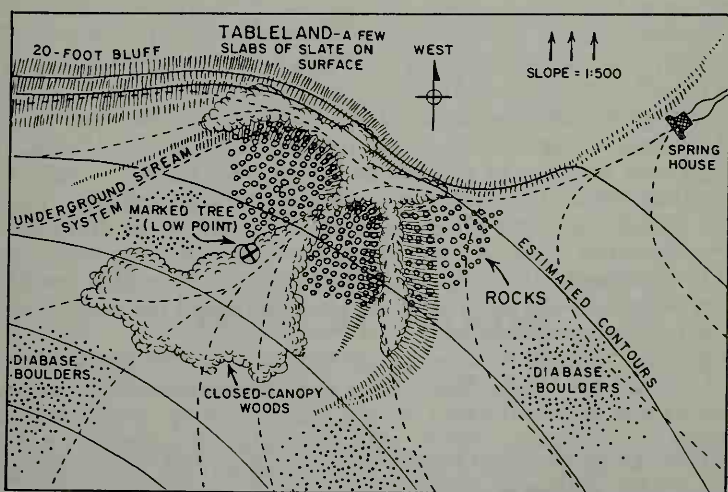
An excellent article appeared in the December issue of Natural History, the popular magazine published by the American Museum of Natural History in New York, entitled "Rock Music", by John Gibbons and Steven Schlossman. This purported to explain why some of the rocks "ring" in the now famous Bucks County rock fields in Pennsylvania. While the reasons they put forward for this phenomenon are doubtless precisely so from the mechanical, mineralogical, and even possibly the geological points of view, their hypothesis, as given in this article and in a lengthier scientific paper published previously, is unfortunately founded in part on some false observations or assumptions. Further, they failed to investigate the biological aspects properly, and especially the botanical. Then there is another matter which they did not take into account, but doubtless because it had not been recorded when they wrote their paper. Let us dispose of this first.

When satisfactory aerial photographs were taken of the rock field at

Upper Black Eddy, and proper maps were drawn from them, a number of highly suspicious conformations came to light. This field turned out to be precisely circular when certain features, other than the bare vegetationless area, were taken into account. Further, there is a deep moat, with a high ridge on the inside, going more than two thirds of the way round this area. There is also a double extension of this wall going down a valley to the northwest, ending around a small basin kept fed by a year-round spring. On a subsequent survey of this location, one of our members, a stone mason (and also a keen spelunker) crawled into a small "cave" between the tumbled boulders on the other side of this ridge and discovered two traces of enormous cutstone blocks that were laid horizontally and morticed. From this we can but assume that, at least at this location, somebody did some building in very ancient times. We are urging further controlled professional excavation by the appropriate authorities to ascertain whether the whole moat and its inner ridge might be man-made, and the latter have a cut-stone footing all around it.

This discovery does not, of course, explain the "ringing" properties of some of these rocks and probably has nothing to do with it. The map of this location looks very much like that of a European cooperage hill fort, and early settlers might simply have made use of these convenient places where rocks did not have to be dug out of the ground or quarried.

Coming to the rocks themselves, we must point out that in describing their occurrence, Messrs. Gibbons and Schlossman omitted one very pertinent fact. Their statement that "The peculiar ability of the rocks in some of the fields to ring...." should have read: "The peculiar ability of some of the rocks on the fields to ring..." There is a world of difference between these two statements, and this is of the utmost significance. And, pertinent to this are two gross misstatements that they repeat several



Upper Black Eddy rock field in Pennsylvania. Contour lines are 10 feet apart and descending from the west.

times. The first is that the rocks cease to ring if removed from the fields ---an observation that is contradicted by their further statement that "Ringing rocks kept dry in geologic [sic] collections continue to ring indefinitely". Second, they state that, if left in moist situations in "rock gardens or other shaded spots, the boulders are soon overstressed and break up". They also make several other flat statements that are just plain nonsense, such as that these rocks are usually flat topped, and that, when broken up with a sledgehammer, they soon stop ringing, and so forth.

By actual counts, about 30% of the rocks in these fields ring (though this seems to vary throughout the year), and ringers are found occasionally under the trees, but only in those two areas inside the circle (see map). We have yet to find a boulder that has ceased to ring (and with the same tone) when removed to our HQ, forty miles away; and we brought the first set from Upper Black Eddy in 1961. Further, we have had some of these rocks completely submersed in one of our ponds, lying about under trees, suspended on wires or set in concrete in a damp cellar, on shelves in our laboratory, and even in our house which is exceptionally dry; and they all continue to ring. Also, we have smashed up innumerable boulders of all sizes, and all the parts continue to ring, even down to cut slices three inches by one inch and 1/4 inch thick as always. The explanation for the physical properties of the ringers, as given by Gibbons and Schlossman may be valid to a point; but the basic premises upon which they erected their theory are (to coin a phrase) all wet.

Then again, they appear to have done nothing whatsoever about the petrological aspect of the matter, which causes us to doubt what mineralogical findings they allege. The constitution of the diorite 'family', of which the diabase country rock of these fields is a member, is "a soda-lime or lime-soda felspar approximating to an andesite in composition, together with hornblende. The possible minerals are oligoclase, andesine, labradorite, hornblende, biotite, augite, enstatite, quartz, apetite, and magnetite" [see Minerals and Microscope, H. G. Smith, London: Thomas Murby, 1922]. Our member 229, chief technician of a large ceramo-metal products manufacturer, ran a considerable number of series of tests of three sets of specimens, identified only by numbers, to wit: (1) ringers, (2) non-ringers from inside the circle, and (3) non-ringers from outside the circle, some from as far away as a mile. In developing gross samples of glasses by fusion from these, it was found that the melting point of (1) differed markedly from (2) and (3). Much more significant was the fact that different metals---in the form of amorphous globules---appeared in these two groupings. The non-ringers gave what appeared to be copper, the ringers a white metal of very high lustre. We have so far obtained only one report on the analysis of the latter, and this claimed that it was molybdenum!

Turning to the biological aspects, we fear we must be much more critical. We have had the Upper Black Eddy field under surveillance on a fairly regular and seasonal basis for ten years, and we have run a series of laboratory experiments. These will eventually be reported on in full, so suffice it to state now that ringing rocks kept (in fish tanks) alongside non-ringers, and in open pond water (filtered), in well water, and in distilled water, in all cases inhibited both contamination and growth of all kinds, while developing from themselves large patches of pure white fungoid mycelia that, in the absence of fructification, cannot be identified. The absence of both animal and plant life on this field---as diametrically opposed to screes and other bare rock fields in the area---is even more peculiar than it at first appears to a non-biologist. The list of animals is comprised solely of a number of species of spider, two microlepidoptera ("mini-moths"), and (so far collected) seven species of Diptera (flies). The last, however, appear all to be of one Family.

It should also be put on record that while neither domestic nor wild-caught animals (both local and imported) on leashes, show any disinclination to cross the rock field, birds seem most reluctant to do so, and may often be observed flying halfway around the circle in order to cross it. We have never found any bird droppings on the field. Turning then to the botanical oddities we must put on record a really most remarkable phenomenon, one that we have never heard of elsewhere---outside a laboratory. This is that a very high percentage of the trees growing in the two areas marked "X" on the map, have what is called onion-bulb trunks, in that their bases immediately above ground are swollen just like a fat onion. Such a condition has been reported in laboratory experiments in which plants were grown in soil containing high concentrations of artificially introduced compounds of (or native) copper. Finally, we should add that trees that either fell onto the edge of the bare rocks, or apparently tried to grow out over it when saplings, perform the most extraordinary horizontal gyrations, usually leading their growing points back under the trees, and all of them develop branches only on the upper side, while these go straight up and then bend back into the shade. This defies all known laws for woody plant growth, and on several scores.

Altogether, while the explanation of the mechanics of the ringing by some of these rocks as given by Gibbons and Schlossman may be perfectly feasible despite so many mistaken premises, it does nothing to explain the incidence of the fields themselves, nor even to explain why only <u>some</u> of the rocks ring. And when it comes to other things not observed by them---such as that there are some larger rocks which, when hit appropriately, give rise to a whole scale; that most of the curious scalloped erosion is on their undersides; that two different ringers when knocked together while suspended on wires produce (invariably, it seems) but one tone, however many different combinations are used: and so on---it is manifest that we have a very long way to go yet before we explain these singular natural phenomena.

MUSICAL SANDS

Along seacoasts and in deserts, wherever sands occur, strange sounds are sometimes heard---hums, bell-like tones, startling roars, even barking sounds. The cause is not hard-to-find; it is a peculiar variety of sand. Musical sand, sonorous sand, or whatever the local populace terms it, emits a surprising variety of sounds when disturbed by man or nature. Some beach sand merely squeaks like snow when trod upon. A booming dune, on the other hand, may be heard a mile away when a small cascade of sand slides down its slope.

No deep dark secrets of nature are implied here, although musical sands have led to numerous intriguing local legends. The notorious Bell of Nakous, in the Sinai, and the legendary "morning cry of the Sphinx" may originate in the action of musical sand. They may also create the strange hums sometimes heard in deserts. No one with a modicum of curiosity can ignore such tantalizing phenomena.

Although the mystery of musical sands is hardly profound, no one really understands how the great variety of sounds is made. Can the same physical mechanism produce a deafening roar in one location and pure, delicate aeolian tone in another? And just why are musical sands so localized; what special geological conditions are conducive to their formation? On the same beach, the line of demarcation between musical and nonmusical sands is generally sharp but indistinguishable to the eye and even to the microscope. Musical sands represent a curious, relatively unexplored byway of geology.

ON AN ACOUSTIC PHENOMENON AT JEBEL NAGUS.....

Palmer, H. S.; *Report of the British Association, 1871,* pp. 188–189.

Jebel Nagus is the name given to a high sand-slope in the western coast-range of the peninsula of Sinai, about five miles north of the port of Tor. The sand of this slope possesses the peculiar property of giving forth loud musical sounds when set in motion by design or by natural causes. According to a quaint native legend, founded on the former monastic occupation of this part of the peninsula, the sounds are said to proceed from the nagus, or "wooden gong", of a monastery buried beneath the sand. Hence the application of the name Nagus to the slope in question.

The sand-slope is about 200 feet high, and 80 yards wide at its base, narrowing towards the top; it faces west-south-west. Sandstone cliffs overhang it, and bound it on either side, and an open sandy plain stretches from the foot of the slope to the sea-shore, about three-quarters of a mile distant. The sand of the slope appears to be that from the neighbouring desert plain, derived in the first place from the waste of the sandstone rocks, and then conveyed to its position on the hill-side by the drifting action of high winds; its grains are large, and consist entirely of quartz. The rock in situ is a soft friable quartzose sandstone, of a pale brown inside, and weathered externally to a dull dark brown. The sand of the slope is so clean, and in its usual condition so extremely dry, and inclined at so steep an angle (about $29\text{-}1/2^{\circ}$) to the horizon, that it may be easily set in motion by such causes as the passage of men or animals across it, falling debris from the cliffs above, or disturbance by the wind. Sometimes also movement on a smaller scale may arise from an abnormal excess of heat and drought, or from the separation of the surface-particles, after their consolidation by rain or dew, on the return of heat and the sun's burning rays. When any considerable quantity of the sand is in movement, rolling gradually down over the surface of the slope in thin waves an inch or two deep, just as oil or any thick liquid might roll over an inclined sheet of glass, and in similar festoons or curves, then is heard the singular acoustic phenomenon from which the hill derives its name, at first a deep, swelling, vibratory moan, rising gradually to a dull roar, loud enough, when at its height, to be almost startling, and then as gradually dying away, till the sand ceases to roll. The sound is difficult to describe exactly; it is not metallic, not like that of a bell, nor yet that of a nagus. Perhaps the very hoarsest note of an AEolian harp, or the sound produced by drawing the finger round the wet rim of a deep-toned finger-glass, most clearly resembles it, though there is less music in the sound of the rolling sand: it may also be likened to the noise produced by air rushing into the mouth of an empty metal flask; sometimes it almost approaches to the roar of very distant thunder, and sometimes it resembles the deeper notes of a violoncello, or the hum of a humming-top. The author found by experiment that hot surface-sand was more sonorous than the cooler layers beneath; it also seemed to run more quickly; the first experiments on any one part of the slope produced louder effects than subsequent ones. Surface-sand, at a temperature of 103° Fahr., exposed to the sun's full glare, produced the grandest effect observed, while sand in shade, at 62°, was almost mute. By day the heat on the slide is generally very great. Movement of the sand when moist is not accompanied by unusual sounds. Excavation was impossible, on account of the continuous flow of the sand when disturbed; in some places nothing solid could be reached by probing; in others, rock was felt a few inches below the surface, but whether in situ or not could not be ascertained. When sand is rolling down and producing sound, there is a distinct vibration on the slide, increasing with the intensity of the sounds. Throughout Capt. Palmer's stay, the wind blew from N.W.; the effects produced on the slide by winds from other quarters have yet to be observed. Experiments on two other sand-slides, a little to the south of Jebel Nagus, and resembling it in many particulars, did not result in producing any similar sounds. But phenomena of a kindred character had been noticed in other parts of the world, as, for instance, at Reg-Ravan forty miles north of Cabul, and on the sandy plains of Arequipa in Peru.

Jebel Nagus had been several times visited and described, but the author had had better means and opportunities for investigation than those of previous travellers, and he submitted this paper in the hope of once more inviting attention to a curious and interesting subject. There could be no doubt that the sound arises from the movement of the surface-sand, and is intimately connected with the siliceous character of the sand and its extreme dryness, but the author was not aware that any exact explanation of the phenomenon had as yet been elicited from scientific men.

SONOROUS SAND IN NEVADA

Anonymous; *Knowledge*, 3:63-64, 1883.

The Reno, Nevada, Gazette describes a remarkable hill of moving sand in the eastern part of Churchill County, Nevada, about sixty miles from Land Springs Station. It is about four miles long and about a mile wide. In the whole dune, which is from 100 to 400 feet in height, and contains millions of tons of sand, it is impossible to find a particle larger than a pine head. It is so fine that if an ordinary barley sack be filled and placed in a moving waggon, the jolting of the vehicle would empty the sack, and yet it has no form of dust in it, and is as clean as any sea-beach sand. The mountain is so solid as to give it a musical sound when trod upon, and oftentimes a bird lighting on it, or a large lizard running across the bottom, will start a large quantity of the sand to sliding, which makes a noise resembling the vibration of telegraph wires with a hard wind blowing, but so much louder that it is often heard at a distance of six or seven miles, and it is deafening to a person standing within a short distance of the sliding sand. A peculiar feature of the dune is that it is not stationary, but rolls slowly eastward, the wind gathering it up on the west end, and carrying it along the ridge until it is again deposited at the eastern end. Mr. Monroe, the well-known surveyor, having heard of the rambling habits of this mammoth sand-heap, quite a number of years ago took a careful bearing of it while sectioning Government lands in that vicinity. Several years later he visited the place, and found that the dune had moved something over a mile.

Sand Mountain, Nevada, noted for its booming sand. (J. F. Lindsay)

THE "BARKING SANDS" OF THE HAWAIIAN ISLANDS

Bolton, H. Carrington; *Science,* 16:163-164, 1890.

About a year ago Nature printed my letter from Cairo, giving a condensed account of an examination of the Mountain of the Bell (Jebel Nagous) on the Gulf of Suez, and of the acoustic phenomenon from which it is named. In continuation of my researches on sonorous sand, which are conducted jointly with Dr. Alexis A. Julien of New York, I have now visited the so called "barking sands" on the island of Kauai. These are mentioned in the works of several travellers (Bates, Frink, Bird, Nordhoff, and others), and have a world-wide fame as a natural curiosity; but the printed accounts are rather meagre in details, and show their authors to have been unacquainted with similar phenomena elsewhere.

On the south coast of Kauai, in the district of Mana, sand-dunes attaining a height of over one hundred feet extend for a mile or more nearly parallel to the sea, and cover hundreds of acres with the water worn and wind-blown fragments of shells and coral. The dunes are terminated on the west by bold cliffs (Pali) whose base is washed by the sea; at the east end the range terminates in a dune more symmetrical in shape than the majority, having on the land side the appearance of a broadened truncated cone. The sands on the top and on the landward slope of this dune (being about 100 yards from the sea) possess remarkable acoustic properties, likened to the bark of a dog. The dune has a maximum height of 108 feet, but the slope of sonorous sand is only 60 feet above the level field on which it is encroaching. At its steepest part, the angle being quite uniformly 31°, the sand has a notable mobility when perfectly dry; and on disturbing its equilibrium it rolls in wavelets down the incline, emitting at the same time a deep bass note of a tremulous character. My companion thought the sound resembled the hum of a buzz-saw in a planing mill. A vibration is sometimes perceived in the hands or feet of the person moving the sand. The magnitude of the sound is dependent upon the quantity of sand moved, and probably to a certain extent upon the temperature. The dryer the sand, the greater the amount possessing mobility, and the louder the sound. At the time of my visit the sand was dry to the depth of four or five inches. Its temperature three inches beneath the surface was 87°F., that of the air being 83° in the shade (4.30 p.m.).

When a large mass of sand was moved downward, I heard the sound at a distance of 105 feet from the base, a light wind blowing at right angles to the direction. On one occasion horses standing close to the base were disturbed by the rumbling sound. When the sand is clapped between the hands, a slight hoot like sound is heard; but a louder sound is produced by confining it in a bag, dividing the contents into two parts and bringing them together violently. This I had found to be the best way of testing seashore sand as to its sonorousness. The sand on the top of the dune is wind-furrowed, and generally coarser than that of the slope of 31°; but this also yielded a sound of unmistakable character when so tested. A bag full of sand will preserve its power for some time, especially if not too frequently manipulated. A creeping vine with a blue or purple blossom (kolokolo) thrives on these dunes, and interrupts the sounding slope. I found the main slope 120 feet long at its base; but the places not covered by the vine gave sounds at intervals 160 paces westward. At 94 paces further the sand was non-sonorous.

The native Hawaiians call this place Nohili, a word of no specific meaning, and attribute the sound caused by the sand to the spirits of the dead (uhane), who grumble at being disturbed; sand-dunes being commonly used for burial-places, especially in early times, as bleached skeletons and well-preserved skulls at several places abundantly show.

Sand of similar properties is reported to occur at Haula, about three miles east of Koloa, Kauai. This I did not visit, but, prompted by information communicated by the Hon. Vladimar Knudsen of Waiawa, I crossed the channel to the little-visited island of Niihau. On the western coast of this islet, at a place called Kaluakuhua, sonorous sand occurs on the land side of a dune about 100 feet high, and at several points for 600 to 800 feet along the coast. On the chief slope, 36 feet high, the sand has the same mobility, lies at the same angle, and gives when disturbed the same note as the sand of Kauai, but less strong, the slope being so much lower. This locality has been known to the residents of the island for many years, but has never before been announced in print. This range of dunes, driven before the high winds, is advancing southward, and has already covered the road formerly skirting the coast.

The observations made at these places are of especial interest, because they confirm views already advanced by Dr. Julien and myself with regard to the identity of the phenomena on sea-beaches and on hill-sides in arid regions (Jebel Nagous, Rig-i-Rawan, etc.). The sand of the Hawaiian Islands possesses the acoustic properties of both classes of places; it gives out the same note as that of Jebel Nagous when rolling down the slope, and it yields a peculiar hoot-like sound when struck together in a bag, like the sands of Eigg, of Manchester (Mass.), and other sea-beaches,---a property that the sand of Jebel Nagous does not possess. These Hawaiian sands also show how completely independent of material is the acoustic quality, for they are wholly carbonate of lime, whereas sonorous sands of all other localities known to us (now over one hundred in number) are silicious, being either pure silex or a mixture of the same with silicates, as felspar.

The theory proposed by Dr. Julien and myself to explain the sonorousness has been editorially noticed in Nature, but may properly be briefly stated in this connection. We believe the sonorousness in sands of sea-beaches and of deserts to be connected with thin pellicles or films of air, or of gases thence derived, deposited and condensed upon the surface of the sand-grains during gradual evaporation after wetting by the seas, lakes or rains. By virtue of these films the sand-grains become separated by elastic cushions of condensed gases, capable of considerable vibration, and whose thickness we have approximately determined. The extent of the vibrations, and the volume and pitch of the sounds thereby produced after any quick disturbance of the sand, we also find to be largely dependent upon the forms, structures, and surfaces of the sand-grains, and especially upon their purity, or freedom from fine silt or dust ("Proceedings American Association for the Advancement of Science," 38, 1889).

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SQUEAKING SAND VERSUS MUSICAL SAND

Bolton, H. Carrington; *Nature*, 43:30, 1890.

Allow me to use your columns to thank Mr. Henry C. Hyndman for the reference in Nature of October 2 (vol. xlii, p. 554) to a locality of sonorous sand in the interior of South Africa. Its occurrence in the interior is new to me, though it has been reported from the west coast at Liberia, and at Cape Ledo, from which latter place my friend, Mr. L. Harold Jacoby, a member of the American Eclipse Expedition, recently brought me specimens.

Dr. Alexis A. Julien and myself quite agree with Mr. Carus-Wilson in his remarks (Nature, October 9, vol. xlii, p. 568) that there is no scarcity of sonorous sand, and only observers are lacking. This we established in 1884, when we announced at once seventy-four localities on the Atlantic coast of the United States, although at the time we began our researches its occurrence at Manchester, Massachusetts, was thought to be unique in America. The localities were in part reported by the keepers of life-saving stations to whom we had sent circulars.

The old theory adopted by Mr. Carus-Wilson, that the sounds are produced by "rubbing together of millions of clean sand grains very uniform in size," is, we think, insufficient to explain musical sand, but well adapted to explain squeaking sand. Two distinct classes of sounds are produced by disturbing sand, both undoubtedly due to vibrations; the more common sound is caused by attrition of the particles, and has a well-known harsh character by no means musical; this in rare cases becomes a loud squeak. The second is caused, we believe, by oscillations of the particles themselves protected from actual contact by elastic air-cushions, and this is decidedly musical in tone. Musical sand yields notes by friction only when dry; squeaking sand yields a harsh, shrill squeak (reminding one of the cry of a guinea-fowl), best when moist. This latter variety is very rare; we have collected by correspondence and in person over 500 samples of sand from around the world, and musical sand seems to be comparatively common, but only two localities of squeaking sand are known to us, both in so-called boiling springs---one in Maine, and the other in Kansas. A very small quantity of squeaking sand pressed between the thumb and forefinger produces, when wet, a peculiar shrill squeak---a phenomenon which we think well explained by the attrition theory. The magnificent acoustic displays which I have witnessed in the desert of Sinai (*Nature*, vol. xxxix. p. 607) and on the coast of Kauai (*Nature*, vol. xlii. p. 389) are, however, manifestly due to greater freedom of oscillatory motion than is possible if the particles merely scrape against each other.

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THE SINGING SANDS OF LAKE MICHIGAN

Richardson, W. D.; *Science,* 50:493-495, 1919.

The dune region of Lake Michigan extends along its eastern shore from Gary at the southern extremity to Mackinac at the northern with comparatively few breaks or interruptions. Throughout this region the sands near the water's edge, in dry weather, emit a peculiar but definite and unmistakable sound when the foot of the pedestrian pushes through them in an abrasive way. This unusual sound from an unusual origin is a source of great delight to children and an inciter of the curiosity of their elders, who, however, rarely pursue the subject far enough to arrive at an explanation for it. The sound is produced not only by the leather-shod foot, but is emitted also if the bare foot or hand is struck through the grains or if a stick is trailed, boy-fashion, behind.

The sound has been compared or the attempt has been made to relate it to that produced by the pedestrian walking through soft snow; to the crunching noise so frequently noticed when walking through snow after very cold weather or by the wheel of a vehicle on such snow; also to the sound emitted by hard, granular snow when one walks through it; but it is like none of these and has a distinctive character all its own.

In a preliminary way several observations should be recorded as to the bearing of location and conditions of various sorts on the singing sands. The sound is produced only when the sand is dry, and apparently the dryer the sand is, the louder the sound produced. In wet weather or when the sand is moderately moist, the sound is not produced. In summer and indeed in the hottest weather the sound seems to be loudest, other conditions being the same, but it can be clearly heard at all seasons of the year, including winter, whenever the sand is dry. As one walks away from the water's edge he may be astonished to find out that the sound-producing sand ceases rather abruptly about fifty to one hundred feet from the shore line. These limits may vary at different locations but on the whole they are substantially correct. Back and away from the shore line, in blowouts and on the sides and tops of the dunes, the sound is never produced. There is no observable difference between the sand located near the shore and that located farther back or that forming the dunes, and indeed the sand which is washed up by the waves is that which, blown by the wind, goes to form the dunes.

The upper beach limit of the singing sands is practically identical with the upper wave limit, that is, the boundary reached by the waves during storms. This limit is marked roughly by the line of driftwood and the lower limit of vegetation. The singing sands are therefore all subjected to periodical contact with the water of the lake and are moistened and washed by that water.

These observations include, I think, all the obvious ones in connection with the singing sands. The most casual observer will remark with astonishment their very sharply defined upper limit. As one walks from the water's edge up the beach and crosses the upper wave limit, he notices a sudden cessation of sound as he passes the upper line of driftwood and the commencement of vegetation. Beyond this point he may proceed into a blowout of clear sand quite identical in appearance, macroscopic as well as microscopic, and of the same composition by ordinary methods of analysis and yet this sand fails entirely to produce the sound of the beach sand. His first conclusion would be that the proximity of the water and waves of the lake must have some relationship to the sound-producing grains.

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MUSICAL SAND IN CHINA

Offord, John; *Nature,* 95:65-66, 1915.

Among the immense mass of ancient Chinese records and manuscripts brought back from the buried cities and caves of ancient Khotan, in Central Asia, and now stored in the British Museum, is one called the Tun-Huang-Lu, a topographical description of part of Khotan itself. This little geography was written in the time of the Tang dynasty, in the seventh century, but probably contains matter from earlier authors.

Among the specially interesting natural phenomena of the country described in the Tun-Huang-Lu is a large sandhill, which at certain times gave forth strange noises, so much so that a temple in its vicinity was entitled the "Thunder Sound Temple."

The geographer, speaking specially of the sandhill, says:---"The hill of sounding sand stretches 80 li east and west and 40 li north and south. It reaches a height of 500 ft. The whole mass is entirely constituted of pure sand. In the height of summer the sand gives out sounds of itself, and if trodden by men or horses, the noise is heard 10 li away. At festivals people clamber up and rush down again in a body, which causes the sand to give a loud rumbling sound like thunder. Yet when you look at it next morning the hill is just as steep as before."

Mr. Lionel Giles, from whose translation of the Tun-Huang-Lu these extracts are made, mentions that this sounding sandhill is referred to in another old Chinese book, the Wu Tai Shih.

ROARING SANDS OF THE KALAHARI DESERT

Anonymous; *Nature*, 140:285, 1937.

Mr. A. D. Lewis has recently given an interesting account of these sands (S. African Geog. J., 19, 33-49; 1936). They lie at the south end of an elongated patch of whitish sand dunes near the south-east corner of the Kalahari desert, and the roars are heard most intensely along the southern face, which rises nearly 100 ft. at a slope of about 1 in 2. Compared with the rest of the desert sands, the grains are perhaps more rounded and of a more uniform size and shape. Mr. Lewis describes two types of noise, a roar caused by pushing the sands forward in a heaped-up manner and a hum by keeping the sand moving slowly down the slope. A very loud roar is produced by sitting on the slope and sliding down it in slow jerks. In the still of the early evening or morning, such a noise is easily heard, like the rumbling of distant thunder, at a distance of 600 yd. Merely moving the fingers up and down the sand produces a roar, the upward motion giving a higher note than the downward. Samples of the sand were taken in bags to Pretoria, and it was found that a roar was obtained by tilting the bag over sharply when half empty. If the bags were left open, the roar was lost after a few weeks, though it could be restored for a short time by heating the sand in an oven.

SOUND-PRODUCING DUNE AND BEACH SANDS

Lindsay, John F., et al; *Geological Society of America, Bulletin,* 87:463-473, 1976.

Abstract. Field and laboratory investigations have confirmed differences between the acoustic and seismic emissions of "singing" and "booming" sands and revealed that booming grains possess extremely smooth surfaces. Singing sand is the most common of the two types of sound-producing sands. It occurs widely as a beach sand and consists of well-rounded highly spherical grains that have a well-sorted highly symmetric grain-size distribution. Sound is produced when the sand is mechanically sheared, possibly causing the closely packed grain array to dilate in a coherent manner. Frequency ($>$500 Hz) is controlled by grain size, and amplitude may

in part relate to grain morphology. Booming sand is a relatively rare phenomenon that occurs in some desert regions. This sand produces a low-frequency ($f \sim 80$ Hz) sound during avalanching. The process efficiently (~ 0.1 to 1 percent) produces very narrow band seismic energy in the 50- to 80-Hz range. Simultaneously produced audio signals are broader band but are composed of signals that peak at the same fundamental frequencies as the seismic emissions. In addition, the acoustic emissions display first and second harmonics. Acoustic production is 400 times less efficient than seismic energy production. Booming occurs in quartz and carbonate sand grains that are well sorted, fine skewed, and mesokurtic. The individual quartz sand grains are only moderately well rounded. When compared to normal eolian grains, however, they have highly polished surfaces that are smooth on the 1-μm scale. The exceptional smoothness of the grains may facilitate booming. The effective Q (magnification factor) and compressibility (k) of the grain system may be the key physical quantities involved in booming. Thus, whereas booming is rare in the terrestrial environment, it may be common in the high-Q soils of the Moon and the near waterless dune environment of Mars.

Introduction. Two types of sands emit loud and distinct---often music-like---sounds when they are sheared. Most common is a particular type of beach sand that emits a short note in the 500- to 2,500-Hz range of a few tenths of a second or less duration when sharply poked or stepped on. Colloquially, these are called singing, squeaking, barking, or whistling sands.

Sound production by desert dune sand is less common and has been likened to that produced by a kettle drum, zither, nakus, bass violin, or low-flying propeller aircraft. All describe a loud, relatively low-frequency sound being produced by loosely flowing or avalanching sand. Lewis estimated the frequency of the sound between 132 and 300 Hz, whereas Humphries placed the frequency at between 50 and 100 Hz. Also common to many descriptions of the sound produced by the desert dune sand is that a much lower beat frequency is discernible once prolonged avalanching is established, hence the term "booming sand." Humphries described the low frequency as beating at about 1 Hz. Dryness is essential for sound production. Warm or hot sand generally seems to boom best but heat is not essential. Avalanches can be many metres on a side (and as much as a few centimetres deep) in the natural case or only a few cubic centimetres when the sound is evoked by pulling one's fingers through the sand. Avalanche velocities range from 20 to 30 cm sec in both silent and booming events. The sound-producing sands are commonly termed "desert thunder," "booming dunes," and "roaring sands." There have been no reports in which one type of sand (squeaking or booming) could be manipulated to evoke both the high- and low-frequency emissions.

The properties of these two types of sands are not well known despite the widespread although rare occurrence. In this paper the morphological properties of sound-producing sands are studied in an attempt to understand their unique characteristics. Criswell and others described in detail the first quantitative measurements of seismic and acoustic emissions of a booming dune. Application of the booming phenomenon to lunar seismic data and thermal quakes on the Moon was discussed by Criswell and Lindsay.

Booming Sand. Booming dunes have been mentioned in mideast literature for at least 1,500 yr and in Chinese literature from as early as the ninth century. Booming sand has since been reported from the Middle East, the Sahara Desert, southern Africa, Chile, Baja California, California, Hawaii, and Nevada.

Instrumental measurements of the acoustic and seismic output of booming sand have never been reported. This is clearly of importance not only to obtain quantitative information on the relative spectral output of the dunes but on the efficiency of conversion of the slumping energy of the grains into seismic and audio output.

Of several known booming dunes in the U.S., two were visited and sampled, and acoustic and seismic signals were recorded at one locality.

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Squeaking Beach Sand. Squeaking sand as a phenomenon is far more common than booming sand and much more widespread in occurrence. Squeaking beach sand occurs on the seacoast of almost every continent, along some lake shores, and on the banks of a few rivers.

A series of squeaking and silent sand samples were collected from Australian beaches between Melbourne and Sydney. Two additional silent sand samples were included, one from the Bolivar Peninsula on the Texas Gulf Coast and one from Mana on the Hawaiian island of Kauai.

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Discussion. The frequency of sound produced by squeaking sand is higher by a factor of 10 to 50 than that produced by booming sand. Our observations in general agree with the earlier conclusions of Brown and others, Takahara, Ridgway and Scotton, and Hashimoto. Sound production in squeaking beach sand is dependent upon the sand being well sorted, well rounded, and highly spherical. Hashimoto also pointed out that the surface of the sand grains should be smooth and clean. Our observations using the scanning electron microscope confirm this observation; however, it should be pointed out that the surfaces of squeaking sand grains bear impact pits and are not polished like the booming sand grains. Hashimoto also found that the shear resistance of squeaking sand is somewhat greater than that of silent sand. The conclusions suggest that Bagnold may be correct in relating the frequency of sound produced by the squeaking sand to the mean grain size of the sands. Other variables seem to be at work, however, when the intensity of sound is considered. For example, the Squeaky Beach sand produces sound much more efficiently than other sand, and yet it lies in the middle of the squeaking sand range in terms of grain size. Possibly sand grains with smoother surface textures dissipate less energy in frictional drag and are more likely to behave coherently during shearing than sand grains with rough surface textures.

There appears to be marked differences between booming sand and squeaking sand that, contrary to Bagnold's work, suggest that two independent mechanisms are at work. All the observed consistencies in the squeaking sand suggest a simple mechanical explanation for sound production based on dynamic shearing of uniform close-packed smooth spheres. Sound production of booming sand appears to be related to the mechanical coupling between grains. The sound-producing mechanism of squeaking sand is effective under wet or dry conditions (although much more effective when the sand is dry), whereas booming sand requires very dry conditions. Grains of booming sand are not exceptionally well rounded, but they are highly polished. Nor does there appear to be a requirement that booming sand be exceptionally well sorted, in fact, to the contrary. Finally, there are no reports of booming sand that squeaks or vice versa.

Conclusions. Booming Sand. 1. Booming sand produces seismic signals composed of one or more narrow frequency peaks that are limited (Sand Mountain) to the 50- to 80-Hz range and appreciable broad-band output below 20 Hz. Acoustic emissions overlay the seismic peaks (but broadened) in the 50- to 80-Hz range, and they also display first-order harmonics between 100 and 180 Hz.

2. Quartz sand grains from booming dunes have polished surfaces on the micron scale. The grains are only moderately well rounded but have high sphericities.

3. The average booming sand at Sand Mountain, Nevada, has a mean grain size of $1.696 \pm 0.181\ \phi$ (309 μm), is well sorted, fine skewed, and mesokurtic. The booming calcite sand of Hawaii is similar but coarser in mean grain size.

4. Booming sand dunes are most likely to occur at the downwind end of a desert dune field. Alternatively, booming sand may occur on back-beach dunes in dry climates where the sand has long residence time on the beach and where longshore currents are weak.

5. The terrestrial booming process is greatly facilitated by the surface properties of the sand grains that control the mechanical coupling (Q and k) between grains. Selection, accumulation, and reworking of grains must combine synergistically to produce extremely polished grains in order to result in a terrestrial booming dune.

6. Booming is a relatively rare phenomenon in the terrestrial environment but may be a common occurrence in the waterless or near waterless environments of the Moon and Mars, if Q and k rather than purely particle morphology are the dominant factors.

Squeaking Sand. 1. Squeaking sand produces sounds in the range from 500 to 2,500 Hz.

2. Squeaking beach sand consists largely of quartz grains that are very well rounded and highly spherical.

3. The particle observations support previous suggestions that the ideal squeaking sand should consist of smooth uniform spheres in a close-packed configuration.

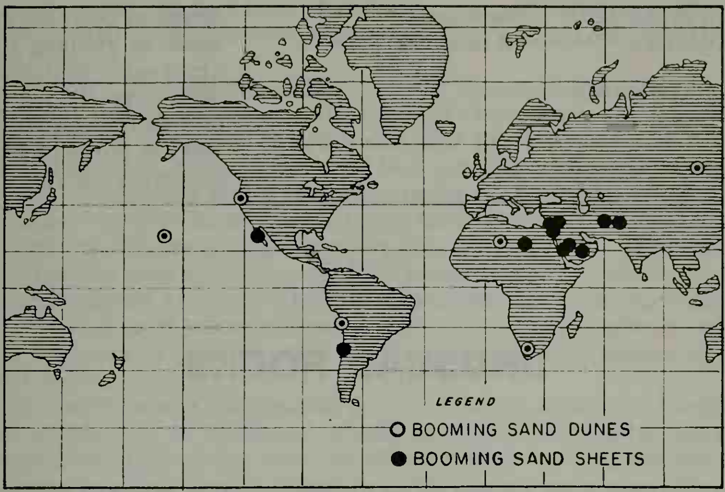
4. An average squeaking beach sand has a mean grain size of $1.571 \pm 0.222\ \phi$ (336 μm). It is very well sorted, symmetrical, and very leptokurtic.

5. Bagnold suggested that the sound produced by squeaking sand resulted from mechanical shearing of the sand that caused the grains to dilate in a coherent manner. If so, the mean gram size of the sand would determine the frequency of the sound, whereas amplitude could be controlled by the surface texture of the grains.

Table 1. Location of Booming Sand Dunes

Name and location (lat, long)	Type and size (height x width x length)	Comments and References
Hill of Sounding Sand Tunyang, China 40°03'N, 95°00'E	Dune field 100 m x 20 km x 40 km	Like rumble of distant carts, drums, or thunder; audible 5.4 to 10 km; near small lake at "Caves of Thousand Buddhas"; possibly at toe of dune field
Reg-i-Ruwan 64 km north of Kabul, Afganistan (approx. 35°N, 69°E)	Sand drift 130 m x 130 m	On detached foothill of Paghman Range; sand supply not obvious; booms spontaneously about 12 times a year; loud hollow drum sound
Rig-i Riwan Between Herat, Afganistan, and Sijistan due north of district of Kalah-i-Kah	Sand drift 200 m x 800 m	On detached ridge of Calakoh Range; on southern face; no sand on adjacent hills, surrounding terrain not sandy; audible at 16 km; like vibration of telegraph wires
Jebel Nakus 11 km north of Tor, Sinai (28°18'N, 33° 33'E)	Sand drift	Faces Gulf of Suez 3 km to the east; in situ humming sound; from a distance, like distant cannon or deep bass of pipe organ; ground vibration and sand detachment during flow
Bedawin Ramadan Wadi Werkan, Sinai, north of Jebel Nakus	Sand drift 13 m x ? x ?	Audible at 30 m; bass note
Oh Shomar Mountain of the Sinai group	Sand drift	Bass note
Rowsa Deffafiat Subbia Itzum	No details	Several nameless dunes identified by nearest oasis, Nefuz desert near El-Hyza, Arabia
Wadi Hamade	No details	Northern Arabia, north of Medina
Nameless Sand of Yadila	Probably barchan 30 m x ? x ?	In Uruq Adh Dhahiya region of the "empty quarter" of Arabia; like foghorn, 2-min duration

Name and location (lat, long)	Type and size (height x width x length)	Comments and References
Nameless Arabia (approx. 22°N, 51°E)	No details	Near dead city of Jahura
Jebel-et-Tabul Arabia	No details	Between Medina and Mecca
Nameless Abraq-al-Manazil, Arabia	No details	Near Taif in sand belt of Arq-al-Subai; many booming dunes
Nameless Khanug, Arabia	No details	150 km ESE of Medina
Nameless Gilf Kebib Desert (23°N, 26°E)	Sand sheets Seifs Barchans	On or close to Nubian sandstone plateau; sand coated with iron oxide; many booming sands in area
Es-Sadat Beirut, Lebanon	Sand drift	In cave on hillside in western Beirut facing "Pigeon Rock"; sound resembles beating of tambourines
Nameless Dakhla Oasis (approx. 25°40'N, 28° 50' E)	Barchan dunes 20 m x ? x ?	Libyan desert west of Nile Valley; after- reverberations of Big Ben or humming of telegraph wires
Nameless near well Bir-el-Abbas (25°N, 6-1/2°W)	Barchan dune	Western Sahara between Timbuctoo and Morocco, Igidi Region; one of a chain of barchan dunes; sounds like a trumpet
Nameless 11 km northwest Korizo Pass (22°30'N, 15°25'E)	Sand drift 30 m x ? x 300 m	Libyan-Chad border region; sounds like low-flying aircraft
Nameless Umm Said, Persian Gulf (approx. 25°N, 51°E)	Barchan dune 30 m x ? x ?	Very loud, synchronous effect similar to overflight of B-29 bombers
Kalahari Dunes Witsands Farm, South Africa (22°28'S, 28°34'E)	Toe of dune field 30 m x 0.5 m x several km	Only on southern toe (lee) of dune field; humming and roaring possibly higher frequency than other booming dunes
Great Sand Dunes Namib Platform (approx. 24°S, 15°E)	All types Very large dune field 160 km x 160 km in area	Booming simply noted as event common to the region



Locations of prominent musical and booming sands. (Adapted from Lindsay et al.)

Name and location (lat, long)	Type and size (height x width x length)	Comments and References
Sand Mountain 25 km east of Fallon, Nevada (39°15'N, 118°36'W)	Seif 120 m x 1.6 km x 7.2 km	Short note on bass violin and roaring (recorded)
Kelso Dunes East of Barstow, California (33°55'N, 115°45'W)	Barchan dunes 180 m x 16 km x 16 km	Roaring sounds from lee slopes
Roaring Sands Mana, Kauai, Hawaii (22°N, 159°48'W)	Backbeach dune 30 m x ? x 800 m	Carbonate sand; 100 m from sea; sounds like thunder, buzz saw, or hooting, possibly broader bandwidth than quartz dunes; similar dunes at Kaluakahua, Nuhau
Cerrito de Huara (or El Bramador) Tarapaca, Chile (20°S, 69°W)	Isolated dune	10.4 km west of Pozo (well) de Ramirez
El Punto de Diabolo Copiapo, Chile (27°22'S, 70°20'W)	Sand drifts in gullies	Moaning sounds detected at 400 m; undulations make standing difficult

Mountain of the Bell Baja California, Mexico ($23^{o}42N$, $110^{o}30'W$)	Backbeach 20 m x ? x ?	Sound of bells or sound made by rubbing finger along edge of glass bowl; dune lens-shaped (possibly barchan); approximately 100 km north of Cape San Lucus on Pacific Coast

UNUSUAL ROCKS

Few people have not picked up an unusual rock on rambles through the countryside. Erosion and other geological forces play many tricks as they knead loose surface materials. However, the unusual rocks of this section tend to be more bizarre in shape and mode of origin than those prizes brought home in coat pockets. Snow rollers and forest-fire clinkers are surely out-of-the-ordinary geological entitles, though their formation if not difficult to visualize. On the other hand, the Mississippi mudlumps and Midwest house-sized concretions are both impressive and enigmatic. Then, there are the lake balls and fairy crosses, stretched pebbles and fluted rocks. In the face of such variety, this section takes on the guise of a geological curiosity cabinet.

• Fluted and Facetted Rocks

FITTING BOULDERS: THE RESULT OF AN IMPORTANT SHORE PROCESS

Shelley, David; *Nature*, 220:1020-1021, 1968.

In the course of petrological studies on the coastal outcrops of Constant Gneiss to the south and west of Westport, New Zealand, some remarkable contact features of boulder against boulder/bedrock were observed. The adjacent boulders or boulder/bedrock have developed closely fitting mutual interfaces, and from the examples given here it can be seen that they are being eroded most rapidly by the processes acting along their interfaces. The phenomenon is therefore of considerable importance to coastal studies. Similar fitting boulders have now been observed in other environments. No reference to the phenomenon has been found in standard works on coastal processes and so I hope that this report will bring it to the notice of geologists and geographers working elsewhere in marine or lake shoreline environments.

The boulders illustrated in Figs. 1 and 2 [omitted] are found in steep gullies cut in rock platforms 1 mile south of Cape Foulwind, 5 miles west of Westport. These examples are above high tide but well within the spray zone of this exposed coast. The rock is a granitic gneiss containing large phenocrysts of feldspar that are visible in the photographs. In Fig 1, a large boulder (centre) is wedged between bedrock to the left and a large boulder, all interfaces having a perfect and intricate fit. The lower large boulder also fits onto a smaller boulder beneath it. Perfect fits between four large boulders are shown in Fig. 2 (the obvious crack near the pocket diary in the centre of the photograph is within a single boulder), and a residual sear can be seen where a boulder had formerly rested on that to the lower right.

Fitting boulders are common on the coast to the south of Charleston, 15 miles south-west of Westport, where rocky outcrops at the top of very steep vegetated cliffs of the order of 500 feet high have strewn the base with a scree in which the individual boulders range up to more than 10 feet across. Here, boulders of dioritic as well as granitic composition fit together in places to produce a mosaic. Fitting boulders are found in the intertidal zone as well as many feet above high tide where the rocks are sprayed by seawater.

....

An explanation of the fits involving mechanical movement and grinding of the rocks does not seem applicable in many of the examples. The fits are often so close and intricate that no jostling is possible; near Lake Forsyth, however, fitting boulders that have presumably moved slowly downwards gravitationally to low tide level are nestled, and the fits enlarged and loosened. At Te Oka Bay, wave action could not have moved the large boulder without completely dislodging the smaller boulders.

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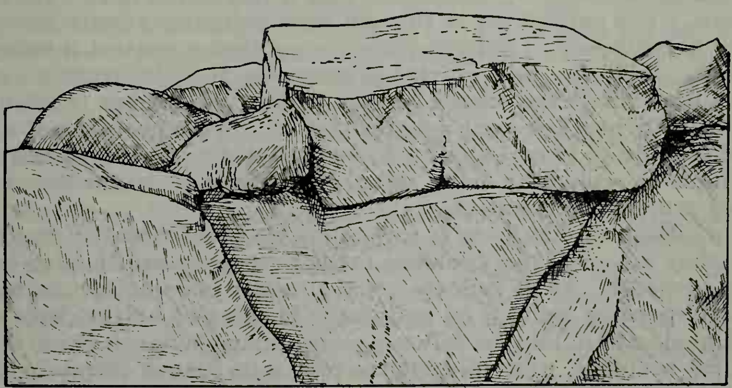


Fitting boulders near Cape Foulwind, England.

Mechanical and organic processes doubtless contribute to the process of erosion, but the dominant process is believed to be disruption by crystallization of salt around the ocean shores and of ice in the severe frost conditions of Lake Wanaka. Water falling on the exterior surfaces of the boulders will either evaporate or run off quickly whereas water penetrating the interfaces will be preferentially trapped because of surface tension and slow evaporation. The eventual crystallization of salt or ice along the interface itself will have an erosional effect, but the tendency to continual dampness will allow the rock pores to be thoroughly penetrated by water, thus making erosion by crystallization more effective. Furthermore, crystallized salt in the interfaces will tend to accumulate whereas that on the exterior surface is easily removed. Rock, pulverized by crystallization along the fitting interfaces, will be washed out during periodic heavy spray or rain, and the areas of contact slowly enlarged.

FITTING BOULDERS

Shelley, David; *Nature,* 227:1377, 1970.

Since the publication of my note on fitting boulders in New Zealand, Hills's descriptions together with correspondence I have received make it clear that the phenomenon is very widespread. Examples from the north Yorkshire coast had been noted by C. Simms, curator of natural history at the Yorkshire Museum, and the following extract from a poem he wrote in 1966 well describes them

"Notice how these sea-shored boulders pack,
not all-sprawled as spate rivers leave them,
but crazy-builded, seamed by crablined crack.
With age they wear closer to one another."

Hills disagrees with my suggestion that salt or ice crystallization is a principal agent involved, and he ascribes fitting boulders to wave action. In my note, I was careful not to rule out wave action as a contributory process: nevertheless, I believe the evidence argues against it being the prime force involved. Hills pointed to examples of fitting boulders at mean sea level where they never dry out, but he is mistaken in believing this necessarily precludes salt crystallization. In the presence of a hot dry wind the rate of evaporation could be such that continual wetting merely leads to replenishment of salt solution, salt crystallization being increased rather than retarded.

Hills's statement that there is a relationship between wave force and the maximum size of fitting boulders needs proper exemplification before it can be accepted. As he indicates, the situation is complex, the maximum size depending not only on wave force but also on height above sea-level. I would add to this the following complexing factors: the size of the original boulders, since clearly the maximum size of fitting boulders cannot be greater than that of the source material; whether or not the piles of boulders are on firm bedrock or shifting fine material; the fabric of the boulders; the resistance of the various lithologies to weathering processes in general. The maximum size of fitting boulders at all the localities at which I have observed them has simply been the maximum size of the boulders present at those localities.

The ideal location to test the relative importance of salt ice crystallization and wave action in the production of fitting boulders would be a freshwater lake where ice crystallization is unknown or rare and salinity always low.

NOTICE OF A CURIOUS FLUTED ROCK AT SANDUSKY BAY, OHIO

Granger, Ebenzer; *American Journal of Science,* 1:6:179-180, 1823.

In an excursion which I made last summer, I observed some most curious appearances on the rock at a place called Portland, or Sandusky city, on the Sandusky Bay.

The shore of the Bay at the town rises about eight feet above the water, and ranges nearly east something more than a mile, and then turns abruptly to the south. The rock appears to be what is vulgarly called bastard limestone. I do not know what it would be termed by Geologists, but its base is silex in fine grains strongly cemented with lime. It contains a great variety of shells, and is unquestionably a marine deposit.

In digging the cellars on the front street of the town, they come down, through four or five feet of earth, to this rock. Its position is nearly horizontal, with sometimes a trifling dip to the east, sometimes to the west, but more generally to the east. Its surface is fluted, with lines or grooves, in a direction nearly east and west, and though differing in width and depth, perfectly straight and parallel with each other. It appears to have been once polished as if by friction; and this polish it still retains in a considerable degree. I was told this rock had been examined by a scientific gentleman from England, who ascertained the direction of the lines to be, north 71 degrees east; agreeing exactly in this particular with a similar appearance, which, as he said, had been discovered in one place only on the old continent.

I examined the bottoms of a number of cellars, and found them similar. I also observed the same appearance in the rock on the shore; and in more than one place, I observed this fluted rock overlaid by another stratum of similar consistence. From the shore to the farthest cellar inland, in which I observed these impressions, must be more than one hundred feet, and I entertain no doubt that the impression, at some short distance farther, is overlaid entirely by another stratum: what its width is, therefore, it is impossible to ascertain.

At the shore of the Bay, where as before observed, it turns abruptly to the south, the fluted rock again makes its appearance, running in the same direction. Here the rock dips gently to the east, and disappears with the impressions under the water of the Bay. From the most westerly point where I observed the impressions, to this place, must be more than one mile, there can be no doubt that it is continued all that distance; how much farther west or east it may extend is unknown.

It has to me the appearance of having been formed by the powerful and continued attrition of some hard body. It resembled in some slight degree, the sides of a saw gate, (if you understand the expression) which has been for a long time rubbing against the posts, which confine and direct it. It was said to have been observed, by the gentleman before alluded to, that the cause of this phenomenon had been the subject of various conjectures in Europe; but that the better opinion seemed to be, that it had been effected by the operation of running water. Such an opinion, however, I think, could never have been formed, by one who had himself examined this appearance; for to me, it does not seem possible that water under any circumstances, could have affected it. The flutings in width, depth, and direction, are as regular as if they had been cut out by a grooving plane. This, running water could not effect, nor could its operation have produced that glassy smoothness, which, in many parts, it still retains.

THE FLUTING AND PITTING OF GRANITES IN THE TROPICS

Branner, J. C.; *American Philosophical Society, Proceedings*, 52:163-174, 1913.

Fluting is a peculiar minor form of topographic relief, but where it occurs over an area large enough to attract attention, it is a very striking feature.

All geologists are familiar with the fluting of limestones, which is a common phenomenon all the world over. Many fine examples of the fluting of limestones are given in Dr. H. Stille's "Geologische Charakterbilder," 10 Heft, published at Berlin in 1912, in which they are called "Karren."

But the fluting of granites or of other crystalline rocks is, so far as I have been able to learn, confined to tropical, and possibly subtropical countries. Two cases that occur on the coast of the state of Pernambuco in Brazil were mentioned by me in a paper on rock decomposition published in 1896. Since that paper was published I have seen in Brazil some very striking examples, and have seen photographs of several others. Good examples are also cited by Max Bauer, who speaks of them as furrows (Rillen).

The cases mentioned by Bauer occur in granites at Point Larue on the Island of Mahe, one of the Seychelle Islands in the Indian Ocean, about latitude 4° 30' south, and longitude 55° east.

The most impressive examples of the fluting of crystalline rocks that I have ever seen were found in 1911 near the village of Quixada in the interior of the state of Ceara, Brazil, latitude 5° 5' south and longitude 19° 20' west at an elevation of 180 meters above tide. In the vicinity of Quixada almost every elevated exposure of the granites shows more or less fluting. Only those of which the best photographs were obtained are shown in the accompanying plates. The hills shown in these pictures are from 100 to 225 meters high, that is above their bases. Efforts to get photographs of the fluting about Quixada have been only partially successful, as may be seen from the illustrations given with the present paper. Horace E. Williams of the Servico Geologico do Brazil has sent me a photograph of fluted granites in the Serra de Borborema, 25 kilometers south of Campina Grande in the state of Parahyba.

Other cases that have come to my attention occur in the interior of Ceara, and about the famous Itatiaya, the loftiest peak in Brazil, situated in the extreme northwest corner of the state of Rio de Janeiro. Itatiaya has an elevation of 2,994 meters above tide. The fluting of that peak was mentioned to me many years ago by Mr. Derby, the present director of the geological survey of Brazil, but I did not then fully realize the extent and amount of it.

Recently I received from Dr. Carlos Moreira, of the National Museum at Rio de Janeiro, some photographs made by him of the Itatiaya peaks together with specimens of the rocks themselves. Dr. Moreira spent some forty-five days on and about that peak, and though his photographs are small, they are clear, and they are the best we have thus far seen of the fluting in that particular region.

Characteristics of the Fluting of Granites. In the fluting of limestones there is generally left at the crest of the miniature watersheds characteristic sharp, but somewhat ragged, combs of the rock. Between these divides are narrow, round-bottomed furrows or grooves that run down the slopes of the rocks by the shortest routes. These shallow grooves suggest the marks made by the fingers when drawn across a mass of plastic clay or putty. The furrows or grooves in limestone, however, are, as a rule, only an inch or so in diameter; that is the fluting of limestones is not usually on a large scale.

The illustrations given in Dr. Stille's "Geologische Charakterbilder," Heft 10, however, show flutings in limestones of various kinds, and some of these have unusually large furrows.

The fluting of granites and other coarsely crystalline rocks, however, is on a large scale, and the grooves have only a remote resemblance to those on limestone surfaces. The fluted surfaces necessarily appear only where the rock is entirely bare of soil. For the most part the furrows start at the summit of the exposed rock or as near it as possible, and run straight down the rock slopes by the shortest possible routes. Those seen at and about Quixada reach a maximum depth of nearly two meters measured at right angles to the general surface of the rock masses. This takes no account of the ordinary gullies cut by the larger streams. Instead of having sharp combs separating the drainage areas of the different furrows, the divides or miniature watersheds on the granite surfaces are always rounded. But while the surfaces of the granite rocks are rounded in general outline, they are quite rough, this roughness being caused by the coarse crystals standing out boldly over the entire exposed rock surface. About Quixada the rocks contain but little quartz, and feldspars are the minerals that produce this roughness of surface.

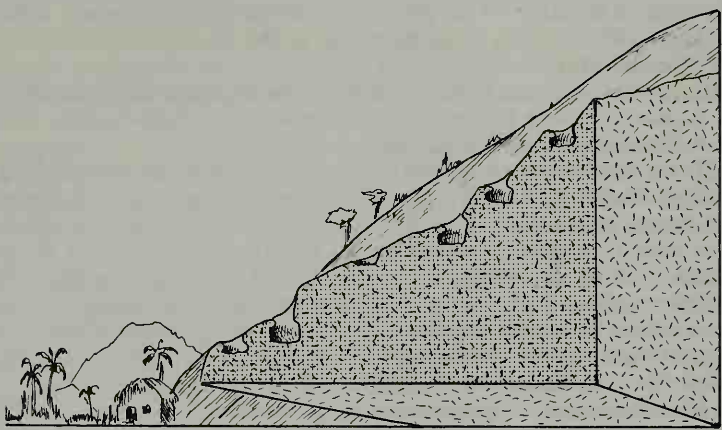
Caldron-like Pits. In the Quixada region the fluted rocks are covered here and there with great rounded caldron-like pits some of which are associated directly or indirectly with the fluting. These pits are shown in some of the accompanying illustrations. They are not usually very deep, that is, they seldom exceed a depth of two meters when isolated, and they reach a diameter of two meters or more, though they are generally not so wide. The fluting sometimes has the appearance of originating in these caldrons, but this seems to be due to the water overflowing and cutting notches in the rims on one side and thus merging the pits and the fluting into each other. In some cases I have seen a series of these pits in a nearly vertical row and connected by a furrow that gives the whole the appearance of a great irregular staircase mounting the hill.

These caldrons are very abundant in some of the rocks, while in others they do not appear at all. They occur on the tops of mountains, hills, or bosses, on the sides and at the bases; they are mostly vertical or nearly so, but some of them are also nearly horizontal. At Quixada they are more abundant on the gentler slopes and especially about the bases of the hills.

....

A good deal has been made of pits or pot-holes in the granites in other parts of Brazil. In Hartt's "Geology and Physical Geography of Brazil," at pages 314-315, is an account of holes observed in granites in the interior of the state of Bahia. Following are the notes of J. A. Allen on the region southeast of the Serra de Jacobina.

"At frequent intervals there were singular holes in the rocks, usually nearly filled with water, to which the inhabitants give the name 'caldeiroes.' These 'caldeiroes' are of frequent occurrence, but I was unable to learn whether all were of a similar character. Nearly all of the considerable number examined proved to be genuine pot-holes, and some of



Composite section through pitted and fluted rock surfaces near Quixada, showing the general forms of the caldrons.

them were of great size. The largest one I measured was elliptical in outline, eighteen feet long, nine or ten in width, and twenty-seven deep, with smoothly worn sides. Beneath the water that partially filled it there must have been many feet of materials that for ages have been falling into it, so that its whole depth must be much greater than my measurements indicate."

Professor Hartt adds the following as a footnote:

"Mr. Allen tells me that these pot-holes often occur out on the plain, far away from any high land, and that they are sometimes found excavated in the summits of slight bulgings in the plain, or even on the top of a hill, as in the case of the Morro do Caldeirao. These holes must have been excavated by falling water. There is only one suggestion that I can make as to their origin, and that is that they were formed by glacial waterfalls, in the same way as the pot-holes found over the glaciated regions of North

America, as, for instance, in New Brunswick and Nova Scotia, where I have had an opportunity of examining them. It is well known that glacial waterfalls, notwithstanding the constant movement of the ice, are very often stationary, and in the Alps they hollow out enormous pot-holes in the rocks. The lake plain is noted for the small amount of decomposition which has taken place over it, owing, I believe, largely to the fact that it has never been covered by the virgin forest, having always been dry."

The explanation here suggested will be referred to later.

. . . .

Conclusions. The fluting and pitting of coarse grained crystalline rocks appears to be confined to tropical countries, and to massive, homogeneous rocks openly exposed.

The grooves that make up the fluted surfaces run down the rock faces by the shortest possible courses, and are made by the small amount of water that falls upon and flows down the fluted surfaces themselves. In other words there are no strong streams flowing across fluted surfaces whose waters are ~~no strong streams flowing across fluted surfaces whose waters are~~ gathered over a wide area.

Fluting seems to be confined to steep slopes. The angle of such slopes cannot be stated, but in the cases observed it usually was forty-five degrees or more.

The process of fluting is partly chemical and partly mechanical and physical. As a whole the process is necessarily a slow one. The localiaation of the run-off leads to an approximately even spacing of the small streams and consequently to the even spacing of the fluting where it appears over a broad surface. Somewhat similar erosion forms are to be seen occasionally in homogeneous sandy clays, though owing to the character of the materials the latter are cut rapidly.

Though fluting seems to be confined to tropical countries, it is worth nothing that the temperature on the Serra do Itatiaya in Brazil, where fluting is very marked, often falls below freezing. Evidently some freezing does not interfere with fluting.

Caldron-like pits are associated with fluting, and occur chiefly on slopes not so steep as the fluted ones. They are most abundant on the lower parts of the bare rock surfaces. They are formed by water dissolving and disintegrating the minerals, and by the inflowing waters mechanically stirring and floating the finer particles over the rims of the basins. The chemical action of the water in the pits is hastened by the decay of plants and other organisms that live and die in the water left standing in the pits by the rain.

Exfoliation is not a prominent feature of the fluted and pitted masses. Indeed exfoliation hardly occurs at all in such places. Disintegration goes on rapidly, but it attacks the entire surface pretty evenly. The feldspars seem to resist weathering better than the accompanying minerals, at least the feldspars are left standing out in high relief over these surfaces. In time the mere heating and cooling of the feldspars breaks them up, and they are washed off by the torrential tropical rains as angular fragments or they are blown off by the winds.

The absence of talus about the bases of these fluted and pitted hills is very striking. Indeed there are quite as many boulders on the summits and sides of the hills as there are about their bases. This seems to be due to the even attack of disintegration over all surfaces, and to the fact that there is no freezing and thawing to chip off the upper surfaces of hills and rocks and to pile up the fragments at the bases of the slopes.

• Rocks with Peculiar Pits

ORIGIN OF RING-SHAPED WEATHERING PITS AT STONE MOUNTAIN, GEORGIA

Hopson, Clifford A.; *Geological Society of America, Bulletin,* 70:1764, 1959.

Abstract. Shallow circular weathering pits, 2–6 feet in diameter, are conspicuous on gently sloping granite surfaces at Stone Mountain, Georgia. Many are ring-shaped; the rim is deeply etched, but the center stands up as a mound. The ring pits are too numerous and well developed to be merely fortuitous.

The ring pits are developed in thinly exfoliating granite, generally where weathering has breached the uppermost, partly detached shell. The next lower shell, bulged up like a blister, forms the central mound. A slight opening beneath the blister is inferred from the hollow sound resulting from a hammer blow. Where weathering has breached some blisters the opening is visible.

The principal cause of exfoliation at Stone Mountain is granite expansion accompanying release of original high confining pressure, as erosion strips away the cover. Where stresses generated by expansion exceed the rock's tensile strength the outer, more rapidly expanding layers burst loose.

During exfoliation the rock expands outward, toward the erosion surface, but remains confined laterally. Lateral expansion becomes possible, however, for the uppermost shells, which bow upward ("blister") from the underlying rock to accommodate their slight increase in surface area. The blisters, once formed, are especially vulnerable to weathering; water works beneath, attacking the thin shells from below as well as above. Breaching of the blistered uppermost shell forms only a simple circular pit. This may develop into a ring pit if the shell beneath also blisters. Water then collects around the low margins, weathering them more deeply.

ON THE ORIGIN OF A CURIOUS SPHEROIDAL STRUCTURE IN CERTAIN SEDIMENTARY ROCKS

Silliman, Benjamin, Jr., et al; *American Association for the Advancement of Science, Proceedings,* 4:10–12, 1850.

Prof. Silliman said that the subject of his communication was simple. All acquainted with the geology of New York were, he said, familiar with the specimens of _______ from the Niagara group, and especially from the vicinity of Lockport. The specimens exhibited presented a curious embossed and concave appearance. The concavities were sometimes opposite to the convexities; they were not, however, opposite to each other in all directions. Prof. S. exhibited casts taken by Mr. Manross, and showed that similar appearances are produced at the present day by natural causes. It was noticed as somewhat remarkable, that the regularity of the arrangement of these impressions was such that, by taking any one as a centre, six others may pretty generally be counted immediately around it. The appearances occur in non-fossiliferous sedimentary rocks. They have not escaped the attention of New York geologists, Mr. Hall having figured some specimens on p. 93 of his Report upon the Fourth Section of the Survey. The probable cause of the phenomena has been a matter of considerable curiosity with geologists. The causes producing like effects at the present day were stated by Professor Silliman. He had found that excavations are made by tadpoles, identical in appearance with the older deposits of the Sedimentary formation. But there are no batrachians so old as the age of the Niagara group. The cause of the phenomena was attributed, in this dilemma, to the agency of great numbers of small gregarious fishes, and other animals, also gregarious, which are known to have existed at that period.

He here presented a letter from Mr. Manross, as follows---

New Haven, August 15, 1850.

Prof. B. Silliman, Jr.

Respected Sir:---The cast marked No. 1 was taken from a slab of blue limestone, marked as found at Erie, near Lockport, N.Y. It is now in the possession of W. S. Clark, of East Hampton, Mass. The slab is about ten inches in length and breadth, and is split into two layers about 3/4 inch in thickness. All the broad surfaces present the same kind of markings---the upper is covered with depressions, the middle joint fitting, as in the east, and the lower exhibiting protuberances. Those above, however, do not necessarily correspond in vertical position with those below, showing that they were not produced by any force or pressure acting through several layers at once, as in the case of footmarks.

The cast marked No. 2 was taken in the surface of mud now in progress of deposition. The locality is Bristol, Conn. Several square yards of the bottom of the pool from which the mud was taken, were covered with those curious depressions, presenting much the appearance of the indented surface of a thimble. By observing the motions of a swarm of small tadpoles in the pool, the cause of the depressions was easily seen. Whenever the little animals moved from one part to another, they almost invariably stopped in one of these hollows; and an occasional vibration while there, with the few rapid strokes in starting, deepened the hollow at every new visit. On examining both of the casts, it will be seen that the markings occur with similar and surprising regularity. Taking any one for a centre, as in the cells of the honeycomb, six will be found adjoining it. It seems to be only another and, considering their origin, an unexpected example of the rule for economy of surface.

Not knowing whether these observations may be new or not, I submit them for your inspection.

Yours respectfully, (N. S. Monross)

Professor Agassiz remarked that he could not at first conceive how an animal with the peculiar form and appendage of the tadpole could produce such a concavity; but, after reflection, he would not say that he believed it impossible.

Prof. Adams inquired, if the raised parts were turned upward, or if they were below the plane of the surface, in the Lockport rock.

Prof. Silliman replied, that not having visited the locality, he could not so well state the exact position as his friend, Prof. Horsford, who had been there.

Prof. Horsford thought that the cavities were depressed; and, therefore, the explanation of the production of the cavities in the mud at Bristol by tadpoles, would apply here also.

Prof. H. continued, and stated that he had, in company with Prof. Agassiz, observed the production of raised hemispherical surfaces in the mud near Cambridge, by the rising of gases from decomposing organic bodies. He referred also to the depressions caused by rain-drops.

Prof. Silliman reminded the Association, that the tadpoles were certainly producing cavities in Bristol.

Prof. Henry spoke of the surfaces left by rain-drops, and remarked, that water, falling from an elevation through air, took the form, not of a sphere, but was flattened, or hollowed out underneath, and assumed a form somewhat like a parachute. Such masses of water, in their contraction, drew the dust or earth upon which they fell into heaps. Prof. Henry had verified this by experiment.

ANCIENT 'DUBIOFOSSILS' OF WYOMING

Anonymous; *Science News*, 110:346, 1976.

A diverse array of tubelike structures found in Precambrian rock on a mountain in southern Wyoming has the scientists studying them in a quandary. The series of curving indentations of various configurations look like the fossil traces of wormlike metazoan animals. There is only one problem: They are a billion years older than any previous proven metazoan fossil. And that seems way too old to be possible.

The structures, some of them sinuous tubes up to 20 centimeters long, occur in the upper Medicine Peak quartzite of southern Wyoming. The quartzite, slightly metamorphosed, displays well-preserved sedimentary structures formed when submerged near shore in a shallow lake bed. The quartzite has been indirectly dated at 2.0 billion to 2.5 billion years old. Metamorphism in the overlying and underlying schists is dated at 1.65 billion and 1.55 billion years old, respectively.

The tubelike forms resemble metazoan burrows in many ways, report Erle G. Kauffman of the U.S. National Museum in Washington and James R. Steidtmann of the University of Wyoming. Their shape and distribution preclude immediate interpretation as inorganic. But there is as yet no clear proof that their origin is biological either.

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• Singular Fulgerites

NOTICE OF CERTAIN SILICEOUS TUBES (FULGERITES) FORMED IN THE EARTH

West, Charles E.; *American Journal of Science*, 1:45:220-222, 1843.

A remarkable natural phenomenon was observed a few years since in the town of Rome, state of New York. I was particular at the time, to gather what information I could respecting it, which is now submitted to the readers of your valuable Journal.

A lambent flame was seen playing at night upon the surface of a sand bank, some seventy or eighty feet high, which forms the east bank of the ancient channel of what is called Fish Creek. This excited the curiosity of the neighborhood and led to an examination of the spot. After removing some twelve or eighteen inches of the soil, they discovered an irregular tube of very coarse glass, which had evidently been made from the sand of the bank. The sides of the tube were compressed, and very irregular. Its longest diameter was about half an inch. Its interior was highly glazed, while its exterior was rough, being covered with particles of sand. When they had exposed about fifteen feet of the tube, they found it necessary to sink a shaft of logs to prevent the caving in of the bank. They continued to dig thirty feet deeper, when it was discovered that the tube, which had maintained an almost vertical position, made a sudden inclination and passed deeper into the bank. The fear of inhumation now compelled them to relinquish all further effort in tracing its course. They, however, dug five feet more in a vertical line and came to water; making in all rising of fifty feet from the surface. The tube was single for some distance from the top, where it made two bifurcations. Some eighteen inches below the surface were found thin strata of indurated sand, which were easily broken by the shovel; they were highly inclined, and their surface was undulating. Some of them were separated from each other one or two inches, others three or four inches. These interstices were filled with sand, which by digging, had shaken out in some instances and left the strata like the leaves of an open book; they were glazed, but not so highly as was the interior of the tube.

From this narration of facts, two questions naturally suggest themselves. 1st. In what manner was this tube formed? and 2d. What was the source of the light?

Without attempting to offer satisfactory replies to these questions, I would remark in relation to the first, that sand tubes of a few feet in length have been frequently described, but none of them, so far as I know, equals in interest the one referred to. None had its great length. To account for their formation, several theories have been proposed. One, that carbonate of lime held in solution had been gradually deposited around vegetable stalks, which finally wasted away, leaving these peculiar tubes. Another, that they are the work of insects. The third and most popular theory is, that they are produced by lightning. It has been suggested that whenever the electric fluid in its passage into the earth meets with the essential ingredients of glass, it fuses them into these singular tubes, provided the current be of sufficient intensity. It appears to me that neither of these causes is adequate to produce a tube fifty feet in length, such as we have described. That the first two had any agency in the matter, we cannot admit for a moment; for the tube gives evidence of igneous action, and consists of silex instead of lime. With respect to the third, let us inquire, if from the diffusive tendency of electricity to divide itself into a thousand ramifications on coming in contact with moist bodies, it is probable that the fluid would pass for fifty feet or more in a continuous line through moist sand? It strikes us as highly improbable. Again, if lightning is the cause, why did it not produce a solid mass, instead of a tube? And yet, if we set aside these objections, the tube appears as though it were formed in this way. The smooth and highly glazed surface of the interior, admitting atmospheric electricity to be the agent, might be accounted for from the fact of its being nearer the central action of the fluid, and also from the fact that there would be no particles of unmelted sand within the tube to mar its surface, while the exterior in its liquid and afterward pasty state, coming in contact with particles of sand, would be pierced by them and made rough. It would be natural to suppose that a tube produced in this manner would collapse, presenting a flattened appearance.

With regard to the second question, it is now impossible to tell what the gas was which produced the light, because it has disappeared since the destruction of the tube. It may have been phosphuretted hydrogen, derived from the decomposition of animal bones deposited ages ago beneath that sand bank, or it may have been pure hydrogen, resulting from the changes which native protosulphuret of iron undergoes when exposed to moisture; for it is well known in the spontaneous decomposition of water by this mineral when thus exposed, that it absorbs the oxygen of the water, forming a protosulphate of iron, and eliminates heat sufficient to inflame the hydrogen; or it may have been sulphuretted hydrogen derived from the decomposition of iron pyrites, the bisulphuret of iron, which is often associated with organic remains, which would also afford phosphuretted hydrogen, thus yielding a mixture of these gases, one of which burns spontaneously at ordinary temperature.

FULGERTIES FROM WITSANDS, KALAHARI

Anonymous; *Nature,* 140:368-369, 1937.

Among the sand-dunes on the south-east border of the Kalahari desert, A. D. Lewis (S. Afr. Geog. J., 19, 50; 1936) estimates that there are not fewer than 2,000 fulgurites ('lightning tubes') over an area of eight square miles. Curiously, however, the natives say that storms are not frequent and they have never seen the dunes struck by lightning. The friable tubes of fused silica are mostly found as broken fragments lying in the hollows between the dunes, and only rarely are they seen in situ projecting a few inches above the surface of the sand. Five tubes extending vertically downwards were excavated, but without reaching the lower end. The longest recovered (as fragments) measured 8 feet and showed some branching with a variable form and diameter (0.2-0.5 inc.) along its course. Larger tubes (up to 2 in.) have collapsed with the formation of longitudinal ribs. In one case threads of fused silica extend across the cavity, suggesting that the tube again expanded while still in a plastic condition. The sand surrounding the longest tube was seen to be "darkened as if burnt". Some previous records mention that the loose sand adjacent to the fulgurite is iron stained, suggesting that iron was vaporized from the fused silica. The author accepts, though apparently somewhat reluctantly, the view that these tubes were formed by lightning. One of his alternative suggestions is that they were formed by meteorites; this being supported by the statement that lechatelierite (silica-glass) has been found in meteorites---a statement that is quite incorrect.

ANALYSIS OF A SUPPOSED CLAY FULGERTITE FROM ONTARIO

Carron, Maxwell K., and Lowman, Paul D., Jun.; *Nature,* 190:40, 1961.

The existence of 'clay fulgurites' from Kingston, Ontario, was reported recently by Hawkins. These were described as "partially fused ellipsoids" resulting from lightning striking clay sediments. The report was of considerable interest to us because it suggests that lightning may be responsible for the formation of tektites. At our request, Dr. Hawkins kindly sent us a sample of this material. The composition is as follows:

SiO_2	29.69
Al_2O_3	12.45
Fe_2O_3	30.97
FeO	1.63
CaO	0.47
MgO	1.72
H_2O	15.50
MnO	0.31
TiO_2	0.21
Na_2O	0.44
K_2O	1.84
Organic matter	4.18
	99.41

The specimen analysed was an irregular lump 3 cm. long with a yellowish-brown colour and streak, earthy lustre, and hardness of about 1 (Mohs). Portions of the specimen were covered with a shiny brown coating which was soluble in acetone and presumed to be organic. In the analysis total water was determined by the Penfield tube method and organic matter by difference between loss on ignition and total water. The chemical analysis indicates that the specimen may be mostly a hydrated iron aluminium silicate or oxide. An X-ray powder diffraction pattern showed the specimen to contain some quartz, kaolinite, and additional material as yet unidentified. Petrographic oxamitation disclosed no lechatelierite or glass. This specimen has no resemblance to any known fulgarite or tektite in composition. Therefore it appears to have a relation to the origin of tektites.

• Curious Geodes

THE GEODES OF THE KEOKUK BEDS

Van Tuyl, Francis M.; *American Journal of Science,* 4:42:34-42, 1916.

Introduction. Probably nowhere else in America do geodes attain such an exceptional development as in the Keokuk beds of the Central Mississippi Valley, and representative specimens of geodes from this region are now found in the mineral cabinets of many of the museums of the world. Apart from Professor Brush's preliminary examination and description of a few select specimens submitted to him in 1865 by A. H. Worthen, then director of the Geological Survey of Illinois, no study of these remarkable geodes has ever been made in spite of the fact that they bear a variety of metallic sulphides and promise to throw some light upon the origin of more important deposits of these minerals in sedimentary rocks showing no signs of igneous influence. The following brief report on their characteristics may therefore seem justified.

Occurrence. The typical geode area is located in Southeastern Iowa and adjacent parts of Northeastern Missouri and Western Illinois. The most famous localities for geodes in this region are Keokuk and Lowell in Iowa; Wayland and St. Francisville in Missouri; and Warsaw and Niota in Illinois.

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The geodes attain their maximum development in the Geode bed but some layers of the Keokuk limestone are geodiferous locally.

The Geode bed consists in its typical development of an impure, siliceous, dolomitic limestone at the base, usually containing large and well-developed geodes, followed by an argillaceous shale with more numerous but less perfectly developed geodes. Each subdivision is about twenty feet in thickness.

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In size the geodes range from about 0.2 cm up to 75 cm in diameter. But well-developed geodes of either extreme are rarely found. In general, the geodes of a given layer do not vary greatly in size at a given locality, but there may be considerable variation in this respect at different levels in the same exposure. Moreover, there may be marked changes in their dimensions at the same level at different localities. Often geodes of similar size are arranged roughly in bands parallel to the stratification. They usually lie with their longest diameter parallel to the bedding-planes, and at some localities they are closely associated with calcareous concretions of similar shape and size.

The abundance of the geodes in the geodiferous phase of the Keokuk formation is quite variable both laterally and vertically. At times they are so numerous in a given layer that their freedom of growth has been interfered with, and they are thus of very irregular shape. At other times, they may be so sparsely distributed through the rock that none may appear in an outcrop embracing several square yards. Again they may be absolutely wanting at some localities. The proportion of well-developed geodes in the beds varies greatly at different localities ranging from less than ten per cent at some places to more than ninety per cent at others.

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Mineralogy of the Geodes. Mineralogically, the geodes are almost invariably siliceous but a few calcareous geodes have been found. The siliceous types are characterized without exception by a thin outer shell of chalcedony and this is usually followed inwardly by crystalline quartz, but calcite may succeed the chalcedony. In some instances, however, the interior is lined with botryoidal chalcedony and no crystalline quartz nor calcite appears. At other times these minerals may all occur in a single geode, but usually only quartz and calcite or chalcedony and calcite are present. In addition the interior linings of the geodes are frequently studied with dolomite or ankerite, and one or more metallic sulphides are often represented. Moreover, some hollow siliceous geodes contain water, and in the vicinity of Niota, Illinois, many specimens are filled with black viscous bitumen. Finally others contain kaolin in the form of flocculent, white powder.

The primary minerals found in the geodes are: quartz, chalcedony, calcite, aragonite, dolomite, ankerite, magnetite, hematite, pyrite, millerite, chalcopyrite, sphalerite, kaolin, and bitumen. The alteration products represented are: limonite, smithsonite, malachite and gypsum.

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Origin of the Geodes. The origin of the geodes of the Keokuk beds has long been a disputed question, and, although there has been considerable speculation upon the subject, no one theory of their development has, as yet, been widely held.

The existence of perfectly developed geodes in strata often very impervious to underground circulation furnishes a problem which is exceedingly difficult to solve. The containing rock in the Keokuk region is often highly argillaceous and no structures which might serve as passage ways for mineralizing solutions are to be seen.

It was formerly believed that the geodes were formed by the deposition of mineral matter on the walls of cavities formed by the solution of sponges imbedded in the rocks. Thus, Dana states:

"They have been supposed to occupy the centers of sponges that were at some time hollowed out by siliceous solutions, like the hollowed corals of Florida, and then lined with crystals by deposition from the same or some other mineral solution."

This theory has had many followers and S. J. Wallace has even gone so far as to coin a generic name for the sponge whose solution is supposed to have afforded the cavities in which the geodes were developed. To this genus, called Biopalla, eight species were referred upon the basis of difference in size, shape, and surface markings of the geodes. The sponge Hypothesis, however, is not now widely held. No evidence of sponges capable of giving rise to geodes have ever been found in the Keokuk beds. Moreover, the geodes vary widely in size and shape, a fact which argues strongly against any theory which presupposes such an origin. Many specimens are nodular and irregularities of the greatest variety characterize their exterior form. It may safely be said that no two of them assume exactly the same proportions.

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• Cave Pearls and Unusual Concretions

NOTE OF THE OCCURRENCE OF (SO-CALLED) CAVE PEARLS

Brodrick, Harold; *Report of the British Association 1908,* p. 704.

Cave pearls, as they were first called in 'Cave Hunting' (Professor Boyd Dawkins), seem to be of comparatively rare occurrence. They consist of a nucleus of some foreign material, frequently a small pebble of Yoredale rock (in one case a small fragment of lead ore) coated by numerous concentric rings of calcite. All those that I have found have been formed under similar conditions; they have all been found in what might be called nests in the rock, into which drops of water have fallen at comparatively long intervals from a considerable height. Each falling drop will have the tendency slightly to turn the nucleus, and also, by deposition, to coat it with a thin film of carbonate of calcium; this deposition is continued until what is called a cave pearl is formed, ranging in diameter from 0.5 cm. up to 2 cm.

The three types with which I am acquainted come from three separate caves: (1) The Blue John (Derbyshire). This type consists of a nucleus of Yoredale Sandstone covered with layers of calcite, which become harder towards the outside, the exterior being extremely hard, smooth, and opaque; sp. gr. 2.75. (2) The Bagshawe (Derbyshire). This type consists in many cases of a nucleus of Yoredale Sandstone, or, in one case at least, of lead ore; the concentric deposit in this type is somewhat translucent, the outer surface is slightly crystalline; sp. gr. 2.71. (3) Marble Arch (Co. Fermanagh). This type has a nucleus of Yoredale Sandstone, while the covering is composed of carbonate which seems to have included in it a considerable admixture of contained mud; the colour is a dirty grey, and the deposit is comparatively soft; sp. gr. 2.40. As will be seen from the specific gravity in each case, the deposit is in the form of calcite, a condition which might be anticipated from the mode of occurrence. I have carefully examined active streams in numerous caves for similar formations, but have been unable to find them. The caves in which they have been found (to my knowledge) are Caldy Island (Boyd Dawkins), the Blue John Cave (two nests), the Bagshawe Cave (one nest), about thirty pearls; Marble Arch Cave (one nest), at least a hundred pearls.

ARE THESE LITTLE SPHERES PEARLS FROM THE PAST?

Anonymous; *New Scientist,* 71:389, 1976.

Nobody knows just what were the tiny toothlike fossils called conodonts. But whatever parts of whatever animals they represent, the complete creatures seem to have enjoyed---along with the aristocratic oyster--- the ability to secrete pearls. That, at least, is the new theory advanced by three University of Iowa geologists about the minute spheres that are sometimes found in association with conodonts.

Conodonts, composed of calcium phosphate usually with a lamellar structure, are widely distributed through the geological column. The fossils range in age from Cambrian 600 million years old, to Triassic some 200 million years old. They were first discovered in the eastern Baltic in 1856, when palaeontologists took them for primitive fish teeth. In the strata where they are found they generally occur in left- and right-handed pairs. Other associations indicate that they may once have been assembled into some bilaterally symmetrical skeletal element---possibly to form the jaws of polychaete worms or other animals.

Brian Glenister, Gilbert Klapper, and Karl Chauff have now taken a close look at around 2000 of the microscopic spheres which range in size from 0.1 to 0.7 mm in diameter. Their close association with conodonts is borne out by the fact that they are always of the same colour, and have the same mineralogy, as the fossils. Moreover, their abundance in any given layer of rock is roughly proportional to the numbers of conodonts.

The colours of these tiny "pearls" vary from transparent, through honey-coloured, to grey and black. In section they consist of as many as 50 concentric shells of radiating crystallites formed of calcium phosphate. Typically they possess one or two "dimples" which persist downwards through all the layers, implying that the spheres grew in some fixed position rather than rolling around, say, on the sea bed. Their purity implies that, during growth, they were screened from the outside environment, conceivably by organic tissue. That idea is supported by an association of the colour banding with carbon apparently generated organically.

Because the spheres do not always accompany conodonts they cannot be parts of vital structures of the parent organism. Instead, the Iowa workers argue, they must be conodont pearls begotten by secretion on some small foreign nucleus as with oysters and other bivalves: they say that "the mineralogy, structure, faunal associations, and geological occurance of the spheres described by us suggest that they are pearls secreted by the conodont-bearing animal as a response to an organic or particulate irritant."

LOG-LIKE CONCRETIONS AND FOSSIL SHORES

Todd, J. E.; *American Geologist,* 17:347-349, 1896.

During the past season it was my privilege to visit the Laramie formation of western Dakota about the head waters of the Grand and Moreau rivers. The formation is composed of alternations of sand, often passing into yellow loam resembling loess, with drab-colored clays and beds of lignite. The sands are in places hardened into massive sandstone, but are more frequently incoherent. My attention was called, in my earlier acquaintance with the formation, to peculiar elongated concretions lying in the beds of sand. These were particularly conspicuous about prominent points of the landscape. One of the first views observed is shown in plate XII, figure 1. [Plates omitted] It represents a series of these concretions extending a distance of 100 feet and lying in strict order end to end. On either side others are seen less regularly arranged with their axes approximately parallel. Closer examination revealed the fact that they are composed of fine sand cemented together with calcareous matter and showing wavy lamination or ripple marks. The separate blocks or segments are separated by square joints, except at the ends of the series, where they are rounded. One block at the locality especially attracted my attention. It was about twelve feet in length and two feet in diameter. When viewed from one side it had the exact appearance of a saw-log with the bark removed and the ends flat as if cut with a saw. The wavy lamination imitated closely the curly grain sometimes seen in wood. Further acquaintance with the region showed like phenomena very common. In cut banks more or less transverse to the axes of the concretions they were seen to project like logs from a flood deposit.

Some of the variations observed are the following: Sometimes these concretions are only a few feet in length with rounded ends, and occasionally, where their length equals their diameter, they become globular. Sometimes there is a repetition of the log-like feature in a lateral direction, and they are often cemented to each other. Plate XII, figure 2, shows an example of this sort. At other points this variation passes into a regularly formed stratum of sandstone of limited extent. Though often showing almost perfect cylindrical form, more frequently their form and surface are somewhat irregular. They commonly show more or less iron present, as is indicated by their rusty appearance. Sometimes this is sufficient to make them black. No fossils were found in them at any time. They are sometimes associated with concretions of the more common biscuit-shape. The sizes more commonly represented are from one to two and a half feet in breadth, while the sections separated by joints are from two to five feet in length, and the series lying in very direct course sometimes attained a length of 100 or 150 feet. Not only is there the tendency of repetition in a lateral direction but also in a longitudinal. While any one system rarely exceeds a breadth of two rods, the length sometimes may be measured by miles. Not infrequently by climbing to the top of a conical hill and ascertaining the direction indicated by the axes of the concretions, the system can be traced for miles on the same level. These longer series frequently show curves and sometimes angles. Sometimes in the same hill several series may be noted, one above another, which commonly show different directions for their axes.

So far as I am aware this is the first time that attention has been called to these novel formations. Opportunity did not permit me to make a systematic or exhaustive study of them, but it seems not improbable that some such explanation as the following may be established. The concretions are unlike those below in the Fort Pierre formation in form, substance and arrangement. Their most surprising feature is the elongation of the concretions and this in a uniform direction. These features can scarcely be traced to a difference in permeability of the imbedding formation in different directions. Moreover the initiative influence causing them must have been of wide extent. Nothing has seemed more rational than to suppose these systems of concretion mark ancient beaches, and that the determining influence for their consolidation lay in the segregating effects of wave action. We can easily conceive that the sand, upon the ancient shores, was thrown into small ridges parallel with the edge of the water. There would be a differential accumulation of fine material between the ridges, not only from the action of the waves but from the motion of rains and the effect of winds. Here also organic matter would be likely to accumulate and this might be sufficient to determine the centers for concretionary action: and so the log-like concretions which we have described may be traced to the influences attending the ancient shores of the Laramie lakes. It is not improbable that further study may enable us to map out the shore lines of the bodies of fresh water attending the different stages of the Laramie formation. It seems probable that fossils may be found preserved in these deposits, although none were collected during the past season.

This discovery opens up an interesting and novel field of investigation of other formations. Circumstances, however, may not have been so favorable for the formation of such concretions upon marine shores because of tidal fluctuations.

PARALLEL DRAINAGE AND "LOG CONCRETIONS"

Wegemann, Carroll H.; *Geological Society of America, Bulletin,* 43:127, 1932.

Abstract. Alignment of the minor drainage in a direction N 35° W is a characteristic feature of the badlands of northeastern Wyoming. Major streams do not show the alignment. The surface rocks, shales with some sandstone beds, are Wasatch in age and are flat lying.

The direction of N 35° W is parallel to the general trend of the Bighorn Mountains and the Black Hills, and it is evident that the streams are influenced by jointing. There is a second stream trend, less pronounced than the first, and at right angles to it.

Log-like concretions, many of them twenty or thirty feet in length and several feet in diameter, weather out of the sandstone beds. These concretions have a definite alignment parallel to the streams. They are believed to have been produced by chemical precipitation from water solutions and consequent cementation of the sand about the intersections of joint and bedding plains.

Parallel drainage of the same trend is to be observed near Glendive, Montana, and Pierre, South Dakota, indicating that the stresses which weakened the strata in certain directions in Wyoming were not confined to the basin between the Bighorns and Black Hills, but were regional in extent. This peculiar drainage, easily recognized on topographic sheets, may be used as indicating the area affected by certain stresses.

THE REMARKABLE CONCRETIONS OF OTTAWA COUNTY, KANSAS

Bell, W. T.; *American Journal of Science,* 4:11:315-316, 1901.

Situated on the side of a low hill, near Pawnee Gap, about three miles from Minneapolis, in Ottawa County, Kansas, is a group of curious rocks, that have excited the wonder of the ignorant and the speculations of many who call themselves geologists.

Locally, this deposit, consisting of more than fifty detached specimens, is known as "Rock City"; and scattered masses of the same formation may be seen at various places on the higher land in the neighborhood, especially at the locality known as The Cliff.

As will be seen from the illustrations, these rocks are for the most part nearly spherical in shape, and some of them are more than twelve

A "rock city" in Kansas formed from large spherical concretions. Some are more than 12 feet in diameter.

feet in diameter.

They have been embedded in, and most of these specimens still rest on, a coarse soft sandstone, of a light color, which wearing away, has left these harder bodies exposed. In some cases the supporting sandstone has been so nearly removed as to allow the rocks to topple over; while other pieces have become fractured, and portions have fallen or slid from the part that still retains its upright position. These fractures are not on flat planes, but are conchoidal, and nearly all horizontal; the few that approach a vertical direction being zigzaged and interrupted.

In the sandstone under some of these masses is a band or layer five or six inches in thickness, of a dark reddish color, resembling iron; and these saucer-like layers are separated from the spheres above by an interval of several inches, as shown in fig. 2, where a portion of the material that once filled this space has been removed.

These titanic marbles have been weathered to a dull gray color, and in their crevices several species of small ferns are growing; probably Pelleas and Cheilanthes.

Where freshly broken, these rocks are almost white, have a crystalline appearance, and by artificial light, when held in certain positions, reflect a silvery luster. Treated with hydrochloric acid in a test tube, fragments effervesce freely, staining the acid yellowish, and leaving only a few particles of what seems to be silica.

One writer claims that these are glacial bowlders; but it seems unnecessary to make use of any argument to refute this view. A state geologist of Kansas has announced that they are corals but adduces no proofs; possibly for the reason that there are none. If he had visited The Cliff, and noted the hemispherical cavity near its top, from which one of these round masses had been dislodged, and had then gone below, and carefully examined the mass itself, and tested a portion of it, he would have found that it was identical with the larger pieces at Rock City; and a more rigid search there would have failed to show any coralline structure, but would have shown that they are concretionary masses of crystalline limestone, most of them still in place.

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THE BIG CONCRETIONS OF OHIO

David, Arthur; *Scientific American,* 159:239, 1938.

Thousands continue to gaze with wonder upon Ohio concretions. Created some 300,000,000 years ago in the Devonian Period, these strange natural curiosities range from hickory-nut size to monstrous round or oval masses 18 feet or more in diameter. Maximum weight of some of the largest, now in partial or complete state of ruin, is estimated at about 300 tons.

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In Ohio, the largest concretions are found only in a belt of the Ohio Shale a few miles wide, from some distance south of Cincinnati, northward through central Ohio to the Lake Erie shore east of Sandusky. Concretions similar to those found in Ohio are observed in the same formation in the vicinity of Kettle Point, Ontario.

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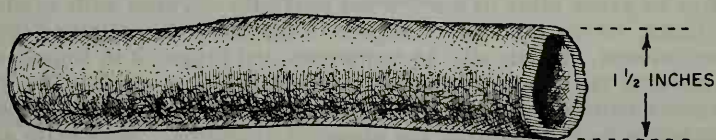
THE IRON CONCRETIONS OF THE REDBANK BEDS

Willcox, O. W.; *Journal of Geology,* 14:243-252, 1906.

In the accompanying illustrations [Fig. 1, other figures omitted], reproduced from photographs, are shown forms of iron concretions which seem to deserve notice alike for their peculiar structure, great length, uniform orientation, and effect on local topography.

These concretions are to be found in immense numbers in the Redbank sands of Monmouth County, New Jersey, a formation which is here a quite structureless bed of loose, rather fine quartzose sand about 100 feet thick, generally red in color from the decomposition of glauconite formerly disseminated through it. The concretions are most numerous near the upper part of the formation, and occur as isolated individuals imbedded in the sand, as well as more or less densely packed in groups.

The primary type of these concretions is a very long, more or less regular, hollow cylinder, which is generally straight and of unvarying diameter, but which sometimes tapers very gradually and may be of indefinite length. Single tubes have been observed which were more than 20 feet long, but it is impossible to remove unbroken such great lengths from the sand in which they are imbedded, owing to the occurrence of transverse cracks which divide them into irregular segments. Fig. 1



Hollow cylindrical concretion from New Jersey. (Fig. 1) is from a photograph of such a segment; the diameter of the tube is 1-1/2 inches. The smallest tube yet observed had a diameter of 1/4 inch; the largest tube of circular cross-section so far seen had a diameter of nearly 1 foot. The interior of the cylinder is generally filled with sand differing in no respect from the sand without; the wall of the cylinder is merely the ordinary material of the sand-bed, cemented together by iron oxide. While the cross-section of the cylinder is often circular, more frequently it is quite irregular. Still more frequently the concretion is not a closed tube at all, but a corrugated sheet.

Besides simple tubes there are the poly-chambered types represented in Figs. 2 and 3. Fig. 2 has two unequal and somewhat dissimilar chambers. Fig. 3 shows an end view of a fragment of a three-chambered specimen. In Fig. 5 are shown cross-sections of a number of selected specimens. Fig. 6 is a sketch of the projecting ends of a group of concretions as they appeared in the bank of a railroad cut. Fig. 4 is from a photograph of a bluff in the Highlands of Navesink also showing projecting ends.

In the compound concretions there is usually one primary chamber which is more or less accurately circular in cross-section, and sometimes more than one. The cross-sections of the secondary or parasitic chambers are only arcs of circles. It is in fact a notable characteristic of all these concretions, of whatever dimensions or however otherwise irregular, that they show in cross-section practically no other lines than greater or smaller arcs of circles.

As may be seen from Figs. 5 and 6, the number of secondary chambers in a single specimen may be large. Often in a compound individual the ratio of the dimensions of the primary and secondary chambers is rigidly maintained throughout its observed length, but this is not invariable. Frequently a secondary chamber will end abruptly in a cul-de-sac; just as frequently it will diminish gradually until its wall merges imperceptibly with the wall of its primary, so that a concretion which is compound at one end may dwindle down to a single primary tube at the other.

A noteworthy but puzzling feature is the fact that, without observed exception, these concretions all occupy a horizontal position, and lie with their longer axes parallel to the strike of the formation, which is E.N.E., the dip being slight. In some exposures they are seen to occur in parallel zones which are considerably inclined to the normal dip of the strata in this region. As noted above, their distribution through the sand is, in general, irregular. In some large areas they appear to be totally absent, and occur but sparsely in others. In still other areas they are found in crowded aggregations containing an enormous number of individuals, all having the characteristic orientation. Where the concretions lie thickly crowded together, this common orientation gives them an appearance suggestive of great piles of cord-wood partially covered with sand. Such aggregations, which are often elongate in the same direction as the concretions themselves, are locally so numerous and large as to impress a peculiar stamp upon the topography, as they serve to protect the loose sand beneath from erosion; the resulting uniformly oriented hills of circumdenudation have somewhat the shape of drumlins. Such hills are numerous on the outcrop of the formation in the eastern part of Monmouth County. The most interesting specimens are not usually found in these situations, as the abundance of iron has led to a thickening of walls and a running together of outlines. The best ones are to be obtained where the glauconite was sparingly disseminated, as in the large cut on the New York & Long Branch Railroad one mile west of Redbank. In this and many other localities the concretions may be dug out of the sand with no other implement than the bare hand; the interior filling may be removed by shaking, or with the aid of a straight stick.

If the removal of the interior filling be cautiously effected, best with the help of a gentle stream of water, there may sometimes be seen fragile, calcified, arborescent forms which ramify through the concretion in complete disregard of the interior partitions, and which are sometimes, but not often, preserved beyond the outer periphery. The dotted lines across two of the cross-sections in Fig. 5 indicate such arborescent forms. They are doubtless fossil stems of plants which were evidently present in the sand before the concretions were formed, and owe their preservation within the concretions to the exclusion of the underground circulation, which has no doubt in most cases removed by solution the parts not so inclosed. If this be the true interpretation, their presence is significant as showing that organic matter was formerly more abundant in the sand, yet they make it exceedingly difficult to believe that these concretions are fossilized remnants of elongate forms of animal or vegetable life, since it is inconceivable how such forms could have inclosed these calcified plants (if such they be) in the manner observed; besides, they bear no resemblance to any known form of life.

Neither is there any reasonable probability that they have resulted from the filling of cracks and subsequent hardening of the filling material. In the first place, they are found in loose sand, which is certainly not a material in which to expect cracks of any kind; in the second place, the formation of long, straight, horizontal, tubular cracks, or such systems of cracks as would be necessary to give the observed forms to the compound concretions, would be a mechanical marvel under the most favorable circumstances. They are clearly not of stalactitic origin. The Redbank formation is ideally porous; where the concretions display their most typical characteristics the formation does not now, at any rate, possess any structural feature which may have served to guide convection currents. All the evidence obtainable seems to show that the material which supported the growth of the concretions was transported to them by diffusion rather than by convection. Transportation by diffusion here refers to movement of dissolved matter in obedience only to the molecular activities of the substance in solution, while transportation of the same by convection implies a bodily movement of the solution in a determinate direction. The distinction is important in this connection, since if water currents, along with other mechanical agencies, are denied any part in the formation of these objects, they must be regarded as an expression of a molecular tendency of the cementing material.

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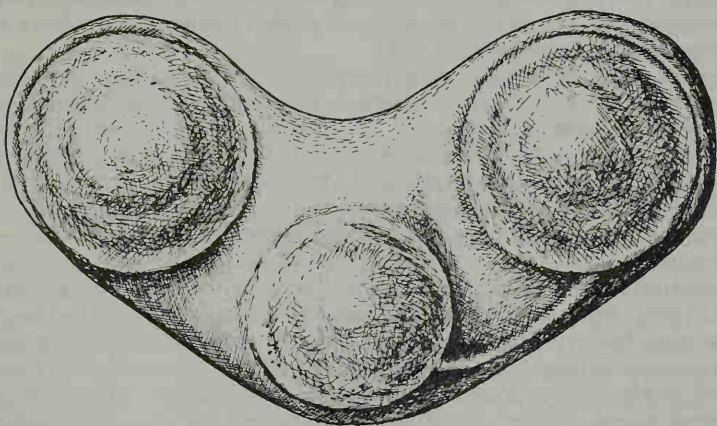
THE CONCRETIONS OF THE CONNECTICUT VALLEY

W., H. B.; *Nature*, 63:566, 1901.

The curiously-shaped concretions met with in the Champlain clays of the Connecticut Valley have for many years attracted attention. Indeed, so long ago as 1670 some specimens were sent to the Royal Society of London. A detailed description of them and of their mode of occurrence, illustrated by fourteen beautiful quarto plates, has now been issued by Mr. J. M. Arms Sheldon. Four principal types of concretions are met with; some are discs which call to mind the Kimeridge coal-money; some are cylindrical or club-like, one example (probably a compound one) being a little more than twenty-two inches long; others are botryoidal, and not a few are "queer little images" resembling "fishes, birds, ant-eaters, elephants, dogs, babies' feet," &c.

These occur in stratified river-drift clays, some of which are of a kind suitable for modelling, and some are more or less gritty. The most remarkable point is that "each clay bed has a form of concretion peculiar to itself," that is to say, the principal types are never found together. The author has seen "forty-eight specimens from one bed so similar it was impossible to tell one from another." Compound forms occur, where, for instance, two or even three discs have coalesced or been joined together (Fig. 2); and intermediate stages of such examples, and of immature concretions of horse-shoe type, are met with.



A triple concretion from the Connecticut River Valley.

These remarkable bodies occur along the planes of bedding in the clays, and the lines of stratification may sometimes be seen to run in unbroken continuity through concretion and clay. In composition they consist of argillaceous and somewhat sandy limestone with small amounts of iron-oxide, magnesia and manganese oxide. They contain from 42 to 56 per cent. of carbonate of lime, whereas the clay possesses but 2 or 3 per cent. The concretions spread out laterally in the clay, as if water holding carbonate of lime in solution made its way along the planes of stratification; and unless in the case of tiny spheroidal concretions they are almost invariably flattened. No doubt they are due to the obscure process of segregation, whereby the mineral matter, tending to collect together, has been unable to assume definite crystallographic shape, but has concentrated itself in nodular form. Some of the concretions show evidence of concentric structure, but no appreciable nucleus has, as a rule, been seen, though it might have consisted of a particle of carbonate of lime. Evidently the concretionary process went on in a quiet way, but not always uninterruptedly, as indicated by the distinct stages of growth seen in some specimens. The shape of the concretions is held to be partly determined by the structure and composition of the matrix which holds it, and by the amount of carbon dioxide and other organic acids present.

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ORIGIN OF THE CONCRETIONARY STRUCTURES OF THE MAGNESIAN LIMESTONE.....

Tarr, W. A.; *Geological Society of America, Bulletin,* 43:189, 1932.

Abstract. The Magnesian limestone (Permian) near Sunderland, on the east coast of England, exhibits a remarkable series of concretionary structures. The forms of these structures are extremely varied and intergrown, producing what are probably the most remarkable patterns in sedimentary rocks found anywhere in the world. The exposures of the rocks containing them appear to be covered by a lovely lace drapery. Other forms are spherical, and others aggregates of rods. The occurrence and origin of the remarkable structures will be discussed.

DEVONIAN CONCRETIONS OF WESTERN AND CENTRAL NEW YORK

Alexander, A. Emil; *Science*, 68:85, 1928.

In studying the stratigraphy of the Devonian, one is impressed with the common occurring concretion.

These peculiar formations, invariably built around a nucleus, may be composed of mud, limestone and even marcasite. The last is of diagenetic origin and is by far the most interesting, from the standpoint of the flora and fauna around which it has formed. As to size, Devonian concretions may range from a few feet in diameter to mere nodules. Their structure usually varies with their composition. Certain upper Devonian concretions possessing the peculiar cone-in-cone structure, for which no explanation has as yet been offered, to the characteristic radial form of marcasite. Again, the larger concretions may be grooved, these cracks being filled with extraneous material, thus giving the appearance of a turtle's shell. Other nodules, as those from the Genundewa limestone, are of even texture, composed entirely of Styliolina fissurella, surrounding the nucleus.

To the paleontologist, the flora and fauna that form the basis of most concretions, especially marcasite, offer a fascinating study. In the marcasite nodules, the iron pyrite has replaced the organic, as the case may be, by its silver-white metal. When broken open, the metal quickly tarnishes upon exposure to air, and in a short space of a few weeks will disintegrate. The nuclei can be preserved by immersion in kerosene or by covering with balsam.

The following invertebrate forms have been found in Devonian marcasite: Phacops rana, trilobite. Goniatites are quite common, especially Manticoceras intumescens. An orthoceras, plus many gastropods and pelecypods, have been found. The latter forms can not very well be identified, owing to the peculiar metallic replacement. As to plant remains, only one specimen has been found in marcasite, probably of the genus Callixylon.

The larger mud concretions and "turtle backs" are invariably duds. Though goniatites are frequently found in these freaks of nature, they are not as well defined as their much reduced relative in marcasite.

The type locality for Devonian concretions is the already famous Eighteen Mile Creek, Erie County, New York.

THE POSSIBLE PRESERVATION IN CONCRETIONS OF TRACES OF ANCIENT METEORITES

La Paz, Lincoln; *Popular Astronomy,* 58:35-39, 1950.

Abstract and Introduction. The absence not only of admittedly genuine meteorites but also of the supposed glass meteorites (tektites) from all but the more recent geological formations is a well-established and intriguing fact. It is not known whether to interpret this absence as evidence that meteorites did not fall in earlier geological times or to look upon it as proof that such meteorites as fell long ago have been entirely destroyed or altered into unrecognizable forms under lengthy attack by the agencies of weathering and corrosion. Most meteoriticists seem to favor the second alternative. The situation just described is closely analogous to that encountered by geologists in investigations of the mineral aggregates present in the geological column. Here, too, it has been customary to explain the greater simplicity of the mineral assemblages in the older strata as the result of long-acting solvent and corrosive agents. But this hypothesis of the geologist, like the corresponding hypothesis made by meteoriticists to explain the absence of meteorites in the earlier formations, has, up to the present, lacked supporting evidence.

In this paper, it is pointed out that very recently such evidence has been supplied by the sedimentary petrologists, who have shown that calcareous concretions in sandstones may preserve within themselves in unaltered or almost unaltered condition heavy minerals and other substances that have disappeared entirely from, or have been greatly altered in the sandstone beds containing the concretions. The results of such modern sedimentary petrological study on the stability of minerals in sandstone strata and in calcareous concretions in the same sandstone suggest that, altho concretions may not be the missing ancient meteorites, as the uninitiated so often mistakenly and stubbornly insist, nevertheless, traces of hitherto undetected early meteoritic and tektitic falls may be preserved within impervious concretions. In particular, it seems open to question whether shards of silica glass found in certain Miocene concretions are fragments of tektites or of volcanic glass. It is urged that meteoriticists systematically investigate the materials preserved within large numbers of impervious concretions. Suggestions are made in regard to the meteoritical evidence to be sought for and the search procedures to be employed.

• Cone-in-Cone Structures

CONE-IN-CONE

Tarr, W. A.; *American Journal of Science*, 2:4:199-212, 1922.

Cone-in-cone is a structural feature found in shales and rarely in coal. It is usually associated with concretions but not necessarily so. An occurrence of cone-in-cone in coal and its development in bands of calcite are such exceptions. The cone-in-cone structure consists of a series of cones within cones, adjacent cones uniting to form lenses or layers. When associated with concretions the cone-in-cone may occur on the upper or lower surface, or, more rarely, within the concretion.

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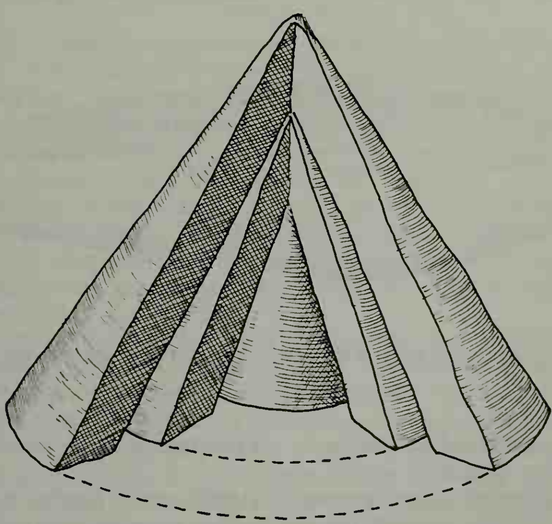
The general features of cone-in-cone are essentially the same for all occurrences. This similarity is true even of the minor features of the structure. The structure consists of a series of right circular cones, which may fit one inside the other. This is the common mode of occurrence, but cones may also occur singly. They are usually grouped along a plane, which, if it occurs on the surface of a concretion, may be curved to fit the surface. Cone-in-cones are usually associated with concretions and in areal extent are generally co-extensive with them. The writer has observed this structure in concretions five feet in diameter. The cones are generally perpendicular in the central part of the layer, but near the edge they are inclined.



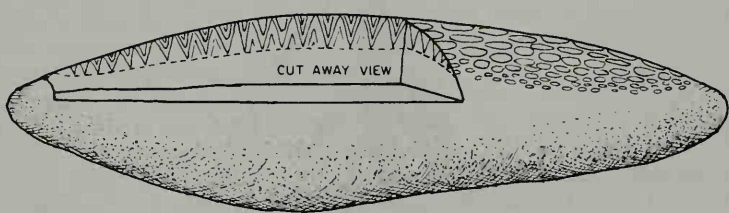
Typical cone-in-cone structure.

The height of the cones varies from a thirty-second of an inch to eight or nine inches. Those from one to four inches in height are the most common. The diameter of the base depends upon the height and upon the angle of slope of the sides of the cones. In many cones this diameter is nearly equal to the height of the cone. The included angle at the apex of the cone ranges from 25° to 70°. If the cone is well developed this angle is generally 60° to 70°. Partially developed cones are sharper.

The sides of the cones are rarely perfectly smooth. Striations such as are seen on slickensided surfaces are common. What Gresley calls "conic scales" are also very common. The sides of the cone may be ribbed or fluted, thus giving a notched outline on the base.

The inside of a cone into which another cone fits is always ribbed with circular rings, which are darker in color than the material composing the mass of the cone-in-cone. These rings are always on the inside of the cone. They vary in width from mere lines to over one quarter of an inch. Within a given cone they are very fine near the apex, and coarsest near the lower edge. This holds true for all specimens examined by the writer and has been so described by others. These rings are composed of clay, usually dark as mentioned above, and are free from carbonates. The ring of clay occupies a depression on the inside of the cone. This clay is similar to the insoluble residue of the cone-in-cone. The rings are broadest and most numerous in the more impure specimens of cone-in-cone. The ridges between the rings are striated and have the same slope as the outer surface of the cone, fitting into the cone-cup.

The cones may be oblique especially near the edge of a cone layer. Some may have the apex removed and others may be more or less bent and twisted. A peculiar feature of the cones in layers, not associated with concretions, is the flaring of the base and the acute apex. Such cones are common in Bond Co., Illinois and in some thin lenses of cone-in-cone in Boone Co., Missouri. The fibers composing the cone-in-



A concretion with a layer of cone-in-cone structures.

cone layers are parallel or inclined. If the latter, they are parallel to the surface of the cones.

The composition of cone-in-cone is significant. Analyses show from 60 to 98 per cent $CaCO_3$, with the remainder usually clay and other insoluble materials. The common occurrence of cone-in-cone in shales and always in association with calcareous portions of the shales would account for the presence of the clay. Probably the association of cone-in-cone with calcareous concretions has a bearing on their occurrence. The writer has found them in thin lenses of fibrous calcite in the Pennsylvanian shales in Boone Co., Missouri.

A point of much value in discussing the origin is whether the cone-in-cone is dominantly calcite or aragonite. Where determinable in the writer's specimens the material is calcite. Cone-in-cone occurs with ferruginous concretions in various localities, hence it is possible that some cone-in-cone is ferruginous, but no cone-in-cone composed of siderite has been seen by the writer or reported in the literature.

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Origin. The published views regarding the origin of cone-in-cone are extremely vague. Pressure is regarded by some as a factor, but why pressure should produce cone-in-cone is not explained. The presumption is that pressure in forcing the material of the structure through the adjacent rock produced cones. Crystallization is also suggested, but why it should develop cones is again not explained. Many minerals are known which may crystallize in radiating masses, but such masses are spherical, or closely related forms, and not conical. It is not clear why crystallization should develop only a fraction of a sphere and do it as perfectly as has been done in the case of cone-in-cone.

The following suggestions represent the conclusions to which the writer has come from his past and recent studies. Future studies will call for much revision and possibly the discarding of parts or all of these suggestions.

The suggestion made here is that cone-in-cone structure has been formed through a combination of pressure, more or less localized, and solution. Contributing factors are both the radial and parallel arrangement of the crystals of calcite composing the structure, and the cleavage of the original carbonate.

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Conclusions. Cone-in-cone is best developed in shales and is generally composed of calcium carbonate in the form of calcite, it having been originally, possibly, aragonite. The calcium carbonate always contains more or less argillaceous material. Studies show that there must have been some movement in the development of the cone structure and also that a certain amount of solvent work had taken place. The insoluble material in the calcite is left behind, through the removal of the calcium carbonate, and forms the rings of material (usually dark) which are seen on the interior of all cones that are well developed. The fibrous structure of the calcium carbonate has favored the parallel arrangement of the rings within the cone.

The cones are probably the result of pressure due to (1) weight of overlying sediments, (2) growth of concretions, (3) (the most important) an increase in volume due to the change of aragonite to calcite, acting in connection with the radial or parallel arrangement of the calcium carbonate fibers; and to solution, which became effective when the pressure had induced the first crack in the layer, groundwater entering and removing the material along this joint. The removal of material along this fracture permitted the further movement of cone within cone.

• Unusual Crystals

CURIOUS CRYSTALS

Anonymous; *Scientific American,* 11:344, 1856.

On the coast of Africa, between Saldanha Bay and the Island of Ichaboe, the beach for miles is covered with sharp crystals, in size about four inches long, two broad, and one thick. Many of them envelope sand as if they had once been in a fluid state, and closed around the sand on the beach. These crystals are soluble in nitric acid, and are principally composed of the carbonate of lime and magnesia.

PATRICK COUNTRY, VA., AND ITS CURIOUS "FAIRY STONES"

Bouldin, Powhatan; *Scientific American,* 79:394-395, 1898.

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All the things that I have enumerated are highly interesting, but nothing that I have seen in Patrick County has interested me so much as its fairy stones.

These curious little crystals are found in only three other States besides Virginia, in no other county in Virginia but Patrick, and nowhere else in Patrick but on and along Bull Mountain, a spur of the Blue Ridge running twenty miles through the county. The fairy stones found elsewhere, judging from the specimens exhibited at the Atlanta and Nashville expositions, are not at all comparable to those found on Bull Mountain. To a few of the people of Patrick they have been known for a long time, but not until about ten years ago did they come into public notice. Some of these stones which have been analyzed contained titanite, tourmaline, garnet, aluminum, and steatite, titanite being the principal material.

Geologists say that they are crystals. Most of them have crosses, some what is called the Roman; some, the Maltese; some, the St. Andrew's; and some, crosses for which there are no names. Those which have no crosses are pretty stones of different forms. Frequently two, sometimes three or four, are joined, making a most curious combination. Possibly a person skilled in the use of the chisel might imitate what might be styled the plain work of the fairies; but it would be impossible for the most skillful sculptor to imitate their fancy work. On many of these stones there are crosses exactly alike on opposite sides. Some of the stones are not larger than the head of a pin, while others weigh as much as an ounce and a half. No two are alike. Nature seems to have tried her hand at variety in making them, as she does in making the leaves on the Otahite mulberry tree. And they are of every shade of color. A number of them placed upon a cardboard make a picture as novel as it is strange and beautiful. No adequate conception can be formed of what a great curiosity fairy stones are without seeing a great many of them together.

Hunting for fairy stones is a new and charming diversion. A walk of two and a half miles from Stuart will take you to where they are found. You will have to climb the mountain, but the scenery along the route is so picturesque that you will forget you are going uphill. And, besides, you will be constantly thinking: What shall I find? Will it be a Roman, a Maltese, or a St. Andrew's? Or will it be a Roman joined to a Maltese or a Maltese joined to a St. Andrew's? or a St. Andrew's joined to one of the crosses for which there is no name? Of one thing you may rest assured, and that is, that every stone that you may find will be different from any that you have ever seen.

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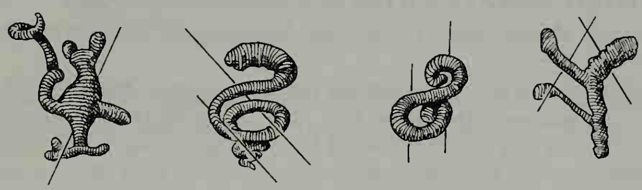
ON RUTILATED QUARTZ CRYSTALS FROM VERMONT.....

Alger, Francis; *American Journal of Science*, 2:10:12-17, 1850.

Imitative forms of mica contained in the Quartz. The surfaces of two of the large crystals exhibited by Mr. Alger, as well as several smaller fragments of crystals, were covered by minute but very brilliant scales of gold-colored mica; and these sometimes penetrated the quartz in company with the rutile, and, in the same manner, seemed confined mostly to the darkest colored varieties of the quartz. But the appearance presented by this mica, is curious and although unique, for in the substance of the crystals, it has assumed the most fantastic forms, appearing in tortuous and vermicular ramifications, some of them bearing such a striking resemblance to organized bodies, as to give the first impression that they are actually the remains of insects or worms. The figures on the next page present a correct representation in a magnified form, of some of the most curious of these appearances exhibited by Mr. Alger's specimens. He had dissected out several of them, and found them to be composed entirely of small plates of mica more or less closely united parallel with the cleavage planes of the mineral. In fact, they are elongated hexagonal crystals of mica, twisted or distorted into every imaginable shape. Their laminated micaceous structure is shown perfectly by the microscope, and is represented by the transverse lines in the figures. The resemblance of the third figure on the fourth row, to some species of Araneides, is not too remote to suggest them instantly to the mind; and the general resemblance of several of the figures to the blood leech and common worms is still more striking---these being produced by the successively diminishing diameters of the little plates of mica until they terminate nearly in a point. But the origin of these resemblances was evidently fortuitous, and could not have been in any way connected with organic matter. They are interesting principally as furnishing a new fact in the department of imitative mineralogy, and they appropriately suggest the term vermiform mica as most characteristic of their general appearance. Vermiform should therefore be included among the imitative shapes assumed by minerals. The striking resemblance between several of these figures and the wormlike projections thrown out by the separating folia of vermiculite when exposed to a red heat, will occur to everyone who has experimented on the mineral. The following examples of them were obtained by heating a fragment of the pure mineral broken from a specimen lately analyzed in Dr. Jackson's Laboratory. They are of natural size.

The straight lines seen passing through several of these figures, are intended to show the needles of rutile that actually intersect these concretions of mica in the body of the stone. In some of them the rutile passes through the circular space left by the folding over of the mica, and its crystallization does not seem to be interrupted by the mica in any case. A characteristic feature of rutile, but never shown in any of the specimens from this locality, (i.e., the geniculated forms,) seems to be imitated by the mica, and is best shown by the second figure in the lower row. The color of this mica by transmitted light, is a pale green, and the mineral seems to agree in external characters with the substance from other localities. Considerable quantity of it was found loose in the



Worm-like forms of mica.

vein, mixed with broken crystals of rutile. The only appearances at all analogous to those just described, which had come to the knowledge of Mr. Alger, were those mentioned and figured by Dr. McCulloch, and described in vol. ii, of the Geological Transactions of London. But in this case, the substance was chalcedony, and the imbedded masses composed of chlorite, had nothing of a crystalline structure, and in fact were rather imitative of vegetable, arborescent forms.

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• Strange Snow and Ice Structures

A SNOW EFFECT

Woodman, Leon Elmer; *Science,* 50:210-211, 1919.

On March 3 of the present year a very interesting snow effect occurred in Orono and vicinity, which is perhaps worth recording in the columns of Science. The writer has not been able to find any one who ever saw a similar effect, and it would be interesting to know if others have observed anything like it in other localities.

About four inches of light dry snow fell during the afternoon and night of March 2. Towards the end of the storm the flakes were very large and the wind blew at a considerable velocity. This high wind continued most of the day of March 3. After the sun had been shining on the snow for three or four hours and had probably formed a thin layer of moist snow on top, the wind would catch up a portion of this moist snow and roll it over and over, forming a snowball of increasing size until the gust of wind had spent its energy, or the ball had become too large to be rolled any farther. Some people who saw this process taking place said that the fields were literally alive with moving snowballs. This peculiar phenomenon continued until about noon and the fields around Crono and Bangor were left with countless snowballs everywhere. Back of each snowball could be seen the triangular shaped path, from which the snow had been rolled up. In one instance this triangle was found to be approximately thirty-six feet in length, but that was for an unusually large snowball. The snowballs were of all sizes, from two or three inches in diameter up to nearly two feet. Of course the largest ones were formed where the ground sloped so that the ball rolled down hill, but even on the level some of the balls were a foot or more in diameter. One ball in particular, on which measurements were taken and recorded, was elliptical in shape, the horizontal diameter being twenty inches and the vertical diameter being fourteen inches.

SNOW DOUGHNUTS

Price, W. Armstrong; *Science,* 50:591-592, 1919.

To the descriptions of snow-rollers which have appeared in recent numbers of your journal may the following be added?

During the winter of 1916-17 a heavy snow fell in Monongalia county, West Virginia, which provided for a short period an opportunity for travel in sleighs. The snow drifted to depths of several feet in places and formed along some roadside fences steep-walled drifts which were, here and there, overhanging at their tops. The writer traveled in a sleigh for several miles along the side of Chestnut Ridge, the westernmost of the Allegheny Mountain ridges in this region. The snow was at this time fresh and unpacked.

At the foot of these steep-walled drifts and also lying part way down their slopes were, in many places, numbers of small snow rings resembling doughnuts in appearance. The rings were a little slenderer than the average doughnut and the writer's impression is that they were from two to four inches in diameter and about a half inch in thickness. Each had left behind it a track in the snow which led from the foot of the overhanging portion of the drift wall down its side into or nearly to the road. A few curved, columnar pieces of snow were also found which had fallen from the top of the drift and had rolled down the side without forming rings.

It was evident that the rings and columnar pieces had been formed from small tongues of snow which had been built out over the steep side of the drift at its top by the wind. These tongues had separated from the snow wall first at the top and had bowed themselves over until their free ends nearly or quite touched the snow at their bases with the result that they broke away and rolled down the bank.

As in the case of the attainment of large size by the "rolls" described by Karl M. Dallenbach in your issue of October 17, so in this instance the completion of the ring form was a matter of balance during the process of bending forward and rolling down since a few fragments had broken away and rolled on their sides without having attained the ring form.

While the wind seems in this case to have operated in building out the tongues of snow until they became too heavy to maintain their equilibrium it was probably not involved in the rolling process which seems to have been due altogether to gravitational attraction.

• Flexible Rocks

THE FLEXIBLE MARBLE OF WHEELING, VA.

Hay, George; *Scientific American*, 26:148, 1872.

Dear Sir: I have, at your request, carefully analyzed a portion of the flexible marble slab, now in your possession and on view at 22 Fifth avenue, Pittsburgh. Its constitution is as follows:

Carbonate of Lime	97.50
Magnesia, a trace	
Silica	2.05
Water	.45
Total	100.00

The above composition and its crystalline character together proclaim it to be a true marble, and, at the same time, a pretty pure specimen of that mineral. The indubitable flexibility of the slab is its most remarkable feature. Dana states that "some of the West Stockbridge marble is flexible in thin pieces when first taken out." The slab in the possession of Mr. Holliday is about two inches thick, and is nearly as flexible as an equal thickness of vulcanized india rubber. I shall not attempt to explain the flexibility of this extraordinary slab. It may be due to a species of ball and socket movement among the minute crystals which compose the mineral, or it may be due to molecular motion alone; I cannot tell. Certain it is, however, that the slab consists of marble, nowise different in chemical constitution from ordinary marble, and possesses an unusual degree of flexibility for marble which has been so long out of the quarry. Those who are interested in what is curious or strange in Nature should go and see this remarkable slab.

FLEXIBLE SANDSTONE

F., G.; *English Mechanic,* 40:319, 1884.

On the south side of the entrance to the Tyne lies a well-known isolated rock called the Marsdon rock. It is, as well as the adjacent coast, composed of magnesian limestone, but of a very sandy and friable character; it appears to have been deposited in layers of very varying thickness, from that of several feet to others of not more than a quarter of an inch in thickness.

When some years since I resided in Newcastle-on-Tyne, I frequently ran down by rail or river to North and South Shields, spending some hours in the vicinity of this rock, and extracting pieces of the thin layers of the limestone. These layers are remarkably flexible, in a greater degree, I should imagine, than the sandstone alluded to recently by more than one of the correspondents of the Mechanic. With great care and some little trouble, pieces of these thin layers, from 2 ft. to 3 ft. in length, and about 4 in. in width, may be obtained by cutting away above and below the layers, and may be safely transported if placed at once in a box or frame. So flexible are some of these layers that they may, whilst still damp, be bent into a circle, and on being allowed to dry, will retain their form. Pieces of about 3 ft. or upwards only can be thus safely manipulated, and very great care is necessary before one may be successful.

In the museums of Newcastle and elsewhere in the North, pieces of this flexible limestone may be frequently found. From broken pieces I have made excellent samples of the sulphate of magnesia or Epsom salts.

• Forest-Fire Clinkers

PECULIAR CLINKERS FOUND IN SNAGS AFTER FOREST FIRES

Englis, Duane T., and Day, W. N.; *Science,* 69:605-606, 1929.

Considerable interest is being shown by the personnel of the U.S. Forest Service over the occasional finding of peculiar rock-like clinkers in hollow snags which are sometimes left after a forest has been burned over. These clinkers usually have a greenish tint and by some people are thought to be of meteoric origin and responsible for the starting of certain forest fires. While this theory of their origin seemed improbable there was still a general feeling that the presence of the clinker material might be associated with hold-over fires, and a definite knowledge of their composition was desired. The matter was referred to us by Dr. Raymond Kienholz, of the department of botany at the University of Illinois, and all samples analyzed by us were collected by him while he was engaged in forest research work in the northwest. A fuller account of the finding of these clinkers with respect to geographic distribution, forest species and fungal action will be reported later by Dr. Kienholz in the Journal of Forestry.

Samples I and II were found on the Kaniksu National Forest near Priest Lake in northern Idaho. Sample III was from the Wind River country of southern Washington, as was also the sample of sound wood. All were taken from the western hemlock (Tsuga heterophylla).

The results of the Analyses are given in the following table.

Chemical Composition of the Clinkers and Ash of Sound Wood

Constituent	Percentage of constituent			
	Clinker I	Clinker II	Clinker III	Sound wood
Crude SiO_2	.32	.38	.41	--
P_2O_5	6.96	6.58	5.47	.0227
R_2O_2 (Fe_2O_3) (Al_2O_3)	1.68	.99	.34	.0096
SO_3	Trace	Trace	.67	--
Cl	Trace	Trace	Trace	--
CaO	22.02	21.90	21.79	.0424
MgO	6.28	4.48	4.06	.0226
Mn_2O_4	1.21	1.32	7.17	.0252
K_2O	25.01	24.54	30.42	.0750
Na_2O	5.31	2.06	4.20	.0173
CO_2	19.76	25.47	--	--
Total	88.35	87.72	74.47	.2148
Difference (including H_2O, carbon, etc.)	11.65	12.28	25.53 (incl. CO_2)	

An examination of the table shows that the clinkers are all of quite similar composition. This is especially true of the two from the same locality. Very little data on the complete analysis of ash of American woods is available for the comparison of composition, but rather wide variation would be expected. The species, section of the tree from which the wood was taken, locality in which the tree was grown, and other factors would have a marked influence. If the ratio of each other constituent to K_2O be calculated for clinker III and the ash of the sound wood from the same locality a very close analogy of composition will be observed.

There is no justification for the assumption that the clinkers are of meteoric origin.

Their greenish tint is due to manganese in the manganate state. Although the manganese content of Sample III is much greater than that of either of the other samples, it is not unusual. Various investigators report quantities of Mn_3O_4 which range from less than 1 per cent. to over 40 per cent. of the pure ash of the wood.

The peculiar rock-like character of the clinkers is probably due to the collection of a large quantity of the ash in the hollow snag, followed by occasional wetting from rain and finally a fusion of the mass during a later vigorous burning of the surrounding wood. It is doubtful if any chemical action due to the clinker would be capable of causing ignition of a snag and a rekindling of a fire. The formation of the clinkers is probably incidental to hold-over fires.

• Mud Lumps

MUD-LUMPS

Scott, A.; *Knowledge,* 12:19-20, 1915.

In a recent "professional Paper" of the United States Geological Survey (No. 85 B) E. W. Shaw gives an account of the remarkable clay formations which occur at the mouths of the Mississippi, and are locally designated "mud-lumps." Such an immense amount of material is brought down annually by the Mississippi, and deposited at its mouths, that land is built out at an estimated rate of three hundred feet per annum, and, consequently, the channels, islands, and bars are constantly changing their positions. The mud-lumps, however, differ from the usual delta deposits in a number of ways. They occur some distance off the shore, near the submarine bars at the various "passes" through the delta, and form islands up to an acre in extent. They rise in a few weeks to a maximum height of from two to eight feet above sea-level, and at first are elliptical in shape, but soon become irregular, owing to erosion by tide and river action. After attaining their maximum height, they become quiescent, and finally disappear as the result of being worn down by the water. Sometimes they appear to subside in much the same manner as they rise.

The central core of the "lumps" is composed of a sticky bluish-grey clay, very fine-grained, and containing little of the coarser delta deposits. Surrounding this are various beds of sand and silt, which have been thrust up in an anticlinal fashion by the rise of the core. The whole is very much fissured and faulted, but the clay itself is structureless, and contains practically no organic remains. Apparently connected with the fissures are numerous active mud-springs, which discharge salt, "sludge," and gas. The gas is mainly methane, with subordinate amounts of nitrogen, oxygen, and carbon dioxide, and seems to be formed by the decomposition of organic material.

Various theories have been put forward to account for their origin. They cannot be uplifted by subterranean gas, as borings have failed to reveal any gas reservoirs, while their uniform height and occurrence only at the ends of the "passes" also militate against such an origin. The most probable explanation is that they are due to the seaward flow of a semi-fluid clay under the shallow water near the ends of the passes, and that this flow is caused by the pressure of the sediments deposited by the river, the upward buckling being due to the resistance offered by the so-called "foreset" beds, which are comparatively thick deposits of coarse sandy material just off the shore.

MUDLUMPS AT THE MOUTHS OF THE MISSISSIPPI RIVER

Morgan, James P.; *Geological Society of America, Bulletin,* 63:1282, 1952.

Abstract. Mudlumps are a physiographic phenomenon unique to the delta of the Mississippi River. They are elongate upswellings of poorly

sorted sediment, composed predominantly of clay-sized particles. Localized forces, arising from the static pressure of accumulating sedimentary deposits, are relieved through the upwarping of near-surface sediments. Many mudlumps are forced above the water surface to form islands, some approaching 30 acres, but the majority occur as submarine eminences. Mudlump islands have cores of plastic clay which may arise from depths as great as 300 to 500 feet. Surrounding and often capping the clay cores are stratified recent sediments of the original bar or bay bottom. The strata typically delineate doubly plunging anticlinal structures. Tensional fissures and faults paralleling the strike of the elongate islands are common. Mud, gas and salt water are discharged from vents along the faults, often building low, flat cones. A positive correlation exists between mudlump growth, mudvent activity, and active sedimentation at each of the several passes. South and Southwest Passes, which have been modified by means of jetties, display an arc of mudlumps outside and parallel to the periphery of the bar deposits. On natural passes, mudlumps are affected by submerged natural levees as well as the bar deposits. Though often exhibiting several periods of uplift, individual mudlump islands are temporary features, either being removed by wave erosion in a few years or else becoming incorporated into the rapidly growing marshland.

REPORT ON THE 1964 CHATHAM MUD ISLAND, ERIN BAY.....

Higgins, G. E., and Saunder, J. B.; *American Association of Petroleum Geologists, Bulletin,* 51:55-64, 1967.

Abstract. In August, 1964, a new mud island appeared above the sea about 1-1/2 miles offshore from Chatham on the south coast of Trinidad. It rose to a maximum height of approximately 25 feet above mean sea-level and had an original area of about 10-1/2 acres at low tide. It lay close to the axis of the Southern anticline, a tectonic feature that shows well-marked mud-volcano activity on the adjacent land.

The mass of the island was composed of silty clay containing numerous boulders that ranged from a few inches to 2-1/2 feet in diameter. The components ranged in age from Late Cretaceous to Miocene but it is considered probable that all those older than Miocene were derived from rubble beds of that age associated with the Southern Range anticline.

Extrusion of soft mud took place during the first 2 days, apparently beginning from the east and extending along a line trending NNW-SSE. Growth ceased in a few days and compaction and erosion followed until the island disappeared below sea-level 8 months later.

The main force causing the extrusion of the mud and the formation of the island could have been tectonic, the result of gas pressure, or a combination of both. Although gas was given off in quantity, the lack of evidence for the high pressures necessary to extrude the estimated 9 million cubic feet of material leads the writers to believe that tectonic movement was the principal reason for the phenomenon.

• Spherical Structures of Unknown Origin

BALLSTONE

Tyrrell, G. W.; *Knowledge,* 11:308, 1914.

An elaborate study of the peculiar lenticular structure known as ballstone, occurring in the Wenlock Limestone of Shropshire, has been made by Miss M. C. Crosfield and Miss M. S. Johnston (Proceedings of the Geologists' Association, XXV, 1914). The ballstones are unstratified, ovoid, or lenticular masses of limestone embedded in hard courses of stratified limestones. The bedding-planes of the latter generally stop abruptly where they abut against ballstone, but near the top of the lenticle they may curve over without discontinuity. The size of the ballstones varies greatly, but some reach a height of sixty to eighty feet. Both the ballstone and the adjacent stratified limestone contain a rich coral and stromatoporoid fauna; but in the former the fossils are mainly in the position of growth, and are enveloped by a flour-like calcareous matrix, whereas in the stratified limestones the fossils are largely in the condition of broken fragments.

The ballstones are considered to be the relics of large coral and stromatoporoid colonies still in the position of growth. They are identical in form and structure with the unstratified limestone masses which have been termed "reefs" by many authors. "The absence of coarse brecciated rock suggests that the colonies lived in comparatively calm or sheltered waters, whilst the fine, flour-like matrix in which the colonies are embedded is indicative of destructive wave-action at no very great distance, which has supplied the material, intercepted by the branching corals, and caught in the interspaces between the colonies. Such conditions are analogous to those now found behind a barrier reef or in a lagoon. That the colonies were originally of greater extent, but subsequently suffered destruction, is deduced from the presence of the large and identical coral fauna found scattered and overturned in the adjacent stratified beds." An instructive comparison is made with similar structures in the Palaeozoic limestones of Yorkshire, Belgium, and Gotland, the Tertiary bryozoan limestones of the Sea of Azov and the Black Sea, and in the Clinton and Niagara limestones of the United States.

The placoidal shape of the ballstones is ascribed to processes of contraction of the calcareous rock-flour during or shortly subsequent to the consolidation of the coral-rock and the death of the corals.

CURIOUS SPHERICAL MASSES IN ASHDOWN SANDS

Abbott, Geo.; *Nature,* 112:539, 1923.

Mr. Harry E. Burns, of Crowborough, this spring informed me of some remarkable spherical masses of sandstone in the Ashdown Sands at High Hurst Wood Quarry, and was good enough later to supply one about

10 inches in diameter to our Museum. He suggested that they might be sand casts of reptilian eggs like that of the Iguanodon. They consist of fine-grained nearly white stone---much of the iron having been leached out. I expected but failed entirely to find on section any pan or stains of limonite such as in the well-known balls of Folkestone Sands.

Recently I have visited the quarry with Mr. Burns, and was able to see a ball 30 inches in diameter in position. We were told they are confined to an upper bed about 14 feet thick, and vary in size from 10 to 30 inches in diameter. We could discover no evidence of a foreign body or of concretionary growth, although such growths are not rare in the Wealden Sandstones---often, too, in a decalcified condition. Those at Crowborough are found loose in a narrow cavity, and the stone appears identical in colour, etc., with that of the surrounding bed. The adjacent stone for a few inches is shattered---due, I suppose, to the pressure of overlying beds against the unyielding sphere, while the narrow clefts are filled with clay, doubtless washed there from the once overlying Wadhurst Clay. Strangely enough, some of these balls have been used as ornaments at the tops of wooden gate-posts! During the forty-five years I have lived in the neighbourhood I have not met such masses before, and find them difficult to explain.

SOLVING THE MYSTERY OF MEXICO'S GREAT STONE SPHERES

Stirling, Matthew W.; *National Geographic Magazine,* 136:293-300, 1969.

We drove to the ruins of the old mine headquarters, then climbed on foot to an elevation of about 6,000 feet. There, atop a mountain spur, lay the five spheres. [Jalisco State, Mexico]

Three of them were half buried, the fourth, washed clean of rubble, stood in an arroyo, and the fifth perched on the top of the ridge. It had a bulge on one side; it was split in two, as if broken while being shaped and left incomplete. All appeared to be made of soft volcanic stone similar to the mountain itself.

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The following morning we began digging out the three half-buried spheres and in their vicinity found six other buried ones. We discovered 11 more large stone balls the following day, bringing the total to 22 at this site. They varied in diameter from four-and-a-half to six-and-a-half feet.

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On the third day Jesus Lopez straightened up from his shovel and asked why we were doing all this digging and mapping.

"At Agua Blanca, just over the top of the hill," he said, "there are many, many of these balls lying in the open on the ground."

Still another site? I was skeptical at first, but decided to investigate. We arranged for horses in the village of Tiro Patria below the old mine entrance and set forth.

A two-hour ride took us up a mountainside through forests of oak, pine, and acacia with inspiring views of distant valleys. As the ground leveled off at the wild and lonely crest of the Sierra de Ameca, stone spheres came into view. First they appeared singly, then in clusters where they had accumulated in small arroyos---more and more, until we estimated there were hundreds.

A spectacular sight! The scene suggested some giant's bowling alley or the ball park of the Aztec gods. The spheres lay fully exposed; they ranged in diameter from about two feet to one giant of more than 11 feet. The average I estimated at five or six feet.

The profusion of stone balls at Agua Blanca completely changed our concept of their origin. Such great numbers surely indicated natural formation. Some of the stone were pear-shaped and a very few were joined as twins or had a dumbbell shape, and these sports certainly tended also to deny human fabrication.

But if the spheres were not man-made, then how had they been formed? Where had they come from in such fantastic numbers? We realized that our expedition had made an astonishing discovery---but that the explanation for it would have to come not from an archeologist but from a geologist.

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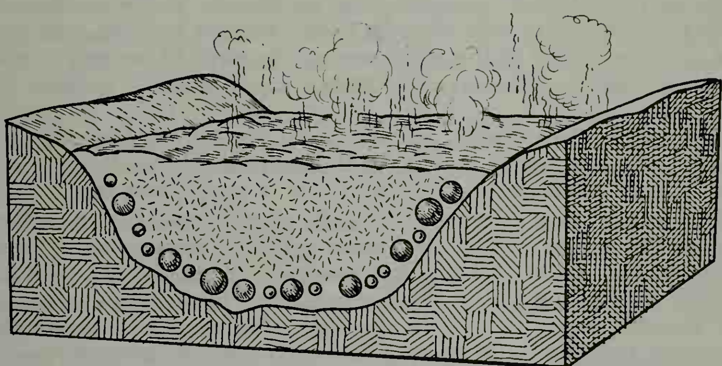
"Crystallization of the Jalisco spheres," Dr. Smith continued, "began in nuclei of single glass particles. Gases released from the glass moved outward in all directions, promoting crystallization of adjacent glass particles and thus forming the spheres. This process continued until stopped by cooling or coalescence of spheres.



Volcanic ash may crystallize in constantly growing spheres. The interior of the mass will merge into a single body, while spheres around the edge fail to coalesce and survive erosion as separate bodies.

"I found one sphere still enclosed in an undisturbed ash matrix which, although consolidated, was softer than the stone ball. But from most spheres the matrix had eroded away, leaving only completely exposed relics.

"I know but one other area of occurrence of similar spheres in ash deposits. This is near Los Alamos, New Mexico, where my colleague R. A. Bailey and I have found about six sites within an area of 500 square miles. The largest stone ball there measured only two feet in diameter. The Jalisco spheres, which range in diameter from two to more than 11 feet, may be unique in the world."

So came the solution of the mystery of the great stone balls that perch, cool and aloof, on the Sierra de Ameca---40 million years removed from their fiery origin.

• Mud Balls

ARMORED MUD BALLS.....

Bell, Hugh Stevens; *Journal of Geology,* 48:1-31, 1940.

Introduction. Mud balls, both ancient and modern, are distributed widely throughout the world. For instance, in the United States they are present in the Patuxent formation on the Atlantic seaboard, the Pico formation in California, the glacial drift of the Great Lakes area, and the valley fills of New Mexico, Arizona, and Oklahoma, on the shores of lakes with beach cliffs of clay wherever they may be located, and in hundreds of streamways in the southwestern quarter of the nation where the ephemeral nature of the streams makes it particularly easy to find them in large numbers.

Despite their ancient lineage and wide distribution they belong in a geological "no man's land," the category Kindle has suggested for concretions, which they often closely resemble. It is surprising that a search of publications in English discloses only three short papers, all closely related, devoted exclusively to mud balls. Two of these actually are more concerned in showing that some concretions may have originated as mud balls than in imparting information about mud balls as such.

Under various names mud balls have received brief and infrequent mention in the geological literature of the past sixty or seventy years. In 1875 Jones and King wrote of "clay galls" as much as 20 inches in diameter, upon the surfaces of which flint pebbles had become imbedded. During the present century Gardner, Haas, Ellis, Twenhofel, Wentworth, Cartwright, and others have written briefly of similar, though smaller, armored balls. Ellis alone seems to have made laboratory studies, the results of which were published in part after his death by Haas. The bulk of his work apparently has never been made available.

The Origin of Mud Balls. As to the origin of mud balls Gardner suggested in 1908 that in the "super-saturated" streams of the Southwest a soft nucleus is formed by the cohesion of fine clay particles as they flow along a smooth bottom, in much the same way that butter is formed in a churn. These, he said, grow by the adhesion in concentric layers of clay, sand, pebbles, and other materials until the stream is no longer able to turn over the mass.

Gardner's view of the origin of mud balls differed radically from the one set forth by Jones and King in 1875. The armored balls found upon beaches, they suggested, were formed by waves rolling chunks of clay that had fallen from neighboring cliffs. It is obvious from the text that these gentlemen were expressing an idea already generally accepted.

For nearly twenty years Gardner's hypothesis went unchallenged. Then, in 1927, after field investigations in the Southwest, Haas expressed doubt that large balls could be formed as Gardner suggested and added: "Of the scores which the author has broken apart not a single one showed a concretionary structure." Haas agreed, however, that the size which balls may attain is determined by the ability of the stream to turn over the mass, and added "or by the narrowest part of the channel through which they have come."

The "pudding balls" found in the Pico beds of Ventura County, California, by Cartwright were occasionally of a concentric, banded structure as well as studded with pebbles. He suggests that they may have been "formed by accretion around a clay nucleus, such as a flake curling up between dessication [sic] cracks, which was caught by the renewed flow of a stream over its muddy bed, or the wash of sea water over a mud flat."

Following the hurricane of mid-September, 1936, Kindle observed clay balls as much as 10 inches in diameter on the beach at Cape May, New Jersey. Apparently these had been eroded recently from beneath silty beds near the beach. Richter states that clay balls may be formed beneath the surface of shallow seas by the erosion of older tidal deposits.

Twenhofel also records the existence of concentrically banded balls and concurs with Wentworth in the now generally accepted explanation that most mud balls are molded and abraded from chunks of clay which fall from the banks or are torn from the bottom of a stream or other body of water. Both Twenhofel and Wentworth noted armoring and explained this as the accretion of pebbles and other substances to the mud balls through pressure. It thus becomes evident that concentric banding results when circumstances permit the accretion of clay fragments and other materials in alternate layers.

Ellis noted that the pebble-filled exterior of balls could be peeled readily from the clay core and shared with Jones and King the distinction of reporting balls having diameters as great as 20 inches. Those mentioned by the other writers were, almost without exception, not over a foot in diameter and usually much smaller.

Opportunity for Study. Thus, briefly, may the literature of mud balls be reviewed. Recognizing the paucity of information available upon this interesting subject, we undertook field and laboratory studies under the most fortunate circumstances during the second half of 1938.

The mud balls themselves were supplied in superabundance by Las Posas barranca between El Rio and Camarillo, California. Literally tens of thousands of excellent specimens had been formed by this stream during a major flood, which inflicted severe damage upon Southern California during the first week of March, 1938.

Fortunately for the investigators, specimens were deposited in large numbers within a few feet of U. S. Highway 101 where, many months after the flood, they could readily be collected. Those which had been exposed to the air were badly disintegrated and apparently confirmed a statement by Haas that they are never preserved unless completely covered at the time of the wash (flood). More than 200 balls, all freshly excavated, were selected for laboratory analysis, and additional hundreds were examined in the field.

So numerous were the balls that they formed an important part of a fill which had virtually obliterated a channel approximately 4 feet deep and 20 feet wide, made useless a triple culvert of concrete, each rectangular section of which was 6 feet square, and had rolled by the thousand onto adjacent acres of formland. [Details of study omitted]

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• Lake and Sea Balls

CONCERNING "LAKE BALLS," "CLADOPHORA BALLS" AND "COAL BALLS"

Kindle, E. M.; *American Midland Naturalist,* 15:752-759, 1934.

It is proposed in this paper to compare two not very widely known organic structures found in certain lakes with analogous Coal Measure structures which are noted for the exceptional perfection of preservation which characterizes the fossil plant remains composing them. It is believed that such a comparison may be helpful in understanding the origin of Coal balls just as would be the comparison of recent tide flat mud-crack and fossil mudcrack, if the origin of the latter was obscure or in dispute.

Lake Balls: Ball shaped structures composed chiefly of aggregations of various kinds of plants or plant fragments and sometimes a variety of other materials occur in certain lakes. They are not found in most lakes though apparently common in localities where they do occur. Few references to them have come to the writer's notice in papers dealing with American lakes. The earliest of these appears in Thoreau's Walden. In Flint's or Sandy pond near Concord, Mass., Thoreau found "curious balls, composed apparently of fine grass or roots, of pipewort perhaps, from half an inch to four inches in diameter, and perfectly spherical. These wash back and forth in shallow water on a sandy bottom, and are sometimes case on the shore. They are either solid grass, or have a little sand in the middle. At first you would say that they were formed by the action of the waves, like a pebble; yet the smallest are made of equally coarse materials, half an inch long, and they are produced only at one season of the year. Moreover the waves, I suspect, do not so much construct as wear down a material which has already acquired consistency. They preserve their form when dry for an indefinite period."

This careful description based on observations made by Thoreau about 1845 on what appears to be a rarely observed or described lake product, indicates that the "lake balls" known to him were formed on sandy bottom and sometimes had a nucleus of sand. The ripple marks found near them appear to suggest that both are products of wave action which makes balls out of vegetable debris while it moulds the sand grains into ripple ridges.

More than 50 years after the publication of Thoreau's description of vegetable balls, W. F. Ganong, described similar structures from Little Kedron Lake, N. B., "composed chiefly of leaves of fir and spruce but with some other vegetable matter such as small twigs, etc., in addition all interlocked together." These balls which had a maximum diameter of 6" to 8" were considered to be probably a product of wave action.

In other papers Ganong assembled several other records of "Lake balls." These structures from an Idaho lake are described as follows:

> Balls and solid cylinders composed, in the main, of decaying pine needles, bits of comminuated bark and wood, Ceratophyllum demersum, leaves and stems of Potamogeta, Charas and Nitellas are of common occurrence in Lake Pend Oreille, in Idaho, and doubtless in Priest and Coueur d'Alene lakes also, in the same State. The wave motion rolls the mixture along the bottom and in its progress shoreward pine needles, decaying splinters of wood, bark and similar debris are taken up and become intimately mixed with the primary mass. Infusorial---slimes---Amoebas, Verticellas, etc.---develop and assist in holding the mass together.

Another record relates to balls composed almost wholly of hair.

> The hair comes from a tannery located on the shore of Lake Michigan a mile or two north of Petoskey, at a point called Kegomic and these hair balls are cast up on the beach about a mile further along, although a few are found at other places around the bay.... The hair balls are of all sizes up to at least five inches in diameter, although my recollection is that balls of that size are much less common than smaller ones.

Vegetable balls have been reported from two Nova Scotia lakes by A. H. MacKay but the specimens figured by him are "sea balls" and were found on the sea shore at Upper Kingsburg, Lunenburg county.

Nova Scotia has also furnished a unique variety of vegetable ball formed by a brook in a pool at the foot of a small waterfall. The only described examples known to me were exhibited at a meeting of the Ottawa Field Naturalist's club in 1903 and described by A. E. Atwood as follows:

> Vegetable concretions or nodules from Nova Scotia. These were several inches in diameter and almost spherical in shape. They had been formed by the matting or felting together of small pieces of grass, ferns, and pine leaves through the action of water in a pool at the foot of a small waterfall on a rivulet.

W. L. McAtee has assembled under the title of "water formed vegetable balls" several of the vernacular names in use for these structures in various parts of the world. The English terms cited by him are burr balls, sea balls, vegetable balls and water-rolled weed balls. He puts on record still another term,---"Buffalo balls" which is used for the balls of peculiar composition observed at certain lakes in the western United States.

> These "Buffalo Balls" as they are locally called were very abundant in August, 1917, along the shore of one lake near Dawson, North Dakota. Large masses of detached Ruppia maritima were observed floating in the water, churned up with a goodly amount of the foam which is readily produced in this alkaline water. Continual wave action apparently resulted in the formation of the balls which were washed up on shore in sufficient number to make two or three

wagon loads. These balls were variable in size, from about 1-1/2 inches in diameter to somewhat over 3 inches; they were rarely spherical, usually being somewhat longer in one diameter and often flattened. They were composed entirely of stems peduncles and seeds of Ruppia maritima, all bound closely together in a solid, firm mass; the surface was fairly smooth and often incrusted with small white spots of crystallized salts and occasional fragments of algae. Similar balls have been reported from Miller Lake, Oregon, by Dr. George W. Field.

Numerous other references to the structures here called lake balls or allied structures may be found in a paper by Schroder.

None of the vernacular terms in use are adequate to include all of the structures described by the authors cited. The thousands of balls formed by salmon bones carried down by the Karluk river Alaska reported by McAtee might appropriately be called River balls and for the vegetable balls here under consideration Lake balls seems to be a suitable name.

These rather rare ball-like structures usually composed of a variety of plants represent a product of wave action with which probably few geologists are acquainted. Since they are products of wave action they must have been produced in Carboniferous times about as frequently from the abundant forest debris of Coal Measure lakes as they are in modern lakes.

Cladophora balls: There is another type of vegetable lake ball which is the result of the growth of one kind of plant. The best known lake balls of this type are called by algal botanists "Cladophora balls" after the name of the genus of algae responsible for them. Their globular shape is regarded as the result of the peculiarities of the growth habits of the algae represented, operating under the influence of wave or current action. Concerning the formation of these structures and their rare occurrence in the United States Professor G. M. Smith writes as follows:

> Cladophora balls are irregular in shape when first formed and with the filaments irregularly intertwined. Growth of the filaments that have been rolled into a ball is largely radial. The continued abrasion of the plant mass, as it swishes back and forth across the sandy bottom, results in its assuming a globular form. As the ball continues to increase in size, there is often a death and decay of the filaments at the center of the ball. Gases given off during photosynthesis may accumulate in this cavity and cause the balls to rise to the surface of the lake. Cladophora balls are common in certain lakes of Europe. They seem to be of rare occurrence in this country and are definitely known only from a lake in Massachusetts.

The single reported American occurrence of Cladophora balls reported by Smith is credited to F. S. Collins.

During the early part of the summer of 1932 the writer discovered what appears to be the first reported Canadian occurrence of "Cladophora balls." They were found in considerable numbers along a sandy beach on the northwest side of Lake Dore, Ontario, about a mile above the outlet, June 20th. Although found abundantly at Lake Dore, in both 1932 and 1933 they have not been encountered elsewhere by the writer who has examined the shores and bottoms of various Ottawa valley lakes with some care. This seems to indicate that Cladophora balls are rare in the Ottawa valley. There appears to be no previous record of their occurrence in Canada. The balls from Lake Dore were sent to Professor Lowe of the University of Manitoba who determined them as Cladophora (Aegagropila) balsatica Kutz. These balls occurred along the edge of a sandy beach adjacent to an area where yellow pond lilies and other shoal water plants occupied an acre or more of the shoal water. The abundance of the balls on the shore adjacent to this yellow pond lily assemblage and behind it appeared to indicate that the balls originated on the bottom in the midst of the water plant assemblage. Search for these on the lake bottom resulted in finding them abundant in places on patches of the bottom a few feet square. The maximum water temperature observed at this locality was 78°F. The west shore of Lake Dore was revisited on July 16th when air temperature was 78° and water 76° when the Cladophora balls were found to be much less abundant than they were on June 20th.

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From the foregoing it is evident that some "Cladophora balls" possess, with their diurnal ability both to float and rest on the bottom, a degree of mobility exceeding that of many aquatic animals. That they may transport at least fragments of plants other than algae is indicated by the photograph of some Lake Dore specimens, one of which has grown around a plant stem. It will appear from the following discussion that "Coal balls" were likewise endowed with an ability to move away from their place of origin. Some acquaintance with the mobility of the "Cladophora ball" may possibly help to understand the same quality in "coal balls."

"Coal Balls." The nodular aggregations of various kinds of plant remains preserved in calcareous and other kind of concretions found in certain coal beds are commonly designated as "coal balls." The excellent state of preservation shown by the included plant remains gives a particular interest to the question of the origin and history of these structures. "Coal balls" have a somewhat restricted distribution although it has been considerably extended during the last decade. They are unknown in the Nova Scotia field. Until a few years ago they were almost unknown in the United States. But about ten years ago Professor Noe announced their discovery in Illinois, Iowa, Kentucky and Indiana. Coal balls are known also from Austria, Czecho-Slovakia, Germany, Great Britain, Poland, Russia, and Australia. They are commonly found as brown or black lumps in the upper part of coal seams, and are frequently silidified or pyritized. Most of our knowledge of the inner structure of Paleozoic plants has been derived from the study of English and French coal balls. The distribution tables of Feliciano give coal balls known in England and Europe a range through both Upper and Lower Coal Measures while those found in the United States occur in both Allegheny and Post-Allegheny coal seams.

Two opposed hypotheses have been held in discussions of the origin of "coal balls"---the "in situ" theory and the drift hypothesis. The latter is strongly supported by the work of Jeffrey. In Jeffrey's study of coal balls he found masses of charcoal distributed irregularly and without reference to stratification through the petrified substance of the ball. He concludes that coal balls are not derived from material accumulated in situ and that the coals in which they occur "have been laid down under the open water and transport conditions which are universally conceded for the coals of the canneloid category." In presenting the evidence for open water conditions of coal ball formation Jeffrey offers no opinion as to the precise way in which the coal ball aggregations were assembled. But the open water condition of deposition to which his study lead invite comparison of Carboniferous lacustrine conditions and products with those of modern lakes.

The general absence from the coal balls of lines of lamination which are common in most coals and the varied character of the plant material assembled in these structures and its contrast with the aggregations of the beds in which they are found strongly suggest that the material forming the balls has been assembled in a different way from that of the beds holding the balls. Some have probably originated in the same way as the vegetable debris comprising the lake balls figured by Ganong from New Brunswick and Massachusetts lakes. The oscillatory motion of waves under open water conditions would be likely to select from the bottom forest debris material which would lend itself most readily to moulding into ball-like masses which might sometimes be transported some distance from their source. But more frequently they might be expected to become buried under bottom debris near the place of origin. If "lake balls" of our modern lakes such as Thoreau and Ganong have described, are the product of wave action they must have been formed on the bottom of Carboniferous lakes and lagoons quite as often as they are in modern lakes.

Stopes and Watson in their careful and detailed study of English coal balls have held to the "growth in situ" as opposed to the "drifted" origin of "coal balls." They have dealt apparently with structures some of which are quite different from those considered by Jeffrey. These include masses weighing tons allied in origin to the dolomite bed which supplants the coal seam in one mine where quite evidently vegetable and calcarous deposits accumulated side by side in the same lake just as they are doing today in various Ontario lakes. Some of their small "coal balls" remind one strongly of the marl balls produced by lime separating algae in modern lakes. The conveniently vague and inclusive term "coal balls" as used by them embraces structures which appear to be syngenetic concretions comparable with those now forming in various lakes and often enclosing molluscan shells.

The shapes of the "coal balls" have sometimes departed so widely from the more common globular forms that they cannot be compared with "lake balls." Some of these may represent chunks of debris detached from floating islands or rafts.

The rafts or <u>embarras</u> which a century ago made navigation difficult in the lower Mississippi River and impossible in some of its large tributaries are probably comparable in their effects in damming streams to the work of timber rafts in Coal Measure times. Great stretches of some rivers were transformed into huge rafts of forest trees which one might cross without suspecting he was going over a river. Previous to 1816 the Atchafalfa river was covered by a raft for more than ten miles which was 220 yards wide and 8 feet deep. It rose and fell with the water and was covered with green trees and bushes some of which were about sixty feet high in 1835. The Red river raft had attained a length of 124 miles when the U.S. Government undertook its removal in 1833. Twenty-two years later this task was abandoned in favor of improving the bayous for navigation, thus leaving "The Great Raft" in the marshes of the old river to be converted into a great peat bed and possibly "destined to become coal at some future geological period" as Reclus suggests.

It seems clear that the dearth of oxygen in the water of sections of rivers blanketed by these timber rafts with their surface mat of vegetation would yield exceptional conditions for burial by sediments of plant remains where oxygen was nearly or quite excluded. Such conditions should result in fossil plants showing the perfection of preservation which is characteristic of "coal balls."

It is not such an unusual thing to see in certain Canadian lakes in midsummer floating compact masses of Chara and some associated plants which have apparently been detached from the bottom through the development of gases from vegetable decomposition. Comparable masses of floating vegetation may have at times dropped masses of plant assemblages in Coal measure lakes or lagoons which contrasted strongly with the bottom debris on which it grounded. Coal measures mud balls derived from cut banks of carboniferous lakes may also have played a part in supplying the aggregations known as "coal balls."

Summary: It has been the purpose of this discussion to direct attention to the novel structures known as "lake balls" and "cladophora balls" in seeking the origin and nature of "coal balls." It is inferred that "lake balls" were formed in Carboniferous times under the same conditions which now produce them and that some "coal balls" represent plant aggregations assembled in the same way that "lake balls" are now produced. The floating ability of "Cladophora balls" during the season of active growth has significance in connection with understanding the dispersal of some "coal balls" and their preservation in the midst of plant remains quite unlike those represented in the balls. Development of gases within the coal balls probably aided their wide dispersal just as gases generated during photosynthesis result in the migration of cladophora balls. Many of the structures called "coal balls" however, are not in any way related to modern "lake balls" or to "cladophora balls."

THE RUPPIA BALLS OF LITTLE BORAX LAKE

Essig, E. O.; *Scientific Monthly,* 66:467-471, 1948.

On July 5 last, A. A. Trippel, of Nice, Lake County, California, brought to my office several strange-looking balls which had been collected on the shores of Little Borax Lake. These balls were regularly oval in shape, gray in color, and appeared to be composed of a hairlike substance. The collector furnished the following information concerning them:

1. They had not previously been noted in the country even by the Indians or the oldest white inhabitants.
2. They occurred on the shores of this particular lake (when it had dried up) in great numbers---perhaps thousands.
3. They varied in size from a baseball to a small watermelon; in shape they were regularly oval, though a few of the smaller ones were spherical.
4. Their composition was unknown and could not be accounted for.
5. Some of them, certainly, were too large to be stomach hair balls, or aegagropilae.

A cross section of the balls showed an even, closely packed matrix of small, stiff, woody, needlelike fibers nearly uniform in length. These hairlike strands were so tightly and intricately interlaced as to constitute an almost indestructible whole. Yet there was no evidence of any adhesive binding the innumerable bits together, and no obvious core which might have furnished the beginning of the balls. It was evident, however, that the balls had been enlarged gradually, because formations as small as one inch in diameter were subsequently discovered. A few balls, opened later, revealed leafy tissues throughout the matrix, and even slight cavities.

A microscopic examination at once disclosed the true nature of these mysterious balls. The small, hairlike filaments were, in fact, plant material. Many of them terminated in an enlarged black, round seed pod, with a pointed end. Specimens were submitted to Dr. H. L. Mason, professor of botany at the University of California, who identified the plant as Ruppia maritima L., commonly called "ditch grass." The balls appeared to be composed almost entirely of the small seedstalks and, possibly, broken stems of this plant.

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It seems likely that the balls were formed by the loose Ruppia plants being rolled by wave action on the broken remnant of plants along the shallow shore line until the compact, almost indestructible masses were shaped, and that they were rolled up along the shore line only at high water. A close examination of the eastern shore of the lake revealed a great thick mass of small particles of the Ruppia plants imbedded in a matrix of decaying material. This would seem to indicate that only a very small amount of the available material was actually being shaped into these remarkable balls. The inexplicable thing was that practically all the balls were deposited in a relatively restricted strip not more than four to six feet wide. (This might possibly have been caused by a particularly violent windstorm when the lake was nearly dry.)

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• Stretched and Deformed Pebbles

THE PLASTICITY OF PEBBLES AND ROCKS

Blake, William P.; *American Association for the Advancement of Science, Proceedings,* 18:199-205, 1869.

At the Newport meeting of this Association in 1860, the attention of the members was directed by Mr. Charles H. Hitchcock to the peculiar elongated structure of the conglomerate at Purgatory. In that communication and in a subsequent elaborate paper by the late Professor Hitchcock, published in the "American Journal of Science," it was maintained that the pebbles composing the Newport and other conglomerates had been elongated, compressed and distorted by tension and pressure after having been rendered plastic by an elevation of temperature.

Objections were made at the Newport meeting to this view of the origin of the structure, one eminent geologist and physicist, Professor Rogers, arguing that these pebbles had not been drawn out, that their original forms as deposited had not been changed, but that their peculiar elongated forms were due entirely to their having been moulded by wave action out of oblong fragments of the original metamorphic rocks.

At subsequent meetings the subject has been more fully discussed, and there yet appears to be considerable difference in opinion among geologists, upon the origin of this peculiar elongated and flattened structure. Other localities have been noticed in Vermont and in Maine, and I now present some fresh evidence from the distant regions of Arizona and California upon this interesting question.

In Arizona Territory, near La Paz upon the Colorado River, there are extensive outcrops of a conglomerate made up of a paste of micaceous schist filled with pebbles of granular quartz, varying in size from an inch, or less, in diameter to masses weighing many pounds.

These pebbles, in general, present phenomena of elongation and compression similar to those of the Newport conglomerate. They give even more conclusive evidence of having been drawn out and compressed.

Elongated forms, with flattened drawn-out ends, blending at times with the mica schist are most common. The pebbles generally separate easily from the matrix and the ground is covered with those that have been detached by weathering, and which are now mingling with the modern alluvial drift. All these pebbles are uniform in texture and appear to have originally been much water-worn and well rounded by attrition. Some of the pebbles show that they have been broken across in several places, in different directions, and that the fragments have been reunited or reconsolidated as strong as before.

I was formerly skeptical in regard to the asserted distortion and plasticity of the Newport pebbles, and favored the explanation that the elongated forms were produced by wave-action, but the examination of the Arizona conglomerate convinces me that not only it, but the Newport conglomerates, and those of many other localities, have been distorted and drawn out and compressed. I am sure that the examination of the outcrops would satisfy even the most skeptical.

But the evidence of distortion of hard rocks on the Pacific Coast does not rest with the Arizona conglomerates only, it is found on a large scale upon the flanks of the Sierra Nevada of California. Those who have ascended the lower slopes of the range in the gold region are familiar with the remarkable outcrops of slates well described by the name of "gravestone slates," given to them by the miners from their resemblance to gravestones. They stand above the earth in long lines, like tall tombstones, and are sometimes ten or fifteen feet high, and are not over three or four feet broad at the base.

These slates vary in composition; some are like roofing slate, others are arenaceous, and some are semi-metamorphosed conglomerates with small pebbles. They are principally of the secondary period.

An examination of these remarkable slates shows that their peculiar form is due to the elongation of the grains which compose them, and consequently of the whole mass. The conglomerates show the elongation with the greatest distinctness. In some outcrops pebbles appear to have been stretched as much as twice or three times their original length or diameter. They are not only drawn out but flattened so as to become long lenticular masses, thus giving a slaty structure to a rock originally made of rounded pebbles. Examples might be multiplied almost indefinitely. Vast masses of rock have been thus acted on, and this drawing out and elongation of mountain masses of rock is more common than has been generally supposed.

All these phenomena indicate that the flexure or folding of rocky strata on a large scale must give rise to great tension upon the outer curve of the bend. Professor Hitchcock supposes the tension by which the rocks were elongated to have been produced in this way in some cases. He remarks also, that the Vermont rocks appear to be stretched in the direction of the dip, while at Newport they are elongated horizontally. Nearly all the examples in California show the elongation to be in the direction of the dip. But I believe the rocks to have been subjected to a much greater elongation than can have been given by any folding. I regard them as having been subjected to direct tension over large areas, and generally in vertical or highly inclined planes. Moreover, these elongated masses do not appear in such positions that we can regard them (at least in most cases) as forming portions of great anticlinal arches. They may form the sides of great synclinal troughs and have been under great tension during subsidence of a mass of formations in the centre of the trough.

It may here be observed that this great elongation of rock masses, and the flattening of all the grains of sand and of pebbles which compose them (an elongation in some cases to twice or three times their original length), has been accomplished at the expense of their thickness. Thus strata so elongated are much thinner than in their unstretched condition. This is a consideration which bears directly upon the discussion of the probable height of anticlinal folds.

With regard to the condition of the quartz pebbles, and of the rocks during the process of elongation, there is room for wide speculation and a variety of hypotheses. Scrope, Beaumont, Scheerer, Hunt and others, maintain that all the deepseated rocks become plastic. We cannot, of course, easily conceive how this distortion of the hard pebbles could have been effected when in their ordinary condition. That rocks are much softer in the bed or quarry than after they have been raised and exposed to the air, is a familiar fact to all miners and quarrymen. This softness of rocks may perhaps be, and probably is, increased by an elevation of temperature. We may legitimately invoke the agency of heat and water to aid us in accounting for these interesting phenomena, but I conceive that it is not necessary for us to believe that these changes of form were effected at very elevated temperatures. There does not appear to have been anything like semifusion or viscidity of the mass, and when I use the term <u>plasticity</u> I do not connect with it the idea of any great softening produced by heat. The consideration of the phenomena leads me rather to the conclusion that enormous and long continued pressure and tension, at a moderate elevation of temperature, perhaps (but not necessarily so), have been sufficient to produce the molecular movement of these hard and apparently unyielding materials. Water permeating the mass, or the vapor of water, may facilitate this movement, but there does not appear to me to have been any condition involving a great chemical change. The evidences of such changes are wanting. Mechanical force alone appears to have been the agent.

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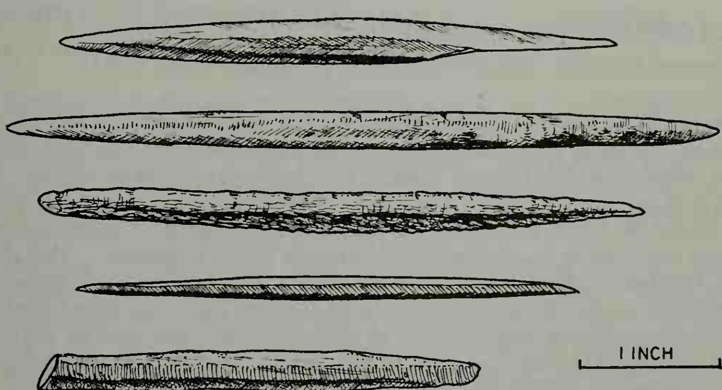
STRETCHED PEBBLES FROM OCOEE CONGLOMERATE

McCallie, S. W.; *Journal of Geology*, 14:55-59, 1906.

The stretched pebbles here described occur in the vicinity of Ellijay, Gilmer County, Georgia, about seventy-five miles north of Atlanta. They are well exposed in a railroad cut on the Louisville & Nashville Railroad a few hundred yards north of the Ellijay station, and are also to be seen at various points both north and south of this place, along the public highway. They seem to be confined chiefly to a narrow belt less than one-half mile wide and about fifteen miles long, lying immediately west and parallel with the Louisville & Nashville Railroad. There are several other points outside of the belt here named where stretched pebbles are occasionally met with, but at no place do they reach such a remarkable stage of elongation. The region in which the conglomerate pebbles occur forms the western margin of the Crystalline rocks of the state. The surface is hilly and rough, but not so mountainous as farther to the east or west. The prevailing rocks of the region are slate, mica-schist, gneiss, marble, and conglomerate, all much folded and contorted. These rocks belong to Safford's Ocoee Series, a group of rocks of great thickness and of unknown age, but apparently older than the Lower Cambrian rocks lying farther to the west.

The beds of stretched pebbles, which at some places are several in number, vary in thickness from eighteen inches to five feet. They are invariably interbedded with mica-schist, and always dip at a steep angle. The beds differ from one another chiefly in the size of the pebbles of which they are formed, and in the extent of elongation of the individual pebbles themselves. In some instances the pebbles have been only slightly flattened or elongated, while in other cases they have been elongated more than twenty times their original diameter. The matrix or binding material, which constitutes only a small percentage of the pebble beds, consists mainly of mica. Where the mica is absent or nearly so, the quartz pebbles are frequently found welded together for the greater part



Stretched quartz pebbles from a Georgia conglomerate.

of their length; however, a slight pressure is usually sufficient to break the bond without injury to the individuals. Each of the several pebble beds examined consists of two kinds of pebbles, namely quartz pebbles and feldspar pebbles. The former are by far the more abundant and are always greatly elongated. The feldspar pebbles, on the other hand, are never elongated, but still retain in a more or less perfect degree their original rounded shape.

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ORIGIN OF RUPTURED EOCENE COBBLES IN THE BEARPAW MOUNTAINS, MONTANA

Pecora, William T.; *Geological Society of America, Bulletin,* 60:1913-1914, 1949.

Abstract. On the western and southern margins of the Bearpaw Mountains in north-central Montana, a conglomerate believed to be an upper member of the Wasatch formation (Eocene) and representing the close of sedimentation in the region is unconformably overlain by volcanic rocks of local origin. Many of the pebbles and cobbles in the conglomerate are fractured, crushed, bruised, gouged, or ruptured, and the displaced fragments are recemented by the matrix sand of the formation. The size, form, composition, and possible source of the material in the conglomerate are described. Various hypotheses to explain the mechanics of the rupturing are critically discussed in conjunction with geological field relations and experimental evidence.

• Shattered Rocks

SPLIT STONES IN THE DESERT

Anonymous; *Popular Science Monthly,* 18:569-570, 1881.

Those parts of the desert of Sahara called the Hamadas---which are also among the most desolate tracts of the region---are strewed with silicious pebbles which are all broken up, presenting sharp edges, as if they had just been split with a hammer. Sometimes fragments of these pebbles could be found lying together with their fractured sides facing each other and fitting perfectly when brought close together. The phenomenon has baffled explanation for a long time. M. J. Brun has recently communicated to the Scientific Society of Geneva his conclusion that it is the result of a curious combination of chemical and mechanical actions. He found by analysis that the sand of the desert was composed of quartz, gypsum, and marl, with traces of salt. The quartz-grains act under the influence of the solar rays as burning-lenses upon the gypsum, and render it anhydrous. The sand and fine anhydrous gypsum-dust are driven about by the winds and cover all the stones; the dust penetrates the little cracks in the stones, when it is wet by the dews, and swells. With continuous accessions of gypsum and repeated heavy dews the accumulation of plaster goes on increasing, the cracks are enlarged, and in time the stone is split.

THE ARABIAN HARRAS

Velikovsky, Immanuel; *Earth in Upheaval,* Dell Publishing Co., New York, 1965.

Twenty-eight fields of burned and broken stones, called harras, are found in Arabia, mostly in the western half of the great desert. Some single fields are one hundred miles in diameter and occupy an area of six or seven thousand square miles, stone lying close to stone, so densely packed that passage through the field is almost impossible. The stones are sharp-edged and scorched black. No volcanic eruption could have cast scorched stones over fields as large as the harras, neither would the stones from volcanoes have been so evenly spread. The absence, in most cases, of lava---the stones lie free---also speaks against a volcanic origin of the stones.

It appears that the blackened and broken stones of the harras are trains of meteorites, scorched in their passage through the atmosphere, that broke during their fall, as bolides do, or on reaching the ground. Billions of stones in a single harra indicate that the trains of meteorites were very large and can be classed as comets. Despite alternate exposure to the thermal action of the hot desert sun and the cool desert night, the sharp edges of the stones have been preserved, which shows that they fell in a not too distant period of time. Following the procedure adopted in this book, literary references to the harras of Arabia in ancient Hebrew and Arabic literatures will not be dealt with here. (p. 96)

AN EXAMPLE OF DISRUPTION OF ROCK BY LIGHTNING.....

Barnett, V. H.; *Journal of Geology,* 16:568-571, 1908.

The accompanying picture (omitted) is a view on the summit of Cross Mesa, one of the Lucite Hills near Rock Springs, Wyoming.

This mesa, like most of the group, is quite barren and flat on top, the volcanic rock of which it is composed being unprotected by soil and vegetation. Like the other Lucite Hills it is a very prominent landmark standing well above the surrounding country.

The angular bowlders seen in the picture have been torn by some apparently violent force from the surface of the lava and some of them still lie in the cavity formed. The space from which the rock fragments are torn is roughly a half-saucer in shape, having the east rim nearly vertical while on the opposite side it is more gently sloping. Two or three cracks, one of which may be observed near the right lower corner of the picture, radiate from the saucer-shaped depression. Whether some of these cracks may not have occurred before the disruption the writer was not able to judge, but it is not likely that all of them did so occur. The rock fragments range in size from an inch or two in diameter up to about two feet and a half, and are sharply angular with fresh surfaces. From the size of the cavity the amount of rock removed is approximately twelve cubic feet and lies within a radius of about ten feet from the fracture and exclusively to the west of it. No fragments were observed to have been thrown very far.

Two hypotheses at once present themselves in explanation of this phenomenon: first, that of an artificial explosion as dynamite or blasting powder; second, that of lightning.

The probabilities of this being due to the first hypothesis seem very slight since it is so far removed from human activities of any kind. The nearest trail is in Long Canon, one mile northwest and four hundred feet lower down. Over this trail there is perhaps not more than one person a week during summer and probably fewer in winter. Several coal prospects have been opened, however, during the last five or six years, in Back Canon and also in Long Canon, not more than five miles to the south, but giant powder only was used in shooting. Had a prospector been so disposed it is the writer's opinion he could not have produced the effect shown in this photograph with ordinary blasting powder. He certainly could not have done it without a drill hole and no evidence of holes were observed. Even with a drill hole it would have been very hard, if not impossible, to have confined the powder sufficiently well. Furthermore, from the very nature of the rock (lava), a prospector would not have been looking for minerals in this place, and if he had been doing it for amusement he almost certainly would have selected a crevice at the limiting cliff of the mesa where the explosion would have loosened a large mass of rock and sent it tumbling down the steep slope which falls away from the escarpment.

The other hypothesis, that of lightning, seems the more probable, and the writer wishes to call attention to it as an example of a kind of phenomenon rather rarely noted in geological literature. A few instances of the disruptive effects of lightning are on record.

Hibbert describes as follows the effect of lightning on the cliffs of micaceous schist on the east side of the island of Fetlar, one of the Shetland Islands.

> A rock 105 feet long, 10 feet broad, and in some places more than 4 feet thick, was, in an instant, torn from its bed, and broken into three large and several lesser fragments. One of these, 26 feet long, 10 feet broad, and 4 feet thick, simply turned over. The second, which was 28 feet long, 17 feet broad, and 5 feet in thickness, was hurled across a high point of a rock to the distance of 50 yards. Another broken mass, about 40 feet long, was thrown still farther but in the same direction, quite into the sea. There were also many lesser fragments scattered up and down.

T. R. Dakyns, in his paper on "Modern Denudation in N. Wales," says:

> During the great thunderstorm that occurred in N. Wales in the middle of August, 1898, a mass of rock was broken and thrown down the Llyn Teyrn. This is known to have been done by lightning, as it was not there until after the storm.

In a conversation with the writer, George Otis Smith has stated that during a thunderstorm in 1904, he observed lightning strike on the summit of Mt. Battie, in the northern portion of the Rockland quadrangle (Maine), and a mass of quartzitic conglomerate several feet in diameter was broken from the glaciated surface and thrown out.

While the most commonly observed effects of lightning on rocks seems to be that of fusion resulting in the production of fulgurites or glassy coatings, no evidence of fulgurites nor of glassy coatings was observed either on these fragments or in the cavity from which they were thrown, but since lightning of the disruptive type is apparently not always accompanied by high temperatures, it does not follow that this phenomenon may not have been caused by lightning.

The most evident effect of lightning is of the disruptive type observed almost every day in the form of splintered telegraph poles and shattered trees and buildings. Lightning, producing this class of results, does not seem always to be accompanied by high temperatures. The writer has observed one instance at least in which a perfectly dry wooden building was shattered without a tendency to firing it.

• Explosive Slickensides

ON EXPLOSIVE SLICKENSIDES

Strahan, Aubrey; *Geological Magazine,* 3:4:400-408, 1887.

During a recent examination of the lead-mines of Derbyshire, I was interested in some accounts of explosions which had taken place, which were not due either to any material used by the workmen or to fire-damp. Though at first inclined to believe that the accounts were exaggerated, I soon found that not only was the evidence of such explosions having constituted a real danger to the men overwhelming, but that accidents are still liable to occur from this cause. The explosions are connected with the structure known as slickenside in the veins. The vein-stuff, consisting generally of galena, calc-spar, heavy spar (sulphate of baryta), and fluor-spar, is divided by the planes of slickenside into more or less vertical sheets or slabs. Such sheets, when bared in the mining operations, fly to fragments with explosive violence on being struck, or even scratched by a miner's pick. The following extracts from old authors, and from communications on the subject that I have received, will serve to illustrate the nature of the explosions and the manner in which the danger was met by the men. The accounts relate chiefly to the mines near Eyam, but explosions occurred also in the Odin Mine near Castleton.

The earliest reference to the subject which I have met with is by Dr. Short:---

"On the North Side of this Mountain [Hucklow Edge, near Eyam].... is a Mine which cannot be wrought; for in picking or striking the Ore, the sudden shaking of the Metal gives such a violent Motion to the Sulphur, that it makes an Explosion like fired Gunpowder, or a Blast in a Rock, so as great Lumps rise up and fly about along with a Kind of Terrae Motus, or Earthquake."

Pilkington, writing fifty years later, remarks that "the crackling and explosions caused by scraping these slickensides with a pick-axe are well known, but hitherto not satisfactorily accounted for. They are said to lose the above property very soon after they are taken out of the mine. In regard to their external appearance, their smooth side greatly resembles black lead very thinly spread over the surface of any smooth body. But the rough side looks very much like to common limestone."

But the most detailed account is furnished by John Whitehurst, and is, I think, of sufficient interest to be reproduced here in full:---

"I purpose giving some account of an extraordinary phenomenon which has frequently happened in Haycliff and Ladywash Mines at Eyam, and in Oden Mine at Castleton: the former are thus circumstanced.

"1. The minerals are contained in the fissures of the limestone, covered by a stratum of shale and grit, which retain their full thickness of sixty fathoms each.

"2. The minerals contained in the above mines are blended together so as to produce the appearance of white Italian marble clouded with black, and are so extremely hard and compact as to require blasting with gunpowder, to separate them from the general mass.

"3. Those in the Ladywash veins are divided in two equal parts parallel to the sides of the fissure. They may be compared to two slabs of marble, whose polished surfaces are absolutely in contact with each other without the least degree of cohesion.

"4. These naturally polished surfaces are not truly flat, but in some degree waved, as if formed by a carpenter's plane, consisting of various members.

"5. The two surfaces are generally coloured with lead ore, thinly laid on, as if only rubbed over with black lead, though sometimes thicker.

"6. The vein in Haycliff Mine contains two of the above seams, and therefore may be compared to three slabs of marble, the middle one polished on both sides and in contact with the other two.

"Thus are the above veins circumstanced. Now what is yet more remarkable is this: if a sharp pointed pick is drawn down the vein with a small degree of force, the minerals begin to crackle, as sulphur excited to become electrical by rubbing; after this in the space of two or three minutes, the solid mass of the minerals explodes with much violence, and the fragments fly out, as if blasted with gunpowder. These effects have frequently happened, by which many workmen have been wounded, but none killed, both in the Eyam Mines, and in that called Oden, at Castleton.

"In the year 1738 a prodigious explosion happened in the mine called Haycliff. The quantity of two hundred barrels of the above minerals were blown out at one blast; each barrel, I presume, contained no less than three or four hundredweight. At the same time a man was blown twelve fathoms perpendicular, and lodged upon a floor, or bunding, as the miners call it, in one of the shafts.

"When the above explosion happened, the barrel, or tub, in which the minerals, etc., are raised to the surface, happened to hang over the engine shaft, which is nearly seven feet in diameter, and 448 yards distant from the forefield, or part, where the explosion happened; this barrel, though of considerable weight, was lifted up in the hook on which it was suspended; and the people on the surface felt the ground shake, as by an earthquake.

"Such are the effects which have frequently been produced in all the above mines; but from what cause they proceed, I have not yet been able to discover, nor even the least traces towards it. The substance having been analized, is found to consist of fluor and the ore of lead, but the cause of explosion still remains equally mysterious, though some attempts have been made to obtain a knowledge of this curious phenomenon.

"These curious observations I received from Mr. Mettam, of Eyam, overseer of the mines, who also addressed the following account of them to Mr. George Tissington, of Winster, principal agent of the works.

"Eyam, 2 July, 1768. Sir,---I send you by the bearer, two specimens of our slickensides, containing all the variety of minerals where the explosions happen; they fly out in such slappits, smooth on one side. The explosions are sometimes heard to the surface, and felt like an earthquake; they frequently blow out all the candles in the mine, and split the stemples into splinters as small as the twigs of a birch besom, to the distance of thirty or forty yards from the forefield; others are broke, and some of them become too short and drop out. The smooth sides lie face to face, and have the appearance of being shot with a plane, consisting of various members. There is generally two of these diversions in our forefield at Haycliff, about eight or ten inches asunder, and a seam of white kebble in the middle of that space, half an inch thick, in which the miners rake down a sharp pointed pick until the crackling ceases; then they run away, knowing that the explosion will follow in a minute or two. Sometimes a noise is heard like the beating of a church clock, after which the greatest explosions happen.---I am, yours, etc., William Mettam.---To Mr. George Tissington, Winster."

John Mawe also writes in 1802 that in the Odin Mine "is found that singular variety of lead ore, called slickenside. This galena presents a smooth surface, as if plated. Sometimes it forms the sides of cavities, and on being pierced with the miner's tool, rends with violence, and explodes with a crackling noise. The cause of this phenomenon has not been fully explained. I have seen a man, when he came out of the mine, only a few minutes after the explosion, who, regardless of the danger, had pierced the sides of this substance, and was much hurt, and cut violently, as if stabbed about the neck and other places with a chisel, whence he was unable to return to the mines for two weeks."

"Sometimes the vein-stuff is found perfectly divided vertically, throughout, and the surfaces polished; and these are called Slickensides or Cracking-whole, which usually are ribbed or slightly fluted, horizontally: the appearances are very similar to those of faults, but extraneous matters do not usually accompany them, the sides being mostly in very close contact; and often, after one side is removed, so as to give room, especially if the surface be pecked or broken, large Slapits, Spels, or fragments fly off, sometimes with loud explosions, and continue so to do for some days or longer, until the gate or passage in such vein is greatly enlarged thereby: this is the case in Gang Mine, in Cromford, where the hard 1st Toadstone also, in the gates and shafts, thus spels off, until they want timbering often, to support the roof and sides. I could not learn, that the Slickensides in the Mines about Eyam explode now, on mere scratching, as they were said to do in the late Mr. Whitehurst's time."

"In Gang Mine, where a Slickenside runs through the Vein, the Miner avails himself of a curious property attending such Veins, by drawing laces, stoops, or nicks, at about six inches apart and four inches deep, with the point of his Pick, from top to bottom of his face of work, when he then leaves for several hours, and on his return, finds all the Vein-stuff so furrowed, spelled, or slappeted off, and laying on the sole ready got to his hands."

"When their edges occur in the face of the vein, on the miner striking his pick into the vein they separate, in some districts without, in others with a slight report; and in some of the mines in the neighbourhood of Eyam, in Derbyshire, with loud reports, particularly in Cracking-hole vein, in Haycliffe title....where in the centre of the vein, termed a shack vein, was a small white impalpable (not effervescing) powder, called a mallion, a quarter of an inch thick, which on being scratched, a loud explosion immediately ensued, before which explosion a singing kind of noise was heard. By setting a blast in the vein at a short distance from the mallion, after the blast was fired, in a few minutes an explosion took place, when a large quantity of the vein fell down. In the year 1790, a loud explosion took place from a slide joint of Slickensides going across, but not into the cheeks of the vein containing the mallion, which caused on its being stirred the loudest explosion and the largest quantity of vein materials to come down.... The last great explosion was in the year 1805. It has sometimes happened that persons have been maimed or even killed by this phenomenon; which, however, has not been noticed from Slickensides where no shale is incumbent."

In writing of the mines on Hucklow Edge, William Wood refers to the Hay Cliff, as "a mine distinguished for having contained in great abundance, that extraordinary phenomenon in the mineral world, provincially called Slickensides.... The effects of this mineral are terrific: a blow with a hammer, a stroke or scratch with a miner's pick is sufficient to blast asunder the massive rocks to which it is found attached....A person named Higginbotham once narrowly escaped with life, by incautiously striking this substance in the above mine. Experienced miners can, however, work where it greatly abounds without much danger. It is also known by the name of Cracking-whole."

The phenomenon is referred to by W. Adam also, who supposes that the slickenside has been produced by the rubbing of the rocks against one another. "The intense heat generated by the motion of such vast masses (expanding the air in its pores) may account for its exploding when broken into, similar to lumps of glass when suddenly cooled, which explode on being scratched or slightly broken."

"To avoid the danger attendant on working in its immediate contiguity, the miners use the precaution of merely making a small incision or aperture, with the point of the pick, and then retire to a place of safety, awaiting the result. In case of an explosion, it generally takes place in ten or fifteen minutes, and by the force attendant on which, considerable masses of ore, and even stuff, are detached."

Sir Charles Lyell, referring to this subject in the 6th edition of his Elements of Geology in 1865, remarked, "these phenomena and their causes (probably connected with electrical action) seem scarcely to have attracted the attention they deserve." In subsequent editions this suggestion of a connection with electrical action was omitted.

Mr. Leonard Maltby, of the Mill Dam Mine, Great Hucklow, informs me that he has had experience of the explosion of slickensides. The explosions take place at the present time in the vein at the Cockersfield Shaft; pieces of mineral burst from the face with a loud noise and with great force, so as to necessitate great care on the part of the men when working. There are also several other places in the Mill Dam Mine where slickensides of an explosive tendency have occurred, as well as in the Silence Mine on the same vein, and in a vein near Eyam, called the Brookhead Vein. At the Lady Wash Mine also, on the eastern range of the vein worked at Mill Dam, the miners noted the same phenomenon. Its prevalence in this neighbourhood leads Mr. Maltby to infer that slickensides will explode more or less, while being cut, wherever they occur. He remarks further that where slickensides occur, the vein is always as hard and fast as it is possible to be, and seems to be under great pressure. "When we work with a pick, cutting one side of the vein, as soon as we have made a little opening, it seems then that the air gets in, and the mineral swells and bursts off with loud noises, and where the vein is hardest and most nipped, the explosions are strongest. It always bursts off just as far as the opening is made." He considers both the slickenside and the explosions to be the result of pressure.

Though some of the veins in which explosions have occurred contain much fluor-spar, yet the phenomenon has been more frequently observed in the hard and tight veins which contain calc-spar, heavy spar (sulphate of baryta) and galena. Fluor-spar, as Mr. Maltby informs me, occurs more commonly in soft veins, such as that at the Dusty Pits, near Eyam, where it was very abundant. In this vein no slickenside was seen and explosions were unknown.

The late Mr. J. A. Phillips, F.R.S., F.G.S., etc., informed me that he had known of several instances of the flying off of fragments of mineral from the slickensided face of a vein, with a sharp report. In one case a fragment was thrown off with sufficient force to break the leg of a man who was passing. The explosions occurred after a portion of the vein had been undercut. Mr. Phillips suggested that the removal of one side of a vein would leave the remaining side in a condition of strain, resembling that of a strung bow, with a tendency to bulge outwards into the workings. The undercutting would free, so to speak, one end of the bow.

Mr. W. Bowman, of Alport, writes that he has seen pieces of limestone in the Ecton Mine fly off with a sharp small crack, some short time after it has been broken by blasting. In one instance, in 1885, two miners were drilling a hole by hand in the Clayton Aditlevel, when a piece of rock burst from the face with a loud report, throwing the men to the ground, and bruising them considerably; the thickness of the fragment was equal to the depth of the drillhole, namely, ten or twelve inches. The toadstone also has been known by Mr. Bowman to break off with a little noise soon after it has been relieved of pressure by excavation. Ecton Mountain is composed of the upper beds of the Carboniferous Limestone, sharply contorted and crushed.

I may refer here also the the description by Mr. W. H. Niles, of the movements of rocks resulting from lateral pressure, and exhibited in quarries. It was found at Monson that the rock has been brought into a compressed condition by a powerful lateral pressure acting in a north and south direction, and that, when opportunity is presented, the compressed rock expands with great energy, often bending, folding, and fracturing the beds, and sometimes producing sudden and violent explosions, and occasionally throwing stones into the air. The expansion became apparent on cutting trenches in the rock in an east and west direction.

At Lemont, Illinois, the bed of rock forming the floor of a quarry was gradually bent up into the form of an anticlinal, trending east and west, and running for about 800 feet with an elevation of six to eight inches. The elevation had taken place in consequence of the removal of the overlying rock, and had been attended by explosive sounds, and sometimes fragments of the rock had been thrown into the air. In the same quarry it was observed that drill-holes bored through two layers of stone became displaced, the upper parts of the holes being no longer vertically over the lower parts. The effects of this force have been noticed at five different localities, ranging over five and a half degrees of longitude.

Mr. Niles refers also to explosions which have sometimes occurred in making railway-tunnels and other excavations, and which could not be accounted for as the results of any artificial power.

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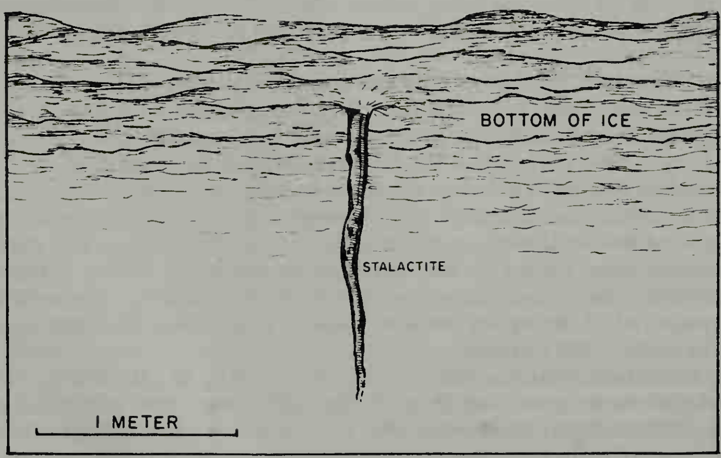
• Curious Stalactites and Stalagmites

A SALTY FINGER IN THE COLD SEA

Anonymous; *New Scientist*, 50:368, 1971.

The Antarctic ocean produces its share of strange phenomena. Pictured here is an ice stalactite of about 1.5 metres length and 10 cm diame-



Salty stalactite growing under Antarctic ice. Length: 1.5 meters.

ter. It was photographed by Paul Dayton, Scripps Institute of Oceanography, California, under ice about two meters thick. He and Seelye Martin, University of Washington, recently reported that these objects, through which brine drains from the ice pack into the water, may have important implications for the poorly understood mechanisms which desalinate sea ice. In some cases the stalactites can drain as much as one litre of brine per minute from the ice (Journal of Geophysical Research, vol 76, p 1595). These protuberances may also give clues to the formation of the Antarctic bottom water. The saline water is dense and thus settles to the bottom.

The Americans observed that the ice fingers can grow at the rate of about two cm/min. Navy divers in the Arctic have subsequently found similar stalactites.

UNUSUAL OCCURRENCE OF STALACTITES AND STALAGMITES

ver Steeg, Karl; *Geological Society of America, Bulletin,* 43:250, 1932.

Abstract. More than 300 stalactites and a number of stalagmites, in all stages of development, are growing under a railroad bridge in the city of Wooster, Ohio. The rain-water which falls upon the bridge, percolates through 4 feet of limestone ballast and a foot of cement before it finds its way through the joints of the steel plates to the street below. The largest stalactite is 12-1/2 inches long and about 1/2 inch in diameter. There are many others more than 6 inches long. During the summer of 1919 the bridge was cleaned and painted. The stalactites are, therefore, not more than 12 years old. On the girders and stone walls, below the bridge, a number of stalagmites have formed. Several of these are more than 2 inches long. Twenty-one of the largest stalactites were measured, after two months of growth (July and August), and found to have increased in length .18 cm. to 1.98 cm. An area was cleared of its stalactites and new ones developed on the sites of the old ones, varying in length from .71 cm. to 1.87 cm., during the same period of time. The writer comes to the conclusion that due to a variety of factors such as concentration of solution, rate of drip, humidity, air movement, etcetera, it is impossible to arrive at any definite rate for the growth of a stalactite or stalagmite. Hence it is impossible to obtain an accurate figure as to the age of a large stalactite or stalagmite in a cave. All one can say is that they are old.

RAPID GROWTH OF DRIPSTONE OBSERVED

Helmick, Larry S.; *Creation Research Society Quarterly,* 14:13-17, 1977.

Introduction. Creationists assume that limestone caverns were formed several thousand years ago, during or immediately following the Genesis flood. The generally accepted phreatic (below the water table) theory of cave formation is in agreement with the Genesis account of a world-wide flood and therefore supports this assumption. Caves may have formed rapidly during the flood (after the major sedimentary deposits had been laid down) or immediately following the flood. As the continents were raised, declining water tables would have drained the caves and produced conditions suitable for growth of dripstone. The present existence of large stalactites and stalagmites would therefore demand recent environmental conditions suitable for rapid formation of dripstone.

Evolutionists, on the other hand, generally assume that dripstone has always formed extremely slowly under the environmental conditons found in caves. Consequently, large stalactites and stalagmites, and the caves containing them, are often considered to be hundreds of thousands to millions of years old.

Data concerning the actual growth rates of stalactites and stalagmites under various environmental conditions should be of interest therefore, to creationists and evolutionists alike.

Since this type of research project was suggested in 1970, several brief articles have appeared in the creationist literature which suggest that stalactite growth can and does occur rapidly. It is the purpose of this communication to discuss the factors which may have affected the rate of stalactite and stalagmite growth since the Genesis flood, and to report actual observations of rapid dripstone deposition.

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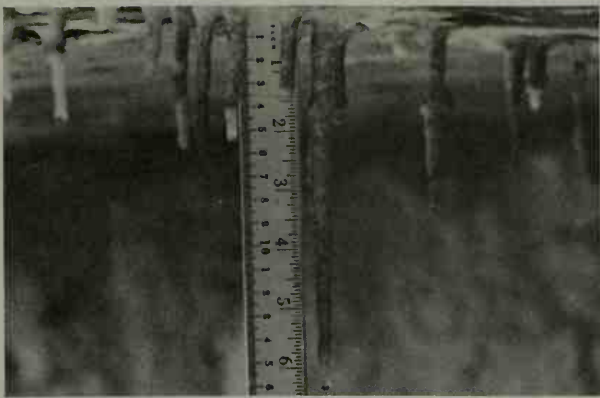
Observations of Rapid Stalactite Growth. In April, 1976, numerous stalactites were observed under concrete bridge Number CLA42-0012 on U.S. 42 approximately five miles east of Cedarville, Ohio. According to construction records, the bridge was built in 1941. Thus, the stalactites measuring up to 150 mm in length and 13 mm in diameter with approximately a 3 mm diameter capillary, have grown in 35 years or less. The minimum average growth rate is therefore 4.3 mm per year.

Since the road surfaces of bridges in this part of Ohio are sealed to reduce penetration and thus erosion by rain water, and since stalactite growth under bridges can only occur during wet weather, this minimum average growth rate is indeed surprising. It is an order of magnitude greater than that reported for stalactites on the spillway ceilings of a dam. Furthermore, the minimum volume of deposition, approximately 0.53 cm^3 per year, is the same order of magnitude as the 0.83 cm^3 per year reported for continuous deposition of calcium carbonate using simulated rain water in a laboratory situation. Finally, it is considerably larger than the average rate of deposition of dripstone of 0.164 cm^3 per year (1 in^3 per hundred years) sometimes mentioned in the geological literature.

The actual growth rates of the stalactites under this bridge may vary considerably during the year, depending upon the temperature, humidity, wind velocity, and rain fall. Between May 22 and October 2, 1976 (19 weeks), the stalactite mentioned above increased in length by 10 mm! Such rapid growth was completely unexpected! Yet, other stalactites under the same bridge appear to have grown even more rapidly though quantitative data are not yet available. Therefore, it must be emphasized that the minimum average growth rate of 4.3 mm per year is indeed a minimum. Actual rates of growth may easily be as much as an order of magnitude greater than this minimum under ordinary environmental conditions.

On September 23, 1976, several white circular calcium carbonate deposits 4 to 5 cm in diameter were also observed on the bare ground under the bridge. They had not been noticed in the spring, and therefore, must



Rapidly growing dripstone under an Ohio bridge. (Larry S. Helmick)

have formed during the summer months. They were located directly under growing stalactites where water dripped from the bridge to the ground, and thus appeared to be premature stalagmite deposits. Therefore, stalagmites might be expected to form very rapidly at these locations. Absence of stalagmites several centimeters in length is undoubtedly due to annual erosion and redeposition of soil under the bridge when the creek rises during the wet spring weather.

Finally, deposition of flowstone (a deposit formed by flowing rather than dripping water) has been reported to be even slower than deposition of dripstone. Yet flowstone deposits up to approximately 1 cm thick on the concrete supporting walls of this bridge attest to the reality of relatively rapid flowstone deposition as well.

Such rapid rates of deposition of calcium carbonate are not limited to this particular bridge or location. Since April, 1976, stalactites have been observed under two other concrete bridges in this same area as well as under a bridge in Grand Rapids, Michigan. They have also been mentioned in the creationist literature by others. Thus, minimum average growth rates measured in millimeters per year for stalactites under concrete bridges appear to be relatively common.

However, environmental conditions under bridges are considerably different from those in caves. Thus, it could readily be argued that these growth rates do not apply to stalactites in caves. Conditions in mines, however, might be expected more closely to resemble those found in caves. But a study of stalactite and stalagmite growth conducted at the Experimental Mine of the United States Bureau of Mines near Bruceton, Pennsylvania, revealed even larger growth rates. Growth rates of stalactites on the concrete roof of the mine range from 12 mm per year to 173 mm per year. These are from 3 to 40 times the minimum average growth rate observed under the concrete bridge! Obviously the environmental conditions in this mine are even more, rather than less, conducive to rapid stalactite growth than those under the bridge.

Finally, an effort was made to obtain evidence of rapid deposition of calcium carbonate under authentic cavern conditions. A survey of the Olentangy Indian Caverns, just off U.S. 23, north of Columbus, Ohio, revealed that the electrical wiring is encrusted with 1 to 2 mm of flowstone in several locations, and in one instance at least, is actually cemented to the wall of the cave by the deposits. Much of the original wiring, installed in 1935, has been replaced in more recent years. Since maintenance records concerning the wiring have not been kept, the exact age of the encrusted wiring is uncertain, but it cannot be more than 41 years old. Obviously, deposition of calcium carbonate can occur at measurable rates even under the environmental conditions found in caves today.

Furthermore, the large stalagmite known as Crystal Spring Dome in Carlsbad Caverns has been reported to be growing as fast as 2.5 in^3 (41.0 cm^3) per year"...in spite of the present dry New Mexico desert above!" At this rate, a 10,000 in^3 stalagmite which would require 1 million years for formation at an average deposition rate of 1 in^3 per hundred years could actually be formed in only 4000 years! Whey the possibility of even greater growth rates in the recent history of the Earth are considered, it becomes apparent that even the largest known dripstone formations could have formed in only a few thousand years. Therefore, it is clearly unnecessary to postulate that large stalactites and stalagmites have required hundreds of thousands of years for their formation.

Conclusions. Dripstone growth rates in caves are directly proportional to the concentration of calcium bicarbonate in vadose water. The concentration of calcium bicarbonate is dependent on the concentration of dissolved carbon dioxide, the solubility of the limestone through which the solution passes, and the contact time between the solution and the limestone. Thus, increased amounts of carbon dioxide in the soil, existence of the limestone strata in a more soluble state, and longer contact time between the solution and the limestone immediately following the Genesis flood would have provided ideal conditions for rapid dripstone growth in caves.

Rapid calcium carbonate deposition has actually been observed under concrete bridges as well as in a cave in the Midwest. Furthermore, rapid growth rates for stalactites on the concrete ceiling of a mine and for stalagmites under actual cavern conditions are known. Therefore, it is concluded that dripstone formations do not always grow slowly. Under appropriate conditions, they may form very rapidly, even in caves. Consequently, it is not necessary to accept the evolutionary postulate that caves have existed for long periods of time in order to allow for the slow growth of stalactites and stalagmites. Instead, the creationist theory involving recent cave origin and rapid dripstone growth is a viable alternative which is in agreement with experimental data concerning dripstone growth rates.

ROCKS THAT MOVE

In the fullness of geological time all rocks move. Tectonic forces raise mountains and squeeze up anticlines. The focus in this section, however, is on individual rocks or small groups of rocks that are urged along by subtle and unexpected forces, resulting in motions and rock accumulations that range from curious to impressive.

Rock streams or glaciers are ponderous festoons of boulders that closely emulate ice glaciers. They move little or not at all today under the influence of gravity. Located primarily in mountainous regions, rock rivers were once quarried from bedrock, collected into streams, and sent flowing down slopes. That ice was the major architect here is the opinion of most geologists. Anomalies do appear though where a few rock streams decorate unglaciated regions and where the terrain is seemingly too flat for rock rivers to flow even with the help of ice.

Ice is also credited with gradually propelling stones shoreward in shallow lakes. (See "walled lakes") The motive force in this instance is not gravity but the expansion of ice.

The freeze-thaw ratchetting action of ice commonly exposes rocks in northern fields, much to the disgust of farmers. But pressures in subterranean water, oil, and natural gas may also be responsible for some cases of "erupting rocks."

Wind would not seem powerful enough to push rocks weighing hundreds of pounds hundreds of feet across level ground, but this is apparently just what happens on several playas in the western United States.

Of course, earthquakes, volcanoes, and the sea toss rocks around with great vigor, but these phenomena are overt and so well recognized that they are omitted.

• Rock Rivers

ON THE ORIGIN OF THE STONE-RIVERS OF THE FALKLAND ISLANDS

Davison, Charles; *Geological Magazine,* 3:6:390-393, 1889.

The stone-rivers of the Falkland Islands have been described by Mr. Darwin, Sir Wyville Thomson, Dr. Coppinger, and other naturalists who have visited those regions. The accounts given by the two first-named are well-known and easily accessible, and render a full description here unnecessary. But it may not be out of place to summarise the principal features of the stone-rivers, which must find an explanation in any satisfactory theory of their origin.

They consist of angular blocks of quartzite, "arranged," according to Pernety, "as if they had been accumulated carelessly to fill the ravines." The blocks are from two to twenty feet long, and rest "irregularly one upon the other, supported in all positions by the angles and edges of those beneath" (Thomson). At the same time, "they are not thrown together into irregular piles, but are spread out into level sheets or great streams" (Darwin), the surface of one visited by Dr. Coppinger being "tolerably flat," and not indicating "a process of accumulation by flow from either side." The streams vary in width from a few hundred feet to a mile or more. Their depth is unknown, but, according to Darwin, is probably great: though "far down below, under the stones," says Sir Wyville Thomson, "one can hear the stream of water gurgling which copies the axis of the valley; and here and there, where a space between the blocks is unusually large and clear, a quivering reflection is sent back from a stray sunbeam." The inclination of the surface of the stone-rivers is very small, and this is their most remarkable feature. "On the hillsides," says Darwin, "I have seen them sloping at an angle of ten degrees with the horizon, but in some of the level, broad-bottomed valleys, the inclination is only just sufficient to be clearly perceived." The actual movement of the blocks does not seem to have been noticed. "As far as I can ascertain," Dr. Coppinger remarks, "no attempt has ever been made to estimate the rate of movement (if any) of these 'runs,' and there is no evidence whatever of their motion during the present century."

The origin of the blocks themselves has been clearly pointed out to Sir Wyville Thomson. "The beds of quartzite are of very different hardness: some are soft, passing into a crumbling sandstone; while others are so hard as to yield but little to ordinary weathering." Being worn away unequally, the harder bands project, and at last the joint-formed blocks fall over. The difficulty, however, is to account for their present position and management, and, for this purpose, the following theories have been proposed:---

1. The action of earthquakes, hurling the blocks down the slopes, and then levelling them out into continuous sheets (C. Darwin, A. J. Pernety).

2. The movement of the soilcap enclosing the stones, the soil being afterwards washed away by the streamlets in the valleys (Sir C. Wyv. Thomson).

3. The former movement of "earth-glaciers," which, owing to a change of climate, became desiccated, the earth being afterwards washed away by rain and streams (J. Geikie).

4. The action of frost and snow, the alternate freezing and thawing of rain (Sir J. D. Hooker).

5. The action of glaciers. "I believe it will not be difficult to explain their origin in the light of the glacial theory, and I fancy they may turn out to be ground moraines similar to the 'horsebacks' of Maine" (J. R. L. Agassiz).

6. The alternate expansion and contraction of the blocks under changes of temperature taking place mainly down the slopes, being assisted by gravity in that direction (C. Davison).

It is not my purpose to discuss these suggestions here; but I may remark that, according to Thomson, "ice had no hand whatever in the production of these grand 'moraines' of the Falkland Islands." The second theory has been criticised adversely by Prof. J. Geikie and Dr. Coppinger with, I believe, conclusive force. With regard to the sixth, though slight movements of this nature must undoubtedly be taking place, they must in this case be unusually small, for the climate of the Falkland Islands is dull and the sky almost continually overcast.

Now, in all of the above-mentioned theories, the transport of the quartzite blocks over considerable distances is taken for granted, and the object of the theories is really to account for this transport over a rough and irregular surface, inclined generally at a very small angle to the horizon. But is it not possible that this assumption is unnecessary; that the blocks, though they have doubtless undergone some movement, still remain in the immediate neighbourhood of the places they occupied before the valleys were formed; that the stone-rivers are, in fact, but an extreme case of the inability of a stream to remove the debris in its course?

On the summits of many of our mountains, we have a phenomenon not unlike the stone-rivers in appearance, and perhaps similar to them in origin. The so-called "blocky structure," so conspicuous, for example, on Scawfell Pike, occurs in many, if not in most, cases where alternate bands of hard and soft rock crop out at the summit. The softer layers, being more easily weathered, are gradually removed by wind and rain; and, in course of time, the joint-formed blocks of the harder projecting bands fall over in various directions, giving rise to that confused, tumultuous appearance, which seems at first sight to suggest the action of an overwhelming force. The blocks remain almost as they fall, for the forces in action on the mountain-summits are insufficient to displace them greatly.

Now, in the Falkland Islands, we have, as we have seen, somewhat similar conditions; bands of hard quartzite separated by seams of soft and crumbling sandstone. When streams began to flow over the primitive surface of the country, they bore away, I imagine, the loosened debris of the softer bands, but the resulting blocks of quartzite were too heavy to be moved by them and hard enough to resist atmospheric disintegration. The streams then flowed between and below the blocks, and continued to remove the softer bands beneath, working their way from side to side of the valleys. The quartzite blocks thus gradually subsided vertically all over the valleys, most along the axis and in the lower regions, least at the sides and in the upper parts, forming on the whole a gently sloping surface, but rough and irregular in its details owing to the different sizes of the blocks and the various directions of their fall. The surface of the stone-rivers might thus be continuous with the slopes of the surrounding country; there would not necessarily, although there might, be bounding cliffs. In the "blocky structure" of mountain-summits, a limit in depth must soon be reached, beyond which wind and frost and rain can have but little effect in weathering and removing the softer rock. But, in the stone-rivers of the Falklands, the process may be carried very much further: as long as streams are able to find their way among the blocks and can remove the sand between them.

This theory seems to me to account satisfactorily for the features of the stone-rivers, so far as they are given in the published narratives. It accounts also for another fact which is not referred to in the theories mentioned above, namely, the proportion of the volume of the quartzite blocks to the volume of the rock that must originally have occupied the valleys. From the slight slope of the surface, and the certainly not small depth, of the stone-rivers, we must infer that this proportion is not inconsiderable. If the formation of the stone-rivers, then, began some time after the commencement of denudation in the islands, not only must the quartzite blocks resulting from previous erosion in some way have been removed, but the valleys must also have greatly increased in width in order to provide the material for the stone-rivers: a large amount of the softer rock must have been carried away: and, therefore, in part, at least, a cause like that suggested in this paper must have been in action. But if we suppose that the formation of the stone-rivers has all along taken place concurrently with the excavation of the valleys, we can, I think, account for the origin of the former without having to call in the aid of any non-existing agencies to explain the transport of the blocks.

ROCK STREAMS IN THE SIERRA NEVADA, CALIFORNIA

Kesseli, John E.; *Geographical Review,* 31:203-227, 1941.

The terms "rock stream" and "rock glacier" have been applied to voluminous tongue-shaped accumulations of rubble and blocks encountered in the mountains of Colorado, Wyoming, and Alaska and in the Alps. Their scattered occurrence in regions so widely separated suggests a much greater frequency than the published accounts indicate. The presence of rock streams in the Sierra Nevada substantiates this conclusion.

The wrinkled surface of the rock streams has challenged the imagination of geomorphologists, who have compared them to lava flows, mudflows, and glaciers. Similarly varied are the interpretations of their origin. They have been explained as glacial moraines, as deposits of landslides of the rockfall type, as landslide material transported a short distance by small glaciers, as the result of creep of landslide deposits, as creeping talus, and as a special form of denudation associated with dying glaciers, and smaller rock streams have also been interpreted as accumulations of talus at the foot of temporary snowbanks. The variety of single interpretations has invited compromise in the form of compound explanations. Sliding of talus over snowbanks, creeping, slumping, and sliding of the regolithic mass, and incipient glacial motion have been combined in one explanation; in another retreat of glaciers has been added to this group of processes; a third calls upon the combination of the dying of glaciers, landslides, and the common formation of talus for the accumulation of regolithic debris from which creep, the main formative force, is assumed to mold the rock streams; a fourth interpretation credits dying glaciation and creep of talus. The testimony of the rock streams of the Sierra Nevada supports only one of these interpretations: rock streams are glacial features.

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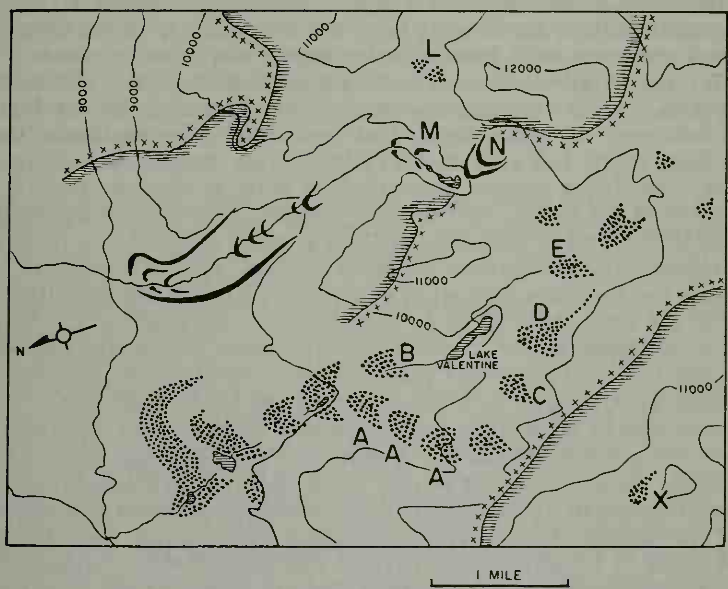
The rock streams of the Sierra Nevada are tongue-shaped accumulations of rubble and blocks. In composition and texture they resemble the numerous talus cones near by. The rubble and blocks of the rock streams can thus be expected to have originated in the same manner as the similar material deposited in the talus cones, namely through common weathering of the neighboring cliffs. The form assumed after deposition, a tongue shape in the case of rock streams, a cone shape in that of talus, is the only difference between the two deposits. Steep lateral and terminal slopes bound the rock streams, slopes which are of a steepness similar to that of talus slopes. Commonly the surface of the streams displays numerous bulges parallel to the edges, frequently forming fairly continuous ridges. They are particularly evident in the lower part of the streams. Occasionally these ridges can be followed laterally into indubitable nivation ridges, that is to say, ridges of blocks that run parallel to, and at a short distance from, the foot of straight cliffs, unbroken by reentrants.

The size of the rock streams varies: some measure less than 200 feet in length, others half a mile; composite streams, evidently the result of superposition of a series of rock streams, may reach a length of more than a mile. The longest of the composite rock streams was encountered in the valley of Sherwin Creek. Heading in a tributary valley and encumbering the lower part of the main valley with its blocks, it measures more than two miles in length. The most frequent length of single streams was about a quarter of a mile.



Distribution of rock streams and moraines in the valleys of Sherwin and Laurel Creeks in the Sierra Nevada.

The thickness of the rock streams also varies: some apparently measure no more than 20 or 30 feet in thickness; others display terminal slopes one to two hundred feet high, a height suggesting a comparable thickness of the blocky deposit. Common to all streams is an increase in thickness toward the lower end. There is no relation between length and thickness of individual streams. There is also no relation between the volume of a stream and the distance the rubble and blocks traveled from the cliffs on which they originated to their present resting place.

The lithologic character and the size of the blocks composing the rock streams also bear no relation to the volume of the deposit.

The surface of the rock streams was never found to be convex upward in transverse cross section. Occasionally a stream may appear to be slightly convex upward if seen from above; but a view from a better vantage point will reveal that the surface is in reality slightly concave upward. The surface of most rock streams is clearly concave, and the lower end frequently assumes the shape of a shallow basin. The lower end of a rock stream two miles south of Mammoth Lakes Post Office contains a very steep-sided depression, more than 40 feet deep, fashioned out of blocks 6 to 12 feet long without a sizable admixture of rubble or sand.

A few rock streams in the area obviously have resulted from a juxtaposition and superposition of individual block ridges. In these streams the ridges clearly are primary features that antedate the completion of the regolithic accumulation. They cannot be interpreted as features that developed through a movement originating within the mass of the stream. In turn this raises doubt whether ridges on more voluminous streams can be assumed to reflect any former or present-day creep of the deposits.

All rock streams start from a valley head, or cirque, or from a recess in a cliff. The smaller streams occupy well shaded nooks. Northern, northeastern, and eastern exposures are most favorable for the formation of these features. In valley heads that open toward the northwest the rock streams keep to the left side of the valley, to the foot of the cliff facing northeast. The block tongues nevertheless point northwest, that is, in the direction of the valley, and thereby suggest a movement that took place nearly parallel to the cliffs and not at right angles away from them. Very commonly the voluminous deposits of these rock streams are solely responsible for the transformation of former valley heads into cirques.

Most of the rock streams were found close to the crest of the Sierra Nevada, at altitudes above 10,000 feet. The most noteworthy exceptions occur in the valley of Sherwin Creek and some small slope valleys adjoining it on the west, where rock streams descend below 9000 feet.

Superposition of rock streams of different sizes is very common. Two main patterns are recognizable. A series of streams may head in the same cirque, an arrangement which, aside from differences in age, suggests modification in process or in duration of the process responsible for their formation. Or a series of smaller streams may head in recesses in the cliffs of a cirque which earlier was the source for a larger rock stream, a relationship which suggests that the older stream may represent the junction of smaller streams.

The rock streams are composed of material of all sizes, ranging from sand to blocks 15 or 20 feet in length. In streams composed of debris derived from metamorphosed sediments and metavolcanics the size is usually not extreme: the blocks most commonly measure about two feet, and rubble and sand are present in rather large proportions and may completely fill the spaces between the blocks. In streams derived from grinitic rock (granodiorite or quartz-monzonite) the blocks commonly measure 10, 15, or 20 feet. The spaces between these blocks are filled with rubble and very coarse sand only in the basal third or half of the accumulation; the surface portion is a simple jumble of huge blocks.

Rock streams are most numerous on crests carved from granitic rocks, occur fairly frequently on crests composed of metavolcanics, but are definitely less common on crests in which metamorphosed sediments are exposed. The streams are found to have advanced the farthest away from their cirques in areas of granitic rock, in spite of the extremely large size of their blocks and the paucity of finer material. A comparison of the rock streams in the valleys of Sherwin and Laurel Creeks reveals the influence of lithology on their number and length. The valley of Sherwin Creek, carved from granodiorite, abounds in rock streams, some of which have advanced beyond the mouth of the valley. Some of the blocks must have covered a distance of more than four miles before reaching their present resting place. In the valley of Laurel Creek, eroded in metamorphic sediments, the rock streams are small and few in number and are restricted to the uppermost reaches of the valley. This influence of lithology results from a marked difference in jointing. Pronounced but widely spaced joints in the granodiorite of Sherwin Creek favor a ready disintegration into large blocks. Further disintegration, lacking assistance by more closely spaced joints, has to proceed through disintegration of the mineral fabric, a process that reduces the size of the blocks only very slowly. A close jointing in the metasediments of Laurel Creek permits disintegration into much smaller blocks with a rather large proportion of rubble and sand and favors also rapid further reduction in size. The prevalence of rock streams in the valley of Sherwin Creek is thus in direct relation to the slow rate of comminution of the granodiorite through the common processes of weathering.

....

Conclusions. The evidence gathered in the study of the rock streams of the Sierra Nevada, as well as logical considerations, supports only one of the many explanations advanced to account for their formation: rock streams are glacial features.

A glacial origin explains all the particularities of rock streams. They are restricted to glaciated or formerly glaciated mountains. The preference for northern and eastern exposures and the heading in cirques or in recesses of cliffs show a relation to the best conditions for accumulation of ice and snow. The difference in length of streams that headed in the same cirque is an indication of the varied conditions of glaciation, that is, the variations in the position of the snow line. The joining of rock streams is an indication that the glaciers which deposited them also joined. The orientation of the larger streams in conformity with the trend of the valleys they occupy, the frequently encountered basin shape of the lower part of the tongue, and the equally frequent occurrence of marked lateral ridges are also well in harmony with a glacial origin. The prevalent location of rock streams close to the foot of cliffs shows that they develop best when the amount of debris is large in comparison with the volume of the body of ice. In turn this serves to explain the great thickness many of these streams attained. The volume of ice was sufficient to transport the material a short distance from the cliffs but was too small to mold the mass of debris into the form of a true glacial basin held by voluminous lateral moraines. The debris was thus spread more evenly over the limited area of deposition, a process that accounts for the voluminous appearance of many streams.

The ridges and wrinkles of the surface of the rock streams must be regarded as an expression of former motion. Pronounced ridges and slopes that clearly separate different superposed parts of the blocky deposits can only be understood to have resulted from variations in size of the bodies of ice that originated the rock streams. The lower and shorter ridges that are in the main subparallel to the edges of the streams may well have resulted from a deformation of the deposit under the weight of the ice that passed over it.

Rock streams are thus relict features. Their present motion, where established, either is due to a remaining core of ice or is secondary, a tendency to creeping acquired after their deposition. This creep, which is possible, however, only where fine material forms a large proportion of the stream, did not originate these large tongues of waste.

Most of the rock streams are of relatively recent origin. Some were deposited during a glacial advance of the end of the last century. Under lithologic conditions favoring a disintegration of bedrock into large blocks, even moraines of the early-Wisconsin stage of glaciation may assume the character of rock streams.

CATASTROPHIC DEBRIS STREAMS (STURZSTROMS) GENERATED BY ROCKFALLS

Hsu, Kenneth, J.; *Geological Society of America, Bulletin*, 86:129-140, 1975.

Abstract. Large rockfalls commonly generate fast-moving streams of debris that have been called "sturzstroms." The geometry of sturzstrom deposits is similar to that of mudflows, lava flows, and glaciers. Sturzstroms can move along a flat course for unexpectedly large distances and may surge upward by the power of their momentum. A currently popular hypothesis to account for their excessive distance of transport suggests that sturzstroms slide on air cushions. Contrary to that hypothesis, evidence is herein presented to support Heim's contention that sturzstroms indeed flow.

The flow of a sturzstrom can be compared to flow of a mass of concentrated cohesionless grains in a fluid medium. Frictional resistance to such grain flow is, according to Bagnold, less than that for sliding of rigid bodies because of the buoyancy of an interstitial fluid which serves to reduce the effective normal pressure of the entrained grains. The presence of sturzstrom deposits on the Moon indicates that the interstitial fluid is not necessarily a compressed gas or a wet mud. The dispersion of fine debris and pulverized rock dust among the colliding blocks may have provided an uplifting stress during the motion of some terrestrial and lunar sturzstroms.

Scale models to provide kinematic simulation of sturzstroms may have practical application. Preliminary results suggest that a bentonite suspension of a certain consistency is a suitable material for scale models and that the flow of thixotropic liquids is kinematically similar to sturzstroms. The parameter "excessive travel distance" is introduced to replace the expression "equivalent coefficient of friction" as a measure of mobility of sturzstroms. There is, on the whole, a positive semilog correlation of the excessive travel distance to the size of the fallen mass. Exceptions to the rule include on the one extreme the unusual mobile Huascaran rockfall which gave rise to a sturzstrom with a dense interstitial mud and, on the other extreme, the least mobile Vaiont rockslide which remained a sliding block and failed altogether to generate a sturzstrom.

Introduction. Large masses of rocks crashing down a steep slope commonly generate a stream of broken debris, which often moves at fantastic speeds over very gentle slopes for unexpectedly long distances. The famous Elm rockfall of Switzerland, 1881, produced such a debris stream; it buried a village and killed 115 persons. Albert Heim stated shortly after the catastrophe that he had never known of such an example. However, he later realized that catastrophic debris streams had been seen before, notably by Ebel in 1749 after the rockfall of the Diablerets and by Meyer in 1807 at Goldau.

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The Phenomenon of Sturzstroms. The sturzstrom generated by the Elm rockfall is probably the example that has been the object of the most study. The Elm event has been characterized by Heim as a drama of three acts: the fall, the jump, and the surge.

A vivid account of the fall phase was given by an eyewitness of the Elm rockfall: "When the falling rock began to slide, the forest moved like a herd of galloping sheep, and the pine swirled in confusion; then the whole mass suddenly sank."

This description suggests that the rockfall ceased to behave as a rigid body in the very initial stage of movement. The fallen block started to disintegrate, yet the broken parts moved in unison like a herd of galloping sheep. The statement that the whole mass sank is not exactly accurate, for one-eighth of the fallen mass broke off from the main block and never did make it to the bottom of the slope. This uppermost part of the original block moved a short distance from the rim of the slide and then got stuck in the seat of the breakaway scar. Those were the black sheep who deserted the galloping herd and remain up there even today, despite the canons of the Swiss Army, which have been fired in vain in a futile campaign to dislodge that hanging mass.

In the second stage at Elm, the fallen mass hit the flat floor of a slate quarry and became completely disintegrated. The debris was deflected and shot horizontally forward, as a witness described.

> Then I saw the rockmass jump away from the ledge. The lower part of the block was squeezed by the pressure of the rapidly falling upper part, became disintegrated and burst forth into the air. ...The debris mass shot with unbelievable speed northward toward the hamlet of Untertal and over and above the creek, for I could see the alder forest by the creek under the stream of shooting debris.

Heim compared this jumping phenomenon to the spraying of a waterfall striking a rock ledge. The undersurface of the rockfall was sharply defined, as is that of a waterfall, and the witness could see houses, trees, and fleeing people and cattle under the moving debris. The upper surface, on the other hand, was a cloud of stones and dust, like the black smoke issuing from a stream locomotive. While the main mass flowed northward, a layer of broken debris was left behind; it buried Untertal. The flowage of the debris can be said to begin in this second phase, for a waterfall is not a slide, but a very rapid flow.

Once the sturzstrom reached the bottom of the slope, a branch was sent directly north and surged up the side of the valley to a height of 100 m. The main surge, however, went down the Sernf Valley and had to turn 60^{o} toward the northwest. The tip of the surzstrom moved another

1.5 km along a nearly horizontal valley floor. Its motion was colorfully described by a survivor, who was only one jump ahead of the speeding debris:

> The debris mass did not jump, did not skip, and did not fly in the air, but was pushed rapidly along the bottom like a torrential flood. The flow was a little higher at the front than in the rear, having a round and bulgy head, and the mass moved in a wave motion. All the debris within the stream rolled confusedly as if it were boiling, and the whole mass reminded me of a boiling cornstew. The smoke and rumble was terrifying. I turned and ran, and a single jump saved me. When the sturzstrom drove past me like a speeding train, its outer edge was only a meter away. During my last jump, small stones were whirling around my legs, being stirred up by the wind. Otherwise I was not hurt by any fallen stones, nor did I feel any particularly strong air pressure.

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A STREAM OF ALLUVIUM

Conway, Martin; *Nature,* 59:390, 1899.

In a private letter, Captain Roberts, Medical Officer at Gilgit, sends me the following information, which may interest some of your readers. He says that near Owir, which is near Drasan in the Turikho valley of Chitral, there is a curious object which he describes as a "glacier of alluvium." It fills the bed of a nullah which comes down from a ridge of Tirich Mir, and is free of snow. It appears to consist entirely of a moving mass of earth, &c. The top of the nullah is at about 12,000 feet and the foot of it at about 5000 feet above sealevel, and it is about five miles long. There is neither ice nor snow above or within this moving mass. It has an undulating, broken surface, and looks like a moraine-covered glacier, except that grass grows upon it in places, and even a few cultivation-terraces have been made upon it by the neighbouring villagers. Its breadth is about 200 yards. There is a stream in a depression on each flank of it, between it and the hillside. The villagers state that it is no new phenomenon. They say that it is always on the move. There are some trees upon it, and by the change in their position, as reported by the natives, it is concluded that the rate of movement is about 200 yards a year. The thing, therefore, is not any sort of mud avalanche. As above stated, parts of the surface are cultivated; but the natives have given up attempting to build houses upon it, because they always tumble down. Captain Roberts is attempting to get a photograph taken of this curious locality.

• Rocks Emerging from Lakes

THE WALLED LAKES OF IOWA

Anonymous; *Scientific American*, 50:246, 1884.

The questions whether the so-called "walled lakes of Iowa" are the work of some extinct race or are natural formations, have periodically appeared for discussion. In his "Geology of Iowa," Prof. Charles A. White presents as a theory that in the shallow portions of the lakes the ice along the shores freezes fast to everything upon the bottom, whether sand, gravel, bowlders, or mud, and the expansive power of the water in freezing is exerted upon them, acting from the center of the lake in all directions toward its circumference. By this means whatever substances are frozen into the ice are pushed up upon the shores as far as the expansive force is exerted, and there left as the ice melts in the spring. By this means embankments have been formed, varying from 2 to 10 feet in width and from 5 to 20 or 30 feet across. The ice, during long ages, has brought these materials together in this manner, having in some instances moved large bowlders and piled them up with other materials.

In corroboration of this, a writer in the Sun states that he has "seen the ice piled up on the shores of Walled Lake, in Wright County, pushed up along these embankments, and containing earthy materials of which the walls are made. Occasionally these walls were found along the old margin of some dried-up prairie slough, proving the existence of an open shallow lake in some time past."

TRAVELLING ROCKS

Anonymous; *Scientific American*, 41:88, 1879.

Lord Dunraven, in an interesting article in the Nineteenth Century about Canada, and his experiences in moose hunting, relates the following:

A strange scene, which came within my observation last year, says his Lordship, completely puzzled me at the time, and has done so ever since. I was in Nova Scotia in the fall, when one day my Indian told me that in a lake close by all the rocks were moving out of the water---a circumstance which I thought not a little strange. However, I went to look at the unheard-of spectacle, and, sure enough, there were the rocks apparently all moving out of the water on to dry land. The lake is of considerable extent, but shallow and full of great masses of rock. Many of these masses appear to have traveled right out of the lake, and are now high and dry some fifteen yards above the margin of the water. They have plowed deep and regularly defined channels for themselves. You may see them of all sizes, from blocks of, say, roughly speaking, six or eight feet in diameter, down to stones which a man could lift. Moreover, you find them in various stages of progress, some a hundred yards or more from shore and apparently just beginning to move; others, half-way to their destination, and others again, as I have said, high and dry above the water. In all cases there is a distinct groove or furrow, which the rock has clearly plowed for itself. I noticed one particularly good specimen, an enormous block which lay some yards above high-water mark. The earth and stones were heaped up in front of it to a height of three or four feet. There was a deep furrow, the exact breadth of the block, leading down directly from it into the lake, and extending till it was hidden from my sight by the depth of the water. Loose stones and pebbles were piled up on each side of this groove in a regular, clearly defined line. I thought at first that from some cause or other the smaller stones, pebbles, and sand had been dragged down from above, and consequently had piled themselves up in front of all the large rocks too heavy to be removed, and had left a vacant space or furrow behind the rocks. But if that had been the case the drift of moving material would of course have joined together again in the space of a few yards behind the fixed rocks. On the contrary, these grooves or furrows remained the same width throughout their entire length, and, have, I think, undoubtedly been caused by the rock forcing its way up through the loose shingle and stones which compose the bed of the lake. What power has set these rocks in motion it is difficult to decide. The action of ice is the only thing that might explain it; but how ice could exert itself in that special manner, and why, if ice is the cause of it, it does not manifest that tendency in every portion of the world, I do not pretend to comprehend.

My attention having been once directed to this, I noticed it in various other lakes. Unfortunately my Indian only mentioned it to me a day or two before I left the woods. I had not time, therefore, to make any investigation into the subject. Possibly some of my readers may be able to account for this, to me, extraordinary phenomenon.

[Any one familiar with ice action in our northern lakes and rivers, will have no great difficulty in accounting for the rock movement described. It takes place in various ways, depending on the depth of water, the breadth of the pond or river, the force of the wind and waves, variations in water level, and other conditions. Just which of these causes, alone or combined, operated in Lord Dunraven's Nova Scotia lake it is impossible to say from the description he gives. Probably the last named, and the wedging of the ice-masses against the larger rocks, when rising and falling with the water, had most to do in moving the bowlders on shore. ---Ed.

TRAVELLING ROCKS

A., J. W.; *Scientific American*, 41:292, 1879.

In the August number of the Scientific American, page 88, you have an interesting article from the pen of the Earl of Dunraven on "Traveling Rocks," which you very justly attribute to the action of ice in the lakes.

I have watched this phenomenon for several years past, and believe I have found its true cause in the expansion of the ice during the winter, which is particularly noticeable in lakes that are shallow near the shore.

In one large lake in Queens county, called Maleegeuk in Indian, but misrepresented "Maleege," these traveling rocks may be seen in different stages of progression.

This lake is shallow on one of its shores, and covered with loose bowlders of all sizes. Ice forms to the depth of two or three feet, embracing in its firm grasp all the loose rocks lying in the shallow water. During the winter the ice in the lake expands from the center, carrying with it shoreward all the loose rocks and debris embedded in its icy fetters. The extent of this expansion varies with the thickness of the ice, the length of the winter, and the size of the lake. It is not unusual for it to expand and carry with it rocks a distance of twenty feet during a winter.

In a part of this same lake the opposite shores are bounded by abrupt and steep walls of rock, over which the ice cannot expand and spread as on the shallow level shores. But as expansion continues nevertheless, as a result, there is first observed a slight upheaval of the sheet of ice in the center of the lake; next a fissure extends across the lake; then the edges of the fissure gradually rise up until there is a ridge like the roof of a house, oftentimes so high as to bar the passage of teams.

In 1871 I found such a ridge in this lake so high and steep, with a deep crack in the ridge extending across the lake, that I could not drive over it with a horse and sleigh, and was compelled to go ashore and pass around it.

This rock movement does not take place in tidal waters; the constant rise and fall of the tide prevents the ice freezing fast to the rocks. The expansion, however, goes on the same.

In Lahave river, at Bridgewater, where the tide ebbs and flows, I have observed the expansion of the ice from the center toward the shores to amount to 20 feet during a winter. As a proof of this, a steam tug was "caught" at one of the wharves by the sudden freezing up of the river, and could not be removed to an anchorage. The ice expansion forced her so tightly against the wharf that the ice on the channel side had to be cut away from her sides, and the tug moved out from the wharf and moored to the outer edge of the opening. This operation had to be repeated several times during the winter, so that in the aggregate, 12 to 15 feet of ice were cut away, and the tug moved all of that distance away from the wharf. I have known the same thing to occur with other vessels similarly stiuated.

Again, the western bank of this river at this point is lined with perpendicular wharves of crib work; the opposite shore is shallow and flat. The ice expands and is forced upon this shore 30 feet beyond the highest tide during a winter, and forms a complete and safe road to the river below, when all snow and ice has disappeared from the other roads.

The rocks here do not "travel," as the tide lifts the ice off of them before it can freeze them solidly in its grasp.

This phenomenon is not confined to the localities mentioned. I have noticed it in a dozen other lakes and rivers in Nova Scotia.

There can be no doubt but that these "traveling rocks" are attributable to the expansion of ice. Will some scientist now explain why ice expands thus, against the common theory that cold contracts and heat expands?

• Wind-Propelled Rocks

ORIGIN OF PLAYA STONE TRACKS, RACETRACK PLAYA. . . . .

Stanley, George M.; *Geological Society of America, Bulletin,* 66:1329-1350, 1955.

Abstract. Curious tracks on playas, obviously made by moving stones, have been interpreted as caused by wind blowing stones over wet level clay. The stones weigh from ounces to several hundred pounds.

Among hundreds of tracks on Racetrack Playa, Inyo County, California, certain ones exhibit near parallelism which implies unit movement; precise measurements and plots confirm this. Certain bends and cusps in these irregular tracks are comparable in all tracks of the same "signature). A transparency plot of analogous points (one for each track in same signature group), when moved along plotted tracks, matches repeatedly at other analogous points. Rotation precluded true parallelism of tracks and identity of lengths and shapes. Distance of unit movement exceeded 300 feet, and maximum spread of stones in unit is 480 feet.

Unit movement over so great a span scarcely allows any reasonable conclusion as to cause other than wind-blown ice floes dragging protruding stones. Ice ramparts and other evidence indicate longshore shearing motion, feasible for ice floes but impossible for ice shove by thermal expansion.

The writer finds no evidence that stones, freely wind blown, have made tracks. Though not disproved, this idea meets serious objections in many other small object tracks than those surveyed and is unfeasible for tracks inscribed by 300 pound stones.

SLIDING STONES, RACETRACK PLAYA, CALIFORNIA

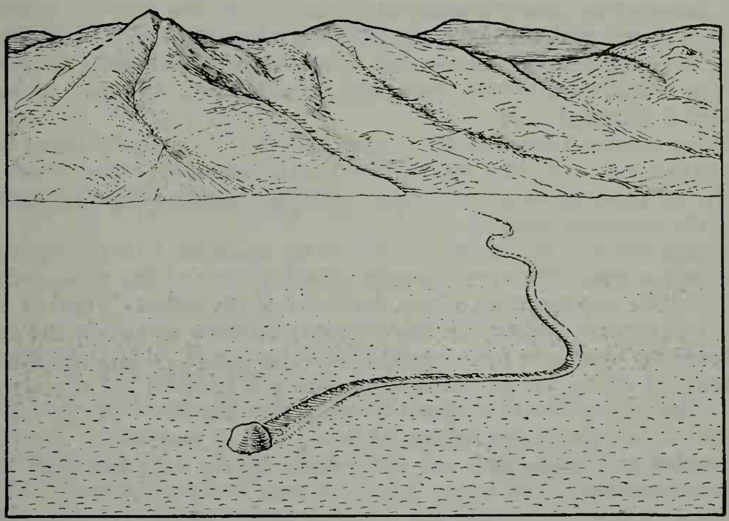
Sharp, Robert P., and Carey, Dwight L.; *Geological Society of America, Bulletin,* 87:1704-1717, 1976.

Abstract. Twenty-eight of 30 monitored stones on the southern part of Racetrack Playa moved within a seven-yr interval, leaving distinct tracks. Movements occurred principally during the winters of 1968-1969, 1972-1973, and 1973-1974. Some stones moved in all three episodes, some only in one or two, and a few on other occasions. Movement is clearly related to wet stormy weather.

Greatest cumulative movement, 262 m, and greatest single-episode movement, 201 m, were by a small, 250-g stone. Other monitored stones weighing as much as 25 kg moved cumulative distances of 60 to 219 m. Net direction of movement was north-northeasterly with deviations to east and southeast on occasions by some stones. Movement most likely occurs within one to several days after playa wetting, and velocities on the order of 0.5 to 1 m/sec are inferred from track characteristics.

Table 1. Playas in Southeastern California and Adjacent Nevada Displaying Stone Tracks

Playa	Location	(lat	long)
Racetrack	Calif.	(36°41'N,	117°34'W)
Little Bonnie Claire	Nevada	(37°10'N,	117°10'W)
Nelson Dry Lake	Nevada	(35°51'N,	114°57'W)
Rogers	Calif.	(34°55'N,	117°47'W)
Rosamond	Calif.	(34°50'N,	118°5'W)
North Panamint	Calif.	(36°20'N,	117°23'W)
Drinkwater	Calif.	(35°30'N,	116°33'W)
Small playa, Edwards Air Force Base	Calif.	(34°53'N,	117°46'W)
Unnamed playa north of Afton	Calif.	(35°05'N,	116°26'W)



Rock R at the end of a 250-meter track made in December 1970, looking south at Racetrack Playa, California.

Thin sheets of ice form in winter on this playa, and eyewitness accounts of ice sheets, some with infrozen stones, being driven by wind across other southern California playas indicate that stone tracks may be made in this manner, as earlier advocated. However, movement of stones out of an encirclement of iron stakes, large changes in neighboring stone separation during movement, disproportionate corresponding reaches within contemporaneous tracks of neighboring stones, and other relationships strongly suggest that monitored stone movements occurred without the aid of extensive ice sheets.

Wind acting directly on the individual stones is considered the prime moving force. A critical element promoting movement may be deposition of a thin layer of fine slippery clay, the material that last settles from suspension after playa flooding.

WIND-INDUCED STONE TRACKS, PRINCE OF WALES ISLAND, ALASKA

Sainsbury, C. L.; *Geological Society of America, Bulletin,* 67:1659-1660, 1956.

The recent discussion by Stanley of the stone tracks of Racetrack Playa, California, leads the writer to record observations of another variety of stone tracks formed in the shallow water of a delta. The writer observed the tracks in 1955, during field work on Prince of Wales Island, southeastern Alaska.

The tracks are formed in water not more than 6 inches deep by stones that are dragged by attached wind-blown kelp. Stones that are partially buoyed up by attached kelp are moved along when the wind blows the buoyant kelp, forming tracks that remain in the sand of the beach as the tide ebbs. The tracks apparently form only when the kelp is blown by an offshore wind during ebb tide.

The drag tracks were formed in the littoral zone of the delta of the Thorne River, on a surface that sloped gently seaward. They were observed in the process of formation on several occasions and presumably are a fairly common feature.

Individual tracks, or grooves, may be as much as 1 inch deep and several inches wide; the size depends upon the size of the stone being dragged and the composition of the material of the delta. Figures 1 and 2 of Plate 1 illustrate tracks cut into a pebbly surface and show the power of the dragging stones to push smaller pebbles aside. [Figures omitted]

Figure 1 of Plate 1 illustrates the length and general parallelism of the tracks. Figure 3 of Plate 1 shows a composite track transgressing ripple marks and shows the preservation of detail that is possible. The fine lines paralleling the larger track were made by the kelp and show that the track was produced in water not more than 1-2 inches deep. The small stone on the left retains the attached kelp, but the fragment that produced the right-hand track has lost its buoyant seaweed. The largest stone fragment observed weighed about 2 pounds and was dragged by a fairly large kelp. Menard and Dietz have observed smaller rocks rafted long distances by kelp.

Observations of the tracks indicate that, although they are common, the conditions that lead to their creation and preservation are rather restrictive. All the tracks were formed on gentle seaward-facing slopes at ebb tide under the influence of a strong offshore wind. None was observed to form as a result of onshore winds, although it is reasonable to assume that the stones are dragged by onshore winds. The reason tracks so made are not preserved apparently is that onshore winds strong enough to move the stones have a fetch sufficient to enable them to create small waves, and under the influence of the waves the stones move along jerkily rather than continuously. Moreover, the wave action probably destroys most of the tracks formed by onshore winds.

The kelp contains lung-shaped air sacs that individually may displace about half a cubic inch of water, and the plant normally is firmly attached to the rock. The writer never has seen a rock floating free, suspended beneath a supporting seaweed, however, as Menard and Dietz report.

The tracks observed corresponded in orientation with wind direction. Although the Thorne River crosses the delta almost at right angles to the tracks photographed, and has a noticeable current at low-tide levels, no tracks were observed that formed by current-moved stones. The driving force of the wind probably exceeds the force of the current.

The stone tracks described here were found in the littoral zone of a small delta, presumably an environment of active sedimentation. It seems likely that stone tracks in this environment occasionally are buried beneath sediments brought down by the Thorne River during high water, thus preserving them in the geologic column, and that similar tracks may be found preserved in older sediments elsewhere. The tracks of kelp-dragged stone described here and the tracks of ice-borne stones described by Stanley would provide evidence of a shallow-water environment. The tracks show that features very similar in shape, size, and orientation can be made by diverse agents in combination, and often the role of one of the agents such as ice or seaweed is not immediately apparent.

• Exploding and Erupting Rocks

BURSTING ROCK SURFACES

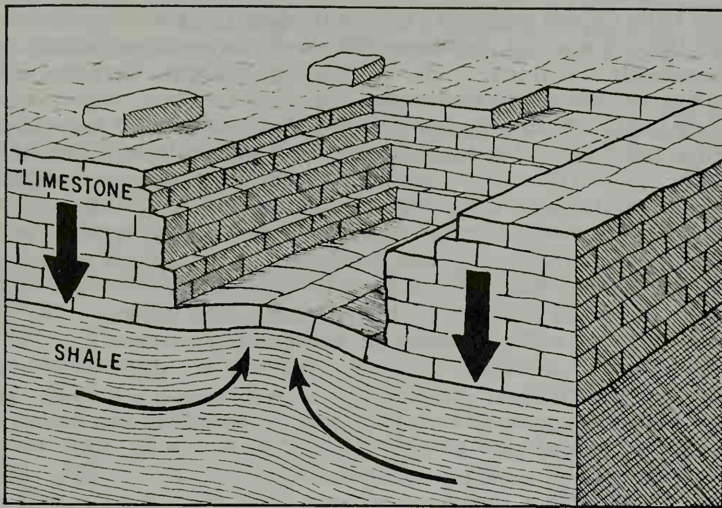
Hughes, T. McKenney; *Geological Magazine,* 3:2:511-512, 1885.

The interesting note by Mr. Strahan in the Geol. Mag. for September, 1887, on explosive slickensides, reminded me of some similar phenomena which were not of unfrequent occurrence near Dent Head and Ribble Head in Yorkshire.

In the limestone quarry from which the black marble of Dent is procured the workmen found that, when they were quarrying the lower beds and struck the rock with a pick or bar, fragments flew up into the air with greater force than could be due to their blow and in an unexpected direction.

Also, when the tunnel was being made above Ribble Head, and the workmen were engaged upon the bed of rock which formed the floor of the tunnel, pieces used to burst off with a loud noise, so that some thought they had discovered a detonating shale.

The explanation in both these cases seemed to be that the bed which was apt to shell off in that unexpected manner rested on shale which yielded to the superincumbent weight on either side, and produced in the tunnel, or



Bursting rock at Dent Head was due to naturally applied pressures.

in the quarry, where the overlying rock had been removed, what would be called in a coal-mine a "creep" (see Woodcut).

The shale behaves as a thick fluid or viscous mass, and transmits the pressure and motion. But in the cases to which I refer, a thin bed of the solid rock was left above the shale. This was not compressible, but, where, in the tunnel or in the centre of the quarry, the weight of the overlying rock had been removed, it rose in a slight arch over the upthrust shale, and was thrown into a state of tension, so that when struck, chips and flakes, and sometimes larger pieces, would fly off. These pieces were in themselves quite sound. It was not that the whole mass was like Rupert's drops in a state of molecular unstable equilibrium, as suggested by Mr. Adam, and supported by Mr. Strahan in the case of the explosive slickensides, but it was rather analogous to the effect of drawing a knife across the outside curve of a bent stick; when jagged ends spring off and stand out straight in the original direction of the unbent stick---only in this case the fibrous character of the material prevents the pieces breaking away altogether as if it were rock. That the conditions in the case of the explosive slickensides were similar to those at Dent Head Quarry and the Ribble Head tunnel seems probable from the observation of Watson that "this phenomenon has not been noticed from slickensides where no shale is incombent," and also from the suggestion of Phillips, "that the removal of one side of a vein would leave the remaining side in a condition of strain resembling that of a strung bow, with a tendency to bulge outwards into the workings. The undercutting would free, so to speak, one end of the bow."

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Chapter 4

BIOLOGICAL ANOMALIES IN GEOLOGY

INTRODUCTION

Geology would not be nearly so fascinating if it did not purport to relate the history of life. Over the endless eons, life arose, was nurtured, and was transformed from simple cell to the human being. This is the fabric of evolution; a tale of ascendancy that could not be told without geology.

Evolution, though, is only a theory, and all scientists must be psychologically prepared for its eventual refutation. Not tomorrow, perhaps not for a century; but evolution will make way for some better hypothesis. This chapter does not pretend to attack evolution head-on. Much is said about biological extinctions and flowerings, but the primary target is geological uniformitarianism. The Siberian boneyards, the fossil evidence of megadeath, the curious gaps in the fossil record, the apparent catastrophic changes in sea level---these ideas form the substance of this chapter.

The basic structure of the fossil record consists of life forms of varying morphological complexity embedded in sequences of strata. The major anomalies occur when: (1) complexity does not seem to proceed from simplicity; (2) explosions or implosions of life-form diversity punctuate the record; (3) fossils are piled up in incredible concentrations suggestive of catastrophe; (4) inexplicable gaps prevail in the record; (5) fossils or living animals exist where they apparently should not; and (6) life seems to transcend time. Some of these anomalies may be illusory, or merely the result of insufficient study, but they all challenge current ideas.

PHENOMENA OF THE FOSSIL RECORD

Before the advent of radioactive dating, fossils were the principal time markers in geology. When a rock stratum had to be dated, the paleontologist noted its fossil content, especially key species that in effect called out the geological hour. The validity of fossil chronometry depends upon the reality of progressive evolution---simple life forms too complex as a function of time. Some of the topics presented in this section cast doubt upon the accuracy of fossil clocks. Most scientists, however, consider the vast accumulation of interlocking radioactive dates and progressive changes in fossils as an unassailable fortress.

Biological anomalies in the fossil record may take the form of supposedly extinct forms in young rocks (the geological equivalent of "living fossils") and the puzzling appearance of young life forms in rocks that seem too old. The fossil record also displays conspicuous gaps that have never been properly filled by missing links despite centuries of geological searching. Either the missing links are vanishingly rare, or life evolved in quantum jumps, or progressive evolution is an illusion. That the fossil clock may have sped up and slowed down over the eons is seen in many apparent biological explosions and extinctions. Finally, there are curious fossils that seem to project through time by penetrating strata supposedly deposited over long periods of time. Such "polystrate" fossils infer catastrophism and possibly a great compression of the geological time scale.

Biological growth rhythms also appear as countable ridges and layers on fossil shells. These clocks do not tell absolute time but by counting with care one can determine the number of days per year or lunar month. Astronomers can then derive the history of the earth's rotation and distance of the moon. These data seem to prove that the moon was once much closer and that there have been sudden, inexplicable changes in the earth-moon system down the corridors of time.

• Unusual Gaps in the Fossil Record

FOSSILS IN EVOLUTIONARY PERSPECTIVE

George, T. Neville; *Science Progress*, 48:3-30, 1960.

It is appropriate, in centennial retrospect, to see how far discovery and research in evolutionary process have over a hundred years removed the stigma of nescience from a fossil record that Darwin even in the final (sixth) edition of The Origin of Species (1872), was at pains to excuse---"Now let us turn to our richest geological museums, and what a paltry display we behold!....it is superfluous to state that our evidence is fragmentary in an extreme degree"---and that had to be explained away by reference to factors that, valid enough, left him with poor stuff for evidence. Despite a declaration of faith expressed with unusual assertion---"all the chief laws of palaeontology plainly proclaim, as it seems to me, that species have been produced by ordinary generation"---he was unable to strengthen his argument by circumstantial proof of fossil evolution, but was compelled to lean heavily on the replacement of fossil groups in time (which was well enough known in days long pre-Darwinian to stratigraphers like Lyell and William Smith, and palaeontologists like Cuvier and Oppel) and to refer to the rise and decline of many groups of organisms whose geological remains are more varied and abundant than their living representatives. But while the significance of the time-scale of faunas did not escape him, it was a significance that in the nineteenth century had a bias towards inference post hoc, and some of his critics were not prepared to concede a derived propter hoc.

There is no need to apologise any longer for the poverty of the fossil record. In some ways it has become almost unmanageably rich, and discovery is out-pacing integration: the growing number of species of Foraminifera that remain undescribed in the cabinets of the oil companies probably is of the order of thousands; and while most other organic groups are not so fully collected the ratio of added finds to palaeontologists studying them is constantly expanding. But what remains to be discovered is likely to be less and less of radical importance in revealing major novelties, more and more of detailed infilling of fossil series whose outlines are known. The main phyla, in so far as they are represented by fossils, now have a long and full history that is made three-dimensional by a repeatedly cladal phylogeny. The gaps are being closed not only by the finding of major annectant forms, the "missing links" that Darwin so deplored, like the fish-amphibian ichthyostegids, the amphibian-reptile seymouriamorphs, and the reptile-mammal ictidosaurs, but also by new discoveries of phyletic affiliations, as in graptolite structure. The establishment of true lines of evolution, critically analysed in the light of neontological population studies and of biometrical systematics, collates speciation with the origin of species, and confers ancestor-descendant relationship on a pre-Darwinian faunal (and floral) echelle des etres. The concept of facies, developed by stratigraphers and appropriated by palaeontologists, embraces the essence of geographical distribution as a factor in the control of evolutionary process, and incidentally throws light on the rapidity of major environmental (ecological) change in even a few feet or inches of sediment. Above all, the geological record provides a time-scale that sets evolution in a more than ample frame, allowing successional species to be transformed without too great crowding of genotypic changes in a dangerously hasty accommodation to acute selection pressure: for instance, hominids that as a group displayed relatively rapid advance in late Pleistocene times crossed the specific barriers at intervals of perhaps once in 50,000 to 100,000 years---or once in 2000 to 4000 generations.

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The fossil record nevertheless continues to be composed mainly of gaps. Its broad lines of evolutionary change are well enough known, and in some groups it is possible to fill in the intermediate stages fairly completely; but as yet only very rarely is a segment of a true lineage recognisable, and almost never a lineage that convincingly displays all the gradations of cladogenic divergence. Newell thinks that perhaps only one per cent. or less of the fossil species that have been preserved have as yet been described. His figures are highly speculative, but they are of an acceptable order; and it requires no great field experience to appreciate the magnitude of the gaps intrinsic in the record as a result of the processes of fossilisation. Darwin, recalling his fossil-hunting experiences in South America, gave a very "modern" assessment of the ways in which great parts of the evolutionary record may be lost or obliterated through accidents of sedimentation, rock-metamorphism, destructive erosion, and burial. At the same time the gaps progressively diminish as closer and more persistent collecting unearths new finds, and drilling continues to penetrate rocks or rock-sequences otherwise inaccessible, even if some of the gaps will in their nature always remain gaps; and the discontinuities of evolutionary succession in Cambrian and younger rocks may in time then be expected to vanish, or at least never to occlude completely and permanently the essential stages of change.

There is however one gigantic gap in the record that is of a different kind---the gap of Pre-Cambrian times. Despite intensified search by many hundreds of geologists, the rocks older than the oldest fossiliferous Cambrian sediments remain almost as barren of fossils as when they were first studied 150 years ago. Some of them are displayed in thicknesses of many thousands of feet, they may be as unaltered and as undeformed as many fossiliferous rocks of later ages, they provide clear indications of having accumulated in environments, lacustrine and marine, apparently wholly favourable to both plant and animal life, and they sometimes underlie Cambrian in a unitary suite of strata little affected by changing geography. Yet they have yielded few fossils that are recognisable as plants, and none that are certainly animals.

On the other hand, the earliest Cambrian rocks, formed about 500 million years ago, are relatively richly fossiliferous and contain a fauna already highly diversified into coelenterates (jelly-fish), sponges, echinoderms, "worms," brachipods, gastropods, and arthropods. Moreover, the major phyla when they first appear display an evolutionary differentiation that implies a complex phyletic history in Pre-Cambrian times---the echinoderms into cystoids and edrioasteroids, the brackipods into atrematous and protrematous forms, and the arthropods into at least three classes of which trilobites are the chief---not to mention the several genera and the 400 species represented. Granted an evolutionary origin of the main groups of animals, and not an act of special creation, the absence of any record whatsoever of a single member of any of the phyla in the Pre-Cambrian rocks remains as inexplicable on orthodox grounds as as it was to Darwin ("To the question why we do not find rich fossiliferous deposits...prior to the Cambrian system, I can give no satisfactory answer").

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The difficulties of organising fossil material into evolutionary series, even when the record is amply full, is particularly well illustrated by the cephalopods. Shells of both the Palaeozoic-Recent nautiloids and the Mesozoic ammonoids are commonly almost perfectly preserved, sometimes in great abundance; and the anatomy of the soft parts is unusually fully indicated by shell form and by septal and other elements of internal structure. They occur in great variety of ornamentation, coiling, and ontogenetic development; the living creatures were mostly powerful swimmers widely dispersed and relatively free from the constraints of a limited geographical environment; they are almost world-wide in their distribution except in non-marine strata; and they range from Cambrian to Recent deposits. In conspective evolutionary development they conveniently fall into the three broad grades of nautiloids, goniatites, and ammonites, though the grades were mainly cladogenic and not successional in origin, the nautiloids having long persisted after the ammonoids became extinct. They have been a rich store of examples of such "principles" as recapitulation, parallelism, trends and orthogenesis, eruptive evolution, macromutation, adaptive divergence, and gerontism.

Nevertheless, they prove to be highly resistant to detailed reconstruction into lineages or even lines of annectant forms that go beyond the generalities of illustrative bioseries, and they are notorious as a source of conflicting views on classification and relationship. This is so because of a changing balance of emphasis amongst taxonomists on one biocharacter or another as a major sign of affinity, and of the permutations of relationship that follow in such a varied group as the ammonites; but also partly because it is now beginning to appear that an intrinsic distinction may not always or often be possible between true ancestor-descendant lines and graded structural series in which affinity may not be direct. The classificatory taxa correspondingly embrace forms less akin than similar to each other. (pp. 18-19)

• Possible Very Early Fossils

COMBINED STRUCTURAL AND CHEMICAL ANALYSIS OF 3,800-MYR-OLD MICROFOSSILS

Pflug, H. D., and Jaeschke-Boyer, H.; *Nature*, 280:483-486, 1979.

Cell-like inclusions detected in the cherty layers of a quartzite, which is part of the Isua series in South-west Greenland, consist of biological materials, according to analyses by Raman laser molecular microprobe. The available radiometric data place the age of the sequence at around 3,800 Myr. Thin sections of our specimens were taken in their primary positions within the rock matrix. The material used was compact and unweathered. No maceration, etching, impregnation or other methods were applied which might have produced artefacts.

About 100 well preserved specimens noted in the material were sealed within the quartz grains or in the silica cement in a three-dimensional condition. This sealing apparently results from a synsedimentary permineralisation caused by colloidal silica, which subsequently crystallised to form chalcedony. Our observations suggest that these specimens are primary constituents of the sediment, and are not contaminants from a later time.

The fossils occur as individual unicells, filaments or cell colonies. Cells and cell families are usually surrounded by multilaminate sheaths which show a characteristic laminar structure. All specimens observed apparently belong to the same kind of organism, named Isuasphaera.

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There is little doubt that Isuasphaera is an organism. This is indicated by the morphological and chemical details. A problem results from the similarities between Isuasphaera and recent yeasts. If we conclude that yeasts existed during Isua times, life must be much older than 3,800 Myr. According to our present knowledge, the Earth's sphere formed about 4,450 Myr ago. Consequently biophile conditions, implying a solid crust, cool temperatures and liquid water cannot have been realised on

Earth earlier than about 4,400 Myr ago. The time span of roughly half a billion years, however, appears too short for the evolution from a simple organic compound to a eukaryotic organism to have occurred.

However, the classification of Isuasphaera to yeasts or other eukaryotes is uncertain. The question of whether an organism is an eukaryote or not can hardly be decided without knowledge of the protoplasm which no longer shows structural details in its fossil condition. The example of the microspheres indicates that cellular budding does not have to be a very complicated process nor does it have to depend on a complicated endocellular apparatus.

Thus, it seems that Isuasphaera in spite of its yeast-like appearance may occupy an evolutionary level far below that of eukaryotes. Consequently, Isuasphaera may represent a half-way line between a microsphere-like protobiont and subsequent evolution.

• Remarkable Biological Explosions

GENETIC REGULATION AND THE FOSSIL RECORD

Valentine, James W., and Campbell, Cathryn, A.; *American Scientist*, 63:673-680, 1975.

The abrupt appearance of higher taxa in the fossil record has been a perennial puzzle. Not only do characteristic and distinctive remains of phyla appear suddenly, without known ancestors, but several classes of a phylum, orders of a class, and so on commonly appear at approximately the same time without known intermediates. Darwin recognized that such gaps presented a major obstacle to demonstrating that evolution proceeded by the slow accumulation of change within lineages; he attributed the lack of antecedents to the incompleteness of the fossil record. Over a hundred years later, we still face the problem of missing ancestors of many higher taxa. Indeed, our present knowledge of the fossil record demonstrates even more clearly the episodic nature of the origin of new higher taxa. If we read the record rather literally, it implies that organisms of new grades of complexity arose and radiated relatively rapidly.

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The fossil record of novelty. The first fossils appear in rocks of very great age, well over 3 billion years old. These early forms somewhat resemble living bacteria and blue-green algae. Animals do not appear until much later, approximately 700 million years ago. During this span of perhaps 2-1/2 billion years, the complex eukaryotic type of cell evolved, with sophisticated metabolic pathways and genetic machinery; such cells form the basic units of which multicellular organisms are constructed. The transition between prokaryotic and eukaryotic cell types is not well documented from the fossil record, but it may have occurred between about 1.7 and 1.4 billion years ago. We shall restrict our attention to the animal kingdom, for which the fossil record is best. The probable times of origin and the first appearances of many of the striking evolutionary novelties in animals are diagrammed in Figure 2. [omitted]

The earliest fossils that represent animals are probably burrows and similar traces that have been preserved in old sea-bottom deposits. They become widespread though rare between 700 and 600 million years ago; during this interval, body fossils of nonskeletonized marine animals also appear. The first animal remains include coelenterates (jellyfish and their allies) and several types of wormlike forms of uncertain affinities. Claims of earlier animal fossils have been disproved or are of doubtful validity.

About 570 million years ago, at the beginning of the Cambrian Period, mineralized skeletons made their first appearance, and thereafter the fossil record improves greatly. All but two of the living phyla that are now well skeletonized had appeared by the end of the Cambrian, and it seems likely that primitive members of even those two (the Ectoprocta, or bryozoan "moss animals," and the Chordata) had appeared but were not then represented by well-skeletonized groups and thus were not preserved. Both these phyla appear in rocks of the next geological period, the Ordovician.

A number of inferences as to the major steps in the origin of animal phyla can be drawn from their fossil records and from the extensive knowledge of their functional anatomy that is now available. The earliest metazoan animals must have been multicellular descendants of single-celled protozoans, but no fossil record is known for either of these groups in Precambrian times. The advantages of multicellularity probably include increased size and homeostasis, enhanced feeding ability, enlarged reproductive capacity, and longevity. The primitive metazoans had to regulate the growth patterns of collections of cells rather than of single cells, and thus required a more extensive regulatory system than their ancestors, one which was sensitive to signals from other cells.

Multicellularity led to the development of differential functions among cells---some of which become chiefly reproductive, others digestive, and so forth---with the advantages of efficiency that accompany functional specialization. This required further regulatory elaboration in order to permit genes to be associated with different batteries in different cells. Sponges exhibit this stage of complexity but appear to have descended independently of other living animal phyla, although also from protozoan ancestors. It is possible that an extinct group of early Cambrian fossils, the Archaeocyatha, were representatives of this level of organization on the main metazoan line. Archaeocyathans resemble sponges in some but not all skeletal features.

The first group we actually find that is, in our opinion, associated with the main line of descent is the coelenterates. These forms have advanced further than sponges, with cells differentiated to form organs such as gonads. Again, the coordination of the differentiated cells that this requires must involve another important step in the evolution of the regulatory portion of the genome. Another advance involved the addition of a middle tissue layer to produce the three-layered "triploblastic" plan exemplified by flatworms. Perhaps the new layer permitted more efficient locomotion on the substrate by providing a more rigid body than that of jellyfish. This simple architectural change alone need not have involved a major regulatory step, yet the flatworm anatomy is so much advanced over that of the coelenterates---involving many more cell and tissue types---that a considerable regulatory increase must have occurred. Unfortunately, there is no fossil record of this step. (Excerpt)

(The biological explosions in the fossil record are discussed in more detail in the section on extinctions later in this chapter. Interestingly enough, extinctions of life are almost always followed by explosions.)

• Ancient Fossils in Young Rocks

SKULL PROMISES GEOLOGICAL UPSET

Anonymous; *Science News Letter*, 14:81, 1928.

Radical changes in our ideas of the course of events in recent geological time---say the last half million years or so---may be brought about by the discovery in Utah of the unfossilized skull of an extinct camel, with a bit of dried flesh still clinging to the bone. The relatively fresh condition of the specimen argues that its one-time possessor died only a few centuries or millenia ago; present ideas hold that this particular sort of camel became extinct a half-million years ago. If this camel really died so long ago, the bone should have been largely or wholly replaced by stone, and there should have been no flesh on it at all.

The find was reported by Prof. Alfred S. Romer of the University of Chicago. The skull was sent to him by Prof. A. L. Mathews of the University of Utah for examination.

Prof. Romer's first guess was that it might be a relic of a herd of dromedaries imported into the Southwest during the 1870's, as an experiment with terminated unsuccessfully. But a critical examination of its anatomical details showed many points of close resemblance to the skulls of very ancient extinct American camels, and marked differences from those of existing Asiatic and African forms. In his opinion the animal belonged to the genus Camelops, which is supposed to have been extinct for at least half a million years.

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Prof. Romer's tentative answer to the riddle is not that the skull has remained unfossilized, yet undestroyed, for half a million years, but that the species did not become extinct then, surviving instead until comparatively recent times.

Such an answer, he points out, would also help to settle the conflict over the antiquity of man in America. Many scientists refuse to accept as authentic the occasional finds made on this continent of stone or bone implements associated with the remains of animals supposed to have been extinct for hundreds of thousands of years. Prof. Romer states that other recently discovered remains of camels, lions and other animals in the West also hint at a longer survival of these extinct beasts than has hitherto been supposed.

THE PROBLEM OF REBEDDED POLLEN IN LATE-GLACIAL SEDIMENTS AT TAUNTON, MASSACHUSETTS

Davis, Margaret B.; *American Journal of Science*, 259:211-222, 1961.

Abstract. The occurrence of pollen of tree genera not found in the modern flora of the United States and Canada in late-glacial sediments from the Williams Street bog near Taunton, Massachusetts, is considered evidence of contamination of the sediments with secondary pollen rebedded from pre-Quaternary deposits. Nearby varved clays also contain these pollen types, and because the local till contains little if any pollen, it is concluded that the secondary pollen was carried in glacial meltwater from the vicinity of Tertiary deposits 25 miles to the northeast. The late-glacial bog sediments were apparently contaminated either directly by meltwater streams, or through the erosion and redeposition of meltwater stream deposits. As the secondary pollen spectrum cannot be determined with certainty, it is impossible to interpret the mixed secondary and primary pollen spectrum contained in the late-glacial sediments.

AMMONITES INDICATE REVERSAL

Anonymous; *Nature*, 225:1101-1102, 1970.

Can the course of evolution turn back on itself? Or does some sort of momentum keep an organism proceeding in a particular evolutionary direction, even if this results in the production of aberrant and non-adaptive types, forming an evolutionary cul-de-sac ending in extinction? Among evidence often cited for the latter point of view is the production of aberrant forms by the familiar spiral-shelled ammonites, of which fossil remains are found from the early Devonian through to the Cretaceous. In these aberrant forms, called heteromorphs, either the whole shell, or part of it, is unrolled. This is interpreted as a sign of overspecialization or racial senility, preceding inevitable extinction.

A drawback of this point of view is that it effectively credits evolution with an intrinsic rhythm, comparable with that of an individual life, with each type having a youthful phase of explosive development, then a long period of advancing specialization, and a final phase of senile overspecialization and morphological degeneration. This is, of course, in direct contradiction to Darwin's selection theory, which cannot explain the appearance of any organisms which are selectively negative. On the other hand, it does tally with the "law" of the irreversibility of evolution which Dollo put forward in 1893.

The use of uncoiling ammonoids to support the idea of an endogeneous rhythm in evolution has now been challenged by Jost Wiedmann, of Tubingen University (Biological Reviews, 44, 563; 1969), after careful study of the heteromorph ammonoids of the Triassic, Cretaceous and Jurassic eras. In particular, he looked to see, first, whether these heteromorphs really appeared explosively at the end of evolutionary lines; second, if their development was irreversible; and third, whether they really were short lived, degenerate or overspecialized, and had lost the ability to adapt or change, thus being "condemned" to extinction.

He found that the Triassic heteromorphs were a single monophyletic group, with a long stratigraphical range through the whole of the later Triassic, suggesting that here the uncoiling was an adaptive change, possibly related to living on the sea bed, and with no indication that it was due to an unselected and somehow internally elicited mutation. The Jurassic heteromorphs, too, seem to have been a monophyletic group persisting for a long time, and some of these do show signs of re-coiling, as do several groups of Cretaceous heteromorphs, Indeed, here some of the uncoiled forms turned out to be older than their coiled supposed ancestors, and so their phylogenetic development must now be read in the opposite direction---that is, from uncoiled to re-coiled.

Wiedmann thus finds no evidence to support the assertion that "a recoiling of forms which have become secondarily rod-like does not occur". In fact, if one regards the ammonites coiling early in their evolution in the Devonian era as being primary, the re-coiling of the heteromorphs he has found here is actually tertiary, with some of the re-coiled forms even showing a later quaternary uncoiling. This means, of course, that the final extinction of the ammonites at the end of the Cretaceous needs some explanation other than endogeneous racial senility. Wiedmann points out that many other marine groups died out at the same time, so that changes in sea level provide a more satisfactory answer than either an immanent evolutionary ageing or factors like cosmic rays or supernovae. Second, it clearly calls for a reconsideration of what he calls the "most undisputed of the phylogenetic laws", namely Dollo's "law of irreversibility". This was originally stated as "an organism is unable to return, even partially, to a previous stage already realized in the ranks of its ancestors" and the too strict application of this rule has already been challenged, especially by geneticists, who have pointed out that reverse mutations should not be ruled out a priori. Now Wiedmann concludes that in palaeontology the over-hasty formulation of such phylogenetic "laws" and "principles", based on insufficient information, has produced "a stiffing set of prejudices" rather than "guide lines crystallized from long experience and observation". This all serves to stress very neatly the often overlooked point that in science, the so-called "laws" are, in Karl Pearson's phrase, "descriptive and not prescriptive", so that where facts clash with the law, and the exception proves (that is, tests) the rule, the facts should always prevail.

• Young Fossils in Ancient Rocks

HAS THE FLY IN AMBER BEEN FAKED?

Anonymous; *New Scientist*, 25:265-266, 1965.

Somewhere in the lost world of prehistory are the great amber forests of the Baltic. They are lost in the sense that although amber is common enough in jewellery shops, and biologists have found a remarkable number of insects and other arthropods such as spiders embedded in the fossilised resin, nobody knows precisely where the amber comes from or why it appeared in such quantities and then apparently disappeared. The greatest amount has been found in deposits along the Baltic coast of former East Prussia and dates from the early Oligocene which makes it about 35 million years old.

The resin is supposedly derived from an extinct coniferous tree called Pinus or Pinites succinifera and contains an exceptionally high content of succinic acid. What has always puzzled biologists about the insects preserved in it is that while some seem to be identical with modern types from Central and Northern Europe, many are extinct species with close affinities with insects in tropical and sub-tropical countries.

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As the Baltic deposits contain little except conifer resin, it is supposed that the amber, the specific gravity of which is only slightly higher than that of sea water, has drifted considerable distances from source which is generally supposed to have lain to the north, in the mass that is now Scandinavia. This is borne out by the fact that the amber frequently appears rolled and water-worn; some of it may be older than the Oligocene.

One theory has been advanced that amber forests existed high up in the mountains and the resin was washed down from considerable altitudes. There is good evidence that early Tertiary Europe was much warmer than it is today, and that would explain the tropical or sub-tropical forms.

But what of the insects resembling those alive today? Mr. Mohammad Abdullah says it seems possible that ingenious technicians of the amber trade had methods of their own for the introduction of insects into amber and that some or all of the modern types originated in this way.

SPORES AND TRACHEIDS OF VASCULAR PLANTS.....

Jacob, K., et al; *Nature*, 172:166-167, 1953.

In a recent paper entitled "Evidence for the Existence of Vascular Land Plants in the Cambrian", by K. Jacob, (Mrs.) Chinna Jacob and R. N. Shrivastava, to be published shortly in Current Science, we have recorded a few spores and fragments of tracheids of vascular land plants from authentic samples of the Neobolus Shales of the Salt Range, the Middle and

Upper Cambrian of Kashmir and the Cambrian of Spiti. Some of the spores described there are provided with bladders and in others they are absent, the latter in some cases showing body ornamentation. In this preliminary note we have tentatively referred these spores to the Pteridophyia and the Pteridospermae; it is possible that some may even belong to the primitive Gymnospermae.

Pursuing these studies further, specimens of the Suket Shales (containing well-preserved specimens of Fermoria) belonging to the upper part of the Semri series of the Lower Vindhyans, near Rampura (lat. 24° 28'; long. 75° 26'), Central India (now Madhya Bharat), were treated with hydrofluoric acid followed by Schultze's fluid. The specimens macerated belong to H. C. Jones's original collection from the above locality (Geological Survey of India, Reg. No. K24/997). Several spores and a few fragments of woody elements were recovered. But the spore assemblage is restricted to only five or six types, all of which appear to be comparatively primitive. In one slide as many as twenty spores, with or without tri-radiate mark, were recovered. Winged spores or those with surface ornamentation or furrow were entirely absent.

In view of the prevailing scepticism regarding the advent of vascular plants so early as the Cambrian, all possible precautions were taken against contamination and the results obtained by us were repeatedly checked.

Although A. K. Ghosh and others have reported the occurrence of spores and tracheids in the Cambrian sediments of India, there still persists some doubt regarding their finds. The present communication re-recording spores obtained from samples of the Suket Shales, together with the results of our examination of Cambrian sediments from the Salt Range, Kashmir and Spiti, may, it is hoped, carry conviction that such organic remains, if carefully searched for, will be found to occur in several Cambrian horizons hitherto believed to be devoid of any trace of vascular plants. From the Olive Shales of the Lower Vindhyans in the Mirzapur district, Ghosh and Bose figured four pieces of woody elements and a single small spore. From the Suket Shales we have recovered several more plant remains, including a variety of spores.

In this short communication no attempt is made to describe the individual spores, though it may be stated that those recovered from the Suket Shales have been provisionally grouped into six major types depending on their morphology, and include spores belonging probably to the primitive Pteridospermae and Pteridophyta (? Psilopsida, ? Sphenopsida), and to doubtful primitive Gymnospermae.

Conclusions. (i) Advent of land plants. Ghosh and Bose examined a sample of the Olive Shales (Semri series, Lower Vindhyan), from a locality east of Patwadh, Mirzapur district, Uttar Pradesh, and reported a few fragments of tracheids and several small smooth-walled spherical spores, one of which was figured by them. The spore, which is rather small in size with a short raised ridge or fold on one side, could also possibly be considered to belong to a primitive non-vascular plant. The several spores recovered by us from the Suket Shales (Semri series) belong to at least six different groups of vascular plants, probably representing the Equisetales and other primitive Pteridophyta, the Pteridospermae and very doubtful primitive Gymnospermae, in addition to some non-vascular cryptogams. The additional evidence now obtained by us, along with the earlier reports of traces of vascular plants in the Cambrian of the U.S.S.R., Esthonia, eastern Sweden and India, should offer food for thought to those who are not inclined to accept the existence of vascular land plants in pre-Silurian times. In view of the poor preservation of the comparatively few spores recovered, however, these tentative suggestions of affinities should be taken with reserve. Nevertheless, it is fairly safe to suggest that the vascular land plants were in existence even as early as the Lower Cambrian.

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The discovery of the remains of vascular land plants from the Vindhyans and other Cambrian sediments in India and elsewhere is of far-reaching significance in stratigraphy and in unravelling the early phylogeny of the vascular plants, on which an entirely new light is now being thrown, necessitating a re-orientation of certain well-established ideas. It is therefore of prime importance to undertake careful and systematic search for the remains of vascular plants in the early Palaeozoic and even in the Proterozoic sediments.

A DECADE OF CREATIONIST RESEARCH

Gish, Duane T.; *Creation Research Society Quarterly*, 12:34-46, 1975.

Palynology. Palynology is the study of fossil pollen and spores. Burdick has reported on his palynological studies of formations in the Grand Canyon. The striking fact about his results was the presence of fossil pollen grains of plants in sedimentary deposits that were allegedly laid down several hundred million years before the plants are believed to have evolved. He reported, for example, the discovery of fossil pollen of gymnosperms, many of them conifers (pine trees), and of angiosperms (flowering plants) in Cambrian and Precambrian formations.

The gymnosperms, or seed-bearing plants, supposedly did not evolve until long after the Cambrian rocks had been laid down, and the angiosperms are supposed to have evolved even later. The Cambrian Period is believed by evolutionists to be a time when no land plants or animals were in existence, in fact, a time when only marine and fresh water invertebrates existed.

A report by Rusch in the Quarterly related the fact that there have been numerous reports in recent years of the finds of fossil pollen of woody plants, including conifers, in Cambrian rocks by evolutionary geologists. Even fragments of woody plants have been found in Cambrian rocks.

These finds decisively contradict the supposed time and order of so-called plant evolution given in almost all books on geology, paleobotany, and evolution. These facts are not even known to the vast majority of geologists and biologists. For example, when I brought these facts to the attention of the audience during a debate with the world-famous botanist and evolutionist, Dr. G. Ledyard Stebbins, he was astounded, and demanded documentation. His astonishment was compounded when the documentation I readily provided included a report by one of his colleagues at the University of California at Davis and a close friend, geologist Dr. Daniel Axelrod!

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Fossil Anomalies. When fossils are found in strata which would be impossible according to standard evolutionary interpretations, these are labeled fossil anomalies. Usually such reports are ignored by evolutionary geologists, since they assume that an error has been made or an obvious explanation must exist. Several such fossil anomalies have been reported in the CRS Quarterly.

Professor Wilbert Rusch has studied the subject of fossil human footprints, personally examining some found in Kentucky. This study has become even more interesting in the light of the reported finds of human footprints along with dinosaur footprints in Cretaceous limestone of the Paluxy River area near Glen Rose, Texas. This latter report has been extensively documented by Stanley Taylor in the film, "Footprints in Stone." Rusch indicates that some of the footprints he researched (not in the Glen Rose area) were carvings, but others appeared to be genuine. He also recounted the report of an iron pot found in coal.

William Meister, while searching in the trilobite beds of Antelope Springs near Delta, Utah, split open a slab of rock to expose what appeared to be a human sandal print in which was imbedded three fossil trilobites. If true, this means that this footprint was made when trilobites were still in existence, but trilobites supposedly became extinct many scores of millions of years before man had evolved! Evolutionary paleontologists and anthropologists merely shrugged off this find as not genuine, but an anomaly due to some natural cause.

Clifford Burdick has reported on his investigation of the find of two modern human skeletons in the Dakota Formation of the Cretaceous (supposedly about 100 million years old) near Moab, Utah. During a mining operation for hydrothermally deposited copper, a hillside had been bulldozed away. The hill was composed of Dakota sandstone. On the floor of the excavated site, Lin Ottinger, a rockshop owner and guide of Moab, discovered two human skeletons. The blade of the bulldozer had sliced through the skeletons, leaving most of the remains exposed at the surface.

Burdick concluded that the bones were definitely in place, with no evidence that the surrounding rock had been disturbed. He believes that the location of the find deep within the hillside indicates that these individuals were buried at the time the Dakota sandstone was deposited.

Prof. Wilbert Busch and I carried out an investigation of this find shortly after Burdick's visit. We also visited the University of Utah to examine the bones, which were in custody of the Anthropology Department. There was no doubt that these skeletons were buried deep within the hillside, and as Burdick reported, there was no evidence the surrounding rock was disturbed.

We felt, however, that since all of the overlying material had been removed, the evidence required to positively eliminate the possibility that these individuals had reached the site via a fissure or cave was not available. Thus, while all the evidence that did exist indicated that these individuals were part of the original deposit, the possibility that they had entered the site at a later date could not be excluded with all certainty. Other reports of the finds of modern human remains in sediments supposedly many millions of years old have been summarized by Cousins.

• Polystrate Fossils

WORKERS FIND WHALE IN DIATOMACEOUS EARTH QUARRY

Anonymous; *Chemical & Engineering News,* 54:40, October 11, 1976.

Workers at the Dicalite division of Grefco, Inc. have found the fossil skeleton of a baleen whale some 10 to 12 million years old in the company's diatomaceous earth quarries in Lompoc, Calif. They've found fossils there before; in fact, the machinery operators have learned a good deal about them and carefully annotate any they find with the name of the collector, the date, and the exact place found. Each discovery is turned over to Lawrence G. Barnes at the Natural History Museum of Los Angeles County. The whale, however, is one of the largest fossils ever collected anywhere. It was spotted by operator James Darrah, and Dr. Barnes is directing the excavation.

The whale is standing on end in the quarry and is being exposed gradually as the diatomite is mined. Only the head and a small part of the body are visible as yet. The modern baleen whale is 80 to 90 feet long and has a head of similar size, indicating that the fossil may be close to 80 feet long.

The diatomaceous earth must be taken from around the fossil with great care because the bones are fragile and disintegrate quickly when exposed to air. As sections of bone are exposed, they are coated with a plastic cement, which hardens, and covered and reinforced with bandages of plaster and burlap. The head and forepart of the whale required 2400 lb of plaster and 700 yards of burlap 36 inches wide.

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(Diatomaceous earth supposedly accumulates extremely slowly. The question is, as it is in all cases of polystrate fossils, why didn't the whale decay and its skeleton disperse long before the carcass was covered up?)

A DECADE OF CREATIONIST RESEARCH

Gish, Duane T.; *Creation Research Society Quarterly,* 12:34-36, 1975.

<u>The Sisquoc Diatomite Fossil Beds</u>. Bernard Northrop researched the diatomaceous earth beds near Lompoc in Santa Barbara County, California. Evolutionary geologists have maintained that these beds formed gradually over vast periods of time, but Northrup's studies provided striking evidence of the rapid and catastrophic deposition of these beds.

In the Sicquoc area, countless billions of the delicately sculptured siliceous cell walls of diatoms (microscopic organisms) have been deposited in such a way that fish were entombed with bones and even body organs intact. Some fossil fish were trapped so that they lie parallel to the bedding plane of the diatom matrix, but many other fish fossils extend across the bedding plane. The latter fossils (standing partly on end) must have been buried quickly, or else the part not buried at first would have been devoured by scavengers, or would have decayed long before it could have been buried by a diatom "rain." Fossils of various fish, sea birds, and whales also indicate that the diatom material was deposited rapidly and catastrophically rather than by gradual and uniform activity.

Northrup postulated that the original diatom supply was first formed in cool waters after the Flood and was redeposited at the Lompoc site during a post-Flood catastrophe.

UPRIGHT TRUNKS OF NEOCALAMITES FROM THE UPPER TRIASSIC.....

Holt, Edward L.; *Journal of Geology,* 55:511-513, 1947.

The Calamites of the Carboniferous grew to great size. Trunks 30 feet long and 1 foot in diameter have been reported. The number of individuals must have been very great, for their casts and impressions are found in large numbers in Upper Paleozoic rocks.

When we come to the Mesozoic, however, the Equisetales, though still found, are rare, and those that have been reported are usually of small size compared with their Paleozoic predecessors.

The find described here from the Upper Triassic of western Colorado is therefore of more than passing interest, not only because of its rarity but also because of the large size of the fossil trunks. Furthermore, the plants are all still in the vertical position of growth, and consequently have not been compressed or distorted.

These fossils were first discovered by the writer in the spring of 1942, but further study was interrupted by army service until 1946, when another trip was made into the area. The fossil locality is in west-central Colorado, on the south side of the Dolores River and about a mile from the town of Bedrock, Colorado.

Preliminary examination indicates that the forest here discovered is comparable in many respects to that of the celebrated Joggins, Nova Scotia, section of Carboniferous age, where upright trunks of Calamites and Sigillaria have excited the admiration of geologists since the days of Lyell, Logan, and Dawson. According to Charles Schuchert and C. O. Dunbar, some of the trees at Joggins have a length of 20 feet, and a few are 4 feet in diameter. While these trees from Joggins are much thicker than those described here, it is believed that these Triassic plants were fully as long. In both localities, however, the tops have been broken off, thus making it impossible to get a true picture of the actual height. A comparison of the photographs of the Colorado plants with those shown by Schuchert and Dunbar of the Joggins fossils shows a striking similarity.

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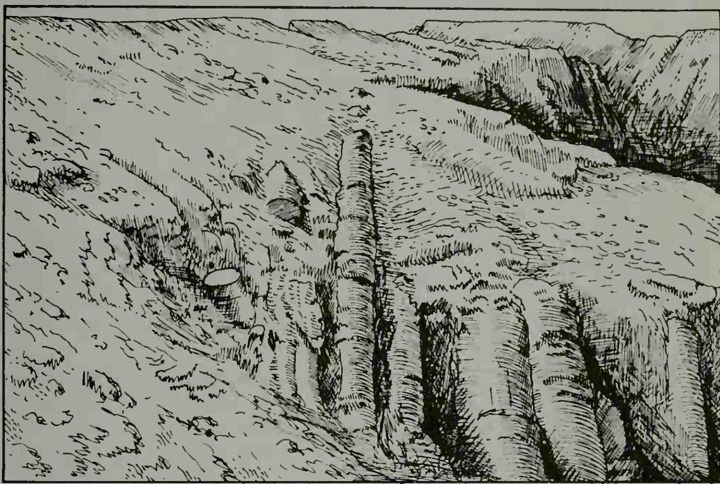
In this area the Chinle formation consists of micaceous red-brown sandstones, maroon sandy shales, and some thin limestone conglomerates. The sandstones are uniformly fine grained, few grains being large enough to be easily recognized. The red sands in which the fossils occur are also of very fine grain, and there is an absence of well-defined bedding planes. Two fossiliferous conglomerate layers, from 12 to 18 inches thick, containing Unio and bone fragments were found at the fossil-plant locality, one above the tops of the trees and the other just below the roots. These conglomerates carry limestone pebbles as much as 1/2 inch in diameter, together with well-rounded quartz and feldspar fragments.



Sketch of erect buried trees from the Upper Triassic in Colorado.

The fossil plants are embedded in this fine-grained sandstone between the two conglomerate layers and about 150 feet below the Wingate sandstone cliff. The trunks of the trees occur as casts, and some measure 12 inches in diameter. All trunks seen were in situ and in the vertical position of growth. They are quite close together. The trunks of five trees were fairly well exposed, and further search revealed the tops of many others projecting above the surface. A 15-foot section of one tree was removed, and some preliminary excavating was done in the hope of finding the roots, but this attempt was abandoned because of lack of time. Considering the 15-foot length of the specimen collected and the fact that the root was not reached that the top was broken off, it is estimated that these giant Mesozoic Equisetales may have reached a height of well over 50 feet. The casts themselves are fairly well preserved and solid and show quite clearly the parallel grooves fromed by the vascular bundles. The nodes and leaf scars are also well preserved, but no woody structure of the actual plant has yet been found. Although no leaf impressions were found, enough of the structure of the nodes is preserved to identify the plants as Neocalamites.

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Perhaps the most striking feature of the fossils is the evidence which they present of very rapid sedimentation. Although these hollow-stemmed plants, as now preserved, are about 20 feet high, yet they were rapidly and effectively buried before they could fall. The absence of coarse sediment and well-defined bedding planes in the strata apparently would indicate deposition under uniform conditions and probably by slow-flowing currents. Yet, if this is true, it is hard to see how slow-flowing currents could bury the plants before they fell. Possibly, sluggish, meandering streams, heavily laden with sediment, broke through natural levees of their channels onto the timbered low lands during the Chinle epoch of sedimentation and thus rapidly buried the trees.

Another problem is how the sands got into the hollow stems to form the casts. Two possibilities are suggested. First, the tops of the trees may have been broken off after rapid sedimentation had buried some 20 feet of their trunks, and sand then had access to the hollow interiors. A second possibility is that they were completely buried before the woody structure of the outside decomposed, thus allowing for the formation of molds, which were subsequently filled with sands. A careful search has revealed no trace of any woody structure; consequently, the writer is inclined to believe that the tops of the plants were broken off and the hollow interior subsequently filled with sand.

BURIED FOREST TELLS GLACIAL TALE

Anonymous; *Science News*, 113:229-230, 1978.

A forest of hundreds of erect spruce trees, some of them up to two feet in diameter, has been accidentally unearthed from more than 25 feet below the surface of a Michigan bog, where it had been buried for 10,000 years. Unearthed during a mining company's excavations about 15 miles from Marquette, the forest may lead to rewriting the history of the great glaciers that alternately advanced and retreated across what is now Lake Superior.

The trees were discovered by heavy-equipment operators of the Cleveland Cliffs Iron Co., who were digging in an area now called the Gribben Basin to make a pit in which to deposit mine tailings. At depths of 25 to 30 feet they encountered a layer of "gravel," in which were the tops of the trees. Further excavation revealed the surviving portions of the trunks to be from 12 to 15 feet high, with growth rings indicating that they had lived as long as 150 years. The 800-foot-wide pit ended up being about 2,000 feet long, with trees over all but about the last 300 feet of length.

One of several vertical spruce and tamarack trees about 10,000 years old found 6 to 11 meters below the surface in Michigan. (John D. Hughes)

Soil and rock deposits in the pit suggest that the forest was drowned by the melt-water preceding a glacier that advanced upslope toward the trees and cut off their natural drainage. The "gravel," carried along with the water, apparently ground off the trees' upper portions.

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The wood in the Gribben Basin trees was "remarkably well preserved," says Merry, with only the bark and a fraction of an inch of the outer layer showing carbonization. The only comparable finds, according to Hughes, have been a glacial forest unearthed about 50 years ago at Two Creeks, Wis., showing the 11,850-year age, and a 6,000-year-old one discovered in Cochrane, Ontario, about 300 miles northeast of the Gribben site.

• Growth Rhythms in Fossils

NAUTILOID GROWTH RHYTHMS AND DYNAMICAL EVOLUTION OF THE EARTH-MOON SYSTEM

Kahn, Pater G. K., and Pompea, Stephen M.; *Nature*, 275, 606-611, 1978.

Abstract. Daily growth lines and lunar monthly septa are formed in *Nautilus pompilius* Linnaeus shells. The number of days per lunar month determined using fossil shells has increased dramatically during the last 420 Myr, indicating that during this period the Moon revolved more rapidly and was much closer to the Earth than has previously been expected.

Introduction. The hypothesis that the Moon and Earth have been closer in Phanerozoic times has received considerable support from studies of the growth cycles of corals, bivalves, brachiopods and stromatolites, as well as from astronomical studies of tidal friction. These studies yield information about the rotation rate of the Earth, or the number of days per year, which is consistent with a closer and faster revolving Moon in earlier times. Tidal friction, by which bulges raised in the oceans by the Moon exert a torque on the Moon, implies the gradual expansion of the lunar orbit as well as an increase in the length of day with time. Both of these predictions have been confirmed for recent years by occultation measurements, and for historical times by studies of ancient eclipses. Unfortunately, the past dynamics of the Earth-Moon system cannot be derived solely from theoretical calculations based on recent and historical astronomical observations since tidal friction is critically dependent on sea level and continental configurations, both of which have changed markedly in the geologic past. Since an accurate charting of lunar orbital evolution has profound implications on lunar origin theories and on cosmological theories which predict lunar orbital expansion as a consequence of a varying gravitational constant, another approach is needed.

One viable approach to prehistoric lunar dynamics is through palaeobiology. Nautiloids are organisms which possess a long evolutionary history (~500 Myr), but until now, they have not been investigated as possible geochronometers. We shall examine the hypothesis that there are daily and lunar monthly growth records preserved in the shells of *Nautilus*, and also in the fossil nautiloid shells beginning in the Ordovician, and discuss the implications for the evolution of the Earth-Moon system. This synthesis suggests that the rate of lunar orbital evolution has been much greater in the past 420 Myr than short-term astronomical studies and theoretical calculations indicate.

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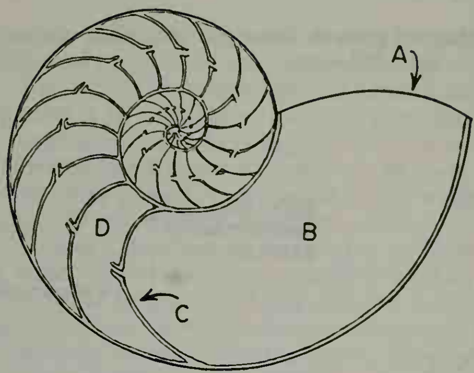
Growth line counts. The chambered cephalopods, including nautiloids, are probably among the most accurately dated of all fossils, due to their rapid evolution and extensive preservation in sedimentary deposits around the world. Fossil nautiloid growth lines are quite easily discerned, well preserved, and unambiguous, as shown in the photographs of growth lines.



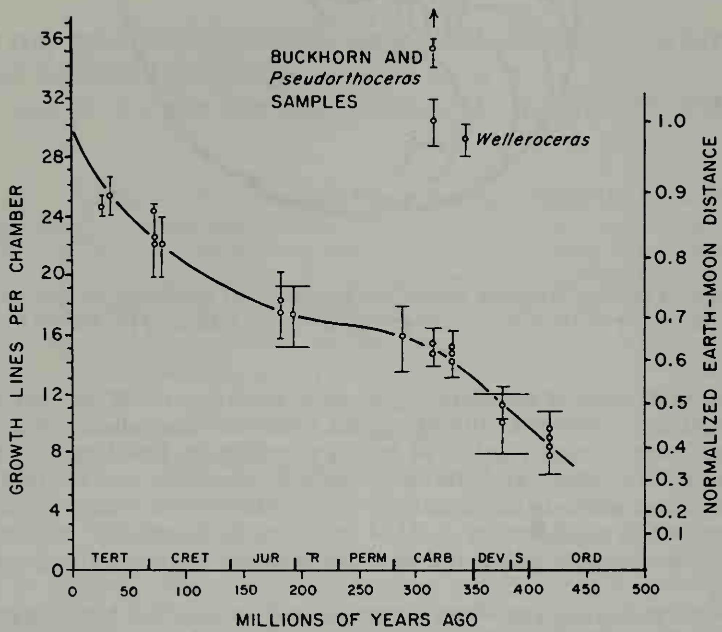
Section of a shell of Nautilus pompilius *showing: (A) aperature margin where growth lines occur; (B) body chamber; (C) chamber wall; and (D) chamber space.*

The growth rhythm of nautiloids appears to manifest itself not just in regional settings. For example Aturia sp. found in Australia exhibits essentially the same growth rhythm as Aturia curvilineata found in Florida. As nautiloid growth lines are believed to be daily in nature and not tide-induced, determination of the nature of the tidal cycles present in the animal's habitat is unnecessary. All of the above factors fulfill criteria essential for reliable and useful nautiloid growth line counts in geochronometry.

Growth lines are present on many superbly preserved fossil specimens. Growth lines on N. pompilius were examined and photographed using a scanning electron microscope or a stereoscopic optical microscope with oblique light to accentuate the growth lines.

The number of growth lines per chamber was counted on 184 different chambers of 9 recent and 29 fossil nautiloid specimens. The specimens represent nine geologic periods and a range of about 420 Myr. Figure 1 illustrates the structure of the N. pompilius shell, showing the location of growth line counts. Figure 2 [not reproduced] reveals the distinct growth lines on the ventral side. All of the counts of growth lines per chamber for consecutive undamaged chambers of recent N. pompilius approximated 30. For individual chambers, the number of growth lines ranged from 28 to 34; the average for all chambers of all specimens was 30 ± 2. The radial lirae, or ridges, on the internal layer of the initial whorl of three N. pompilius specimens were counted, consistently revealing 26-32 lirae per chamber, an average of 29 per chamber per specimen.

As we go back in geologic time, the number of growth lines per chamber decreases. The number of growth lines per chamber had increased from 9 at 420 Myr ago to 30 today. Three broad conclusions can be drawn from our data. First, the number of growth lines per chamber is constant for the various chambers in a single specimen. Second, many of the nautiloids living at any given time secrete the same number of growth lines per chamber. This seems to imply a ubiquitous rate of septal and outer shell deposition at any particular geologic time. Third, and most important, the number of growth lines per chamber decreases with increasing geologic age. (pp. 606-607)



Number of growth lines per chamber length and the earth-moon distance versus geological time.

PALEONTOLOGICAL EVIDENCE OF VARIATIONS IN LENGTH OF SYNODIC MONTH SINCE LATE CAMBRIAN

Pannella, Giorgio, et al; *Science*, 162:792-796, 1968.

The scanty paleontological evidence on the number of days per year and per synodic month in the geological past now available in the literature has been accepted and used by geophysicists as support for their astronomical calculations and theories on the earth-moon system. The evidence seems to confirm the assumption that the tidal torque has affected the earth's rotation rate in a uniform fashion and that the slowing down is in agreement with the rate of 2 milliseconds per century extrapolated from modern observations. The paucity of paleontological data renders this conclusion highly speculative, and much more data must be gathered before it becomes tenable. Although preliminary, the results presented here may help to provide a firmer foundation for geophysical theories.

Before we discuss the data, it would be appropriate to pose the question: how reliable and precise is the information derived from paleontological clocks? Circadian rhythms regulate almost universally the world of living matter, and it is reasonable to think they may leave a record in the skeleton of continuously growing organisms. In fact, there is a large enough body of information on growth bandings in many taxons to justify the conclusion that daily growth increments are a widespread feature in the organic world. Do these daily bandings, however, record solar or synodical time? From experiments on bivalve mollusks it is safe to conclude that solar time is the basic unit reflected in the increments and that synodical time, at least in intertidal and shallow subtidal bivalves, is expressed in the thickness of the increments. During periods of particularly faborable time, such as summer-spring tides, the mantle of certain bivalves expands outward and deposits a ridge. In other bivalves ridges are formed once every synodic month. Generic, specific, and individual differences should be carefully weighed in interpreting the growth patterns. Breeding events, which in many organisms seem to be related to moon phases and to tides, also leave a record on the growth patterns and may be useful in detecting synodical periodicity. When dealing with fossils, however, difficulties arise. Poor preservation, ambiguity of growth patterns, and lack of modern representatives make the counts of growth increments highly subjective. In general, growth patterns record fewer increments than actual days. The gaps in the record, which are randomly controlled by the environment, affect the degree of precision of the information since there is no way to establish the ratio for each specimen. The degree of resolution required by geophysicists is higher than the precision obtainable from the paleontological-clock method when based on the few data so far gathered. Hopefully, with the use of many different taxons, not only corals or bivalves, integrated data will be gathered and the resolution of the method will be enhanced.

Our paleontological evidence for the length of the synodic month is listed in Table 1. [omitted] Most of the data were obtained from bivalves, the exceptions being the cephalopod counts for the Lower Pennsylvanian and the stromatolite counts for the Upper Cambrian. For control and comparison, counts from the Recent bivalve Mercenaria mercenaria from New England are also shown. Counts of growth patterns clearly incomplete or difficult to interpret have been omitted. Due to the difficulty of finding countable seasonal patterns in mollusks older than Cretaceous, only synodic-month patterns are considered here. For each specimen the average number of days per synodic month, the standard deviation, and the standard error are tabulated. The average value of 29.17 for the Recent is 1.0 percent less than the actual value for the synodic month. The ratio of 29.53 to 29.17 should be used to correct all the other values for bivalves, but, considering the variations of the averages, we did not dare to assume that this ratio is constant and characteristic for bivalves. Because we are more concerned with the shape of the curve that can be drawn from these data than with the absolute values for the geological past, we thought that the correction could be omitted.

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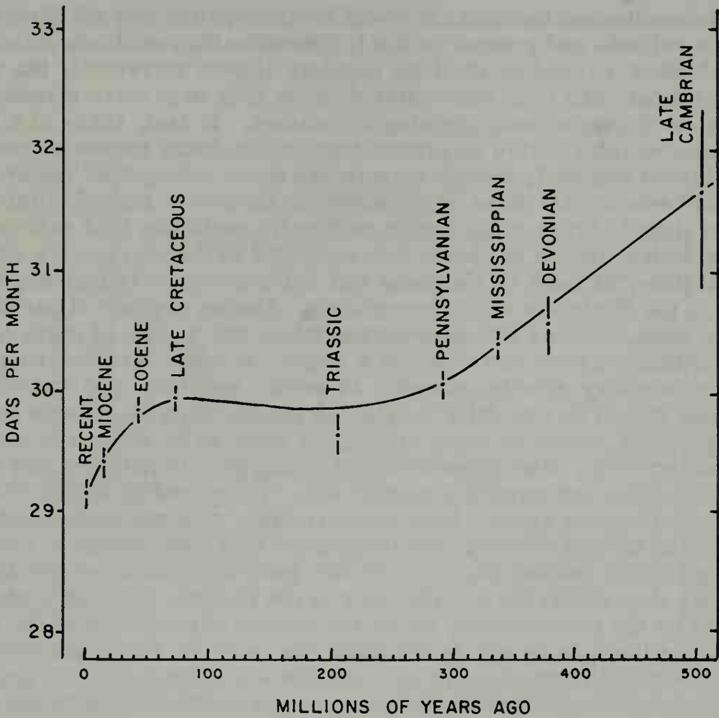
On the basis of this analysis it would appear that the slowing down of the earth's rotation has not taken place at a uniform rate. Two major breaks in slope allow a tripartition of the curve: two parts with a slope higher



Variations in the length of the synodic month through geological time as measured by fossil clocks.

than the predicted one, between Upper Cambrian and Pennsylvanian and between Upper Cretaceous and Recent, and one part with a slope lower than the predicted one between Pennsylvanian and Upper Cretaceous. This latter part of the curve spans more than 200 million years with only one insecure control point for the Middle Triassic. Even though any speculation on the trend of the curve within this span is premature, the end points indicate that from Pennsylvanian to Upper Cretaceous the slowing down has been negligible. It is tempting to relate the changes in slope to some hypothetical events in the earth's history. For instance, if the slowing down since the Late Cambrian is attributed mainly to the loss of energy due to tidal torque in shallow seas, then a different distribution of continents and oceans, and continental shelves and shallow seas would affect the amount of energy dissipated and the rotation rate of the earth. The idea that continental breaking down has not been a uniform process but has taken place in episodes of rapid drift, with little or no drift in between, has been suggested. The high slope between the Cretaceous and Recent could be attributed to the rapid drift episode of the Upper Cretaceous, which probably increased the tidal dissipation by broadening the proto-Atlantic and to the rise of the Alpine orogenic belt which created widespread shallow seas open to oceanic water masses. The lower rate of slowing down between Pennsylvanian and Cretaceous could be somehow related to the phenomena that caused the longest and most persistent period of worldwide regressive seas during Lake Permian, Triassic, and Jurassic. The only way to account for large tidal dissipation rates in pre-Pennsylvanian time, when the Atlantic was not yet formed, would be the presence of extended shallow seas connected with the Pacific Ocean. Paleogeographic maps do show shallow seas along the rim of the Pacific in Asia and in the Americas.

Other assumptions, as speculative as this of the slowing down due mainly to tidal dissipation in shallow seas, can be made; but no matter what theory one likes best, the changes in slope must be related to events that profoundly affected the earth and that left other observable clues. The paleontological evidence presented does show, however, that the deceleration rate has not been constant through time, and that, by using the growth patterns of organisms, it will be possible to shed light on events that affected the general distribution of oceans and continents in the past.

CAMBRIAN FOSSILS AND ORIGIN OF EARTH-MOON SYSTEM

Lamar, D. L., and Merifield, P. M.; *Geological Society of America, Bulletin,* 78:1359-1367, 1967.

Abstract: Analysis of available data on the lunar torque and the mechanism and rate of tidal dissipation and studies of growth lines on Paleozoic corals imply that the Moon became an Earth satellite between 0.5 and 2.0 billion years ago. Origin of the Earth-Moon system by fission or close-capture would have left obvious indications in the geologic record. The absence of such indications is compatible with an origin by capture-at-a-distance or the aggregation of several smaller moons. Evidence of a noncatastrophic origin may nevertheless be present in the stratigraphic record as a consequence of greatly increased tidal ranges and tidal currents and the introduction of a lunar light cycle. Shallow-marine invertebrates, which are highly sensitive to changes in environment, would have been affected by the origin of the Earth-Moon system, and a causal relation with the appearance of hard-shelled marine organisms in Lower Cambrian strata is conceivable. Protective exoskeletons would be an adaptive characteristic for shallow-water bottom-dwellers suddenly confronted with powerful tides. If the origin of the Earth-Moon system provided the impetus for the evolution of hard-shelled organisms, the event occurred in late Precambrian time.

STROMATOLITES USED TO DETERMINE THE TIME OF NEAREST APPROACH OF EARTH AND MOON

Walter, M. R.; *Science,* 170:1331-1332, 1970.

In recent articles and discussion in Science, the use of fossil stromatolites to determine the time of closest approach of the moon to the earth has been considered. Cloud interpreted his stromatolite data as consistent with the view that this time was about 3500 million years ago, a time that he favored for other reasons. Alfven and Arrhenius interpreted the same data as indicating the latest Precambrian (600 to 700 million years ago) as the time of closest approach. These interpretations are based on the belief that, although some presently growing stromatolites are subtidal, "stromatolites that rise conspicuously above the surface on which they grow have so far been found only in the intertidal environment," and, furthermore, that their maximum growth relief equals the tidal amplitude. This, in turn, follows from Logan's interpretation of modern stromatolites in Shark Bay, Western Australia.

Figures quoted by Cloud are interpreted by him as showing that domal Precambrian stromatolites, and especially those older than 1000 million years, had a greater growth relief than younger forms. This, he concludes, is consistent with the hypothesis of moon capture and closest approach during the Early Precambrian. The largest stromatolites mentioned by Cloud are 6 m high and occur in the Otavi "Series" in southwestern Africa. Cloud gives the age of these only as Proterozoic, but they probably are latest Precambrian; this is one reason why Alfven and Arrhenius think that Cloud's stromatolite data fit meteorite evidence suggesting to them that closest approach of the earth and moon was about 600 to 700 million years ago. Alfven and Arrhenius state that the oldest known stromatolites, those from the Early Precambrian of Rhodesia, are only 3 to 4 cm high, a height which suggested to them that tides then were very small. In fact, domed layers within these stromatolites have a relief of up to about 60 cm, as Macgregor's illustrations show. Olsen and Alfven and Arrhenius do not believe, as Cloud does, that moon capture and closest approach to the earth were necessarily simultaneous (in terms of geological time); thus they can accept Cloud's evidence for large lunar tides throughout the Middle and Late Precambrian while postulating the latest Precambrian as the time of closest approach.

A point not mentioned in earlier discussions is the fact that in Early to Middle Cambrian rocks (about 570 to 515 million years old) near Lake Baikal in Siberia there are large domal and subspherical stromatolites up to 15 m high. Individual layers within these have a relief of 5 to 6 m and in some illustrations appear to reach 15 m, although this is not clear. Laminae are not shown in the illustrations, but if successive layers (groups of laminae) have this much relief, then during growth the stromatolite itself must have projected at least this far above its substrate. Thus some Cambrian stromatolites during growth were as high as, or higher than, any known Precambrian forms, and those known Precambrian stromatolites with the greatest growth relief are probably latest Precambrian in age. Therefore if stromatolites are used as indicators of former tidal ranges, one would have to conclude that the largest tides occurred during the Cambrian and latest Precambrian. On the basis of geological evidence, Cloud has discounted the possibility of a very close approach of the earth and moon at that time.

Doubt is cast on these interpretations by the fact that only rarely is there firm evidence that Precambrian stromatolites actually grew in an intertidal environment. Many may have formed subtidally. Furthermore, a recently published observation shows that the assumption that large domal stromatolites could grow only in the intertidal zone is invalid. Playford and Cockbain have very elegantly and cogently demonstrated that

Devonian stromatolites in Western Australia grew in water as deep as 45 m; they state that some of these are "mound-shaped" (the type considered here). These mound-shaped stromatolites had a growth relief of 30 to 150 cm. They occur in the fore-reef facies of Devonian reef complexes, where geopetal structures indicate depositional slopes. Thus an interpretation based on the single published record of Recent stromatolites conforming in growth relief to the tidal amplitude is contradicted by evidence from the geological record. The conclusion that the growth relief of Precambrian and Cambrian stromatolies necessarily indicates the contemporary tidal amplitude is unwarranted.

BIOLOGICAL EXTINCTIONS

According to the evolutionists' view of life, some species cannot cope and drop out of the fossil record. Species extinction, therefore, is to be expected. If, however, many diverse species are extinguished simultaneously, one is impelled to at least search for a common cause beyond normal evolutionary attrition. Some form of catastrophism is usually invoked. Nearby supernovas, collapses of the earth's magnetic field, severe climatic changes, and so on are the most popular stimuli. But catastrophism is to modern geology as alchemy is to chemistry---it does not lend itself to the scientific method.

Nevertheless, the fossil record seems to show many widespread, abrupt terminations (and also flowerings). These purported "crises of life" reveal several intriguing factors:

1. Some claimed extinctions apparently extend over millions of years and can hardly be called catastrophic.
2. The extinctions seem crudely cyclic, inferring some regular, probably extraterrestrial mechanism.
3. Some species did not succumb. Terrestrial plants especially seemed to escape the cosmic ax.
4. Many extinctions are correlated with magnetic reversals in the strata, which may mean that the earth's magnetic field reversed near the time of the extinction.

There is no universal agreement on the reality of biological extinctions in the fossil record. The agent of death, if such existed, is even more controversial.

The distribution and physical condition of fossils sometimes support the idea of catastrophism. The early geologists were greatly impressed with the bone caves and bone-filled fissures found in northern Europe. Ancient catastrophes, deluges in particular, seemed inescapable to Cuvier, Buckland, and their contemporaries. Bone caves have since been found worldwide. They are filled with immense accumulations of diverse, jumbled, smashed bones that certainly suggest environmental turmoil.

Down deeper in the planet's strata are bone beds, bone breccias, and layers jammed with incredible concentrations of fossils. The bone beds and breccias are generally mixtures of unconnected bones. But in some of the great fossil beds, the close-packed life forms reveal no signs of violent death. Was the Grim Reaper gentle at these times while still very thorough?

• Puzzling Extinctions in the Fossil Record

MASSIVE EXTINCTIONS IN BIOTA AT THE END OF MESOZOIC TIME

Bramlette, M. N.; *Science,* 148:1696-1699, 1965.

Record of the Fossil Plankton. The succession shown in Fig 1 for the distribution of calcareous nannoplankton is evident from the direct superposition of strata in Alabama, and is similarly clear for the Danian resting directly on the earlier strata in Denmark and France. The correlation and age assignments agree with those from most recent studies of the foraminifera and other groups of fossils. Samples containing vast numbers of nannoplankton (dominantly protophyta) from the indicated taxa were taken from within a few meters below and above the top of the Mesozoic strata (upper Maestrichtian and the equivalent in Alabama). The skeletal remains of the marine calcareous plankton (nannoplankton and planktonic foraminifera) constitute about one-half the total in these chalk formations---countless millions of the "nanofossils" (upper Maestrichtian and the equivalent in Alabama). The skeletal remains of the marine calcareous plankton (nannoplankton and planktonic foraminifera) constitute about one-half the total in these chalk formations---countless millions of the "nanofossils" (averaging less than 10 microns) occurring in a few cubic centimeters of the chalk. The distribution of the identified taxa of nannoplankton shown in Fig. 1 is fairly representative of other known regions.

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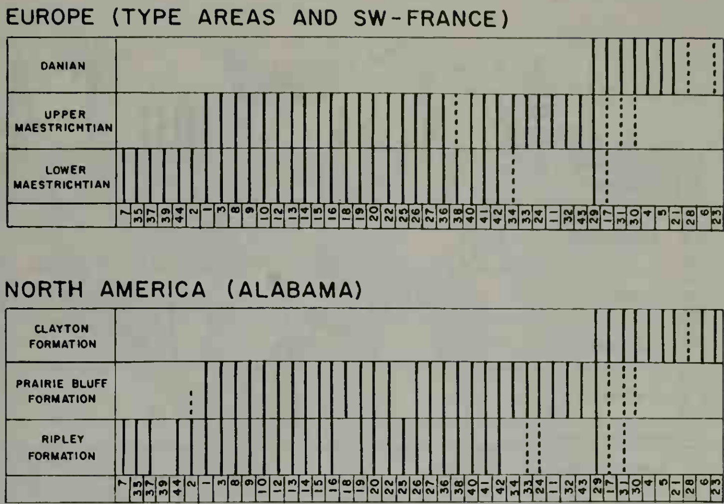
The data on calcareous nannoplankton and planktonic foraminifera are now adequate to indicate this world-wide extinction of most of the distinctive taxa, and to show that the extinction of these large populations was so abrupt that the stratal record of transition still remains obscure. A record, even though an abbreviated one, will doubtless be found which shows diminished numbers of Cretaceous taxa and individuals associated with progenitors of the few early Cenozoic forms. Although some stratal discontinuity is commonly found at this horizon, much evidence indicates that the hiatus was not a long one in geological time, particularly because any large



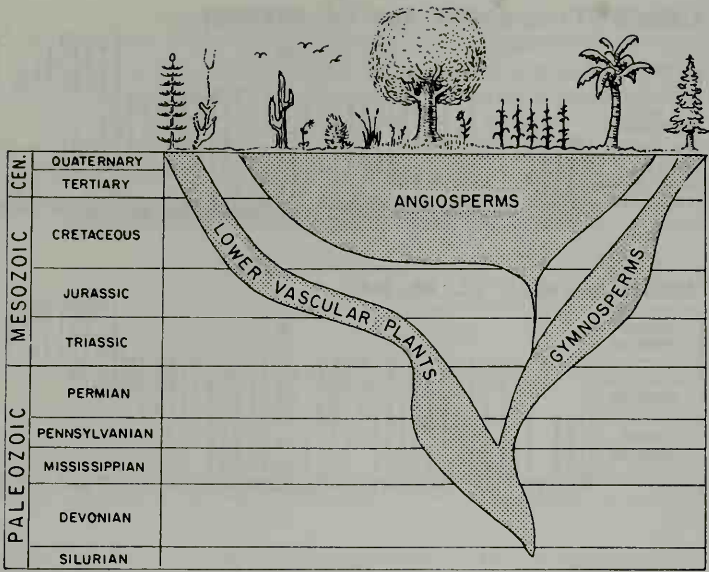
Distribution of calcareous nannoplankton from equivalent European and North American strata, illustrating the global nature of most extinctions. Numerals correspond to taxa names. (See Bramlette and Martini, Micropalaeontology, *10:295, 1964.)*

record of deposition missing in some areas should be represented by sedimentation elsewhere. The hiatus thus may involve many thousands of years but probably much less than a million; comparable changes in the fossil record normally require some millions of years. Such a long period of existence during Mesozoic time is indicated for many of the planktonic taxa which became extinct at the close of that era. It required several million years also for the meager assemblages of the nannoplankton and planktonic foraminifera surviving into the earliest Cenozoic to develop diversification comparable to that found in the late Mesozoic. (p. 1697)

CRISES IN THE HISTORY OF LIFE

Newell, Norman D.; *Scientific American,* 208:76-82, February 1963.

The fossil record of animals tells more about extinction than the fossil record of plants does. It has long been known that the major floral changes have not coincided with the major faunal ones. Each of the three successive principal land floras---the ferns and mosses, the gymnosperms and angiosperms---were ushered in by a short episode of rapid evolution followed by a long period of stability. The illustration shows that once a major group of plants became established it continued for millions of years. Many groups of higher plants are seemingly immortal. Since green plants are the primary producers in the over-all ecosystem and



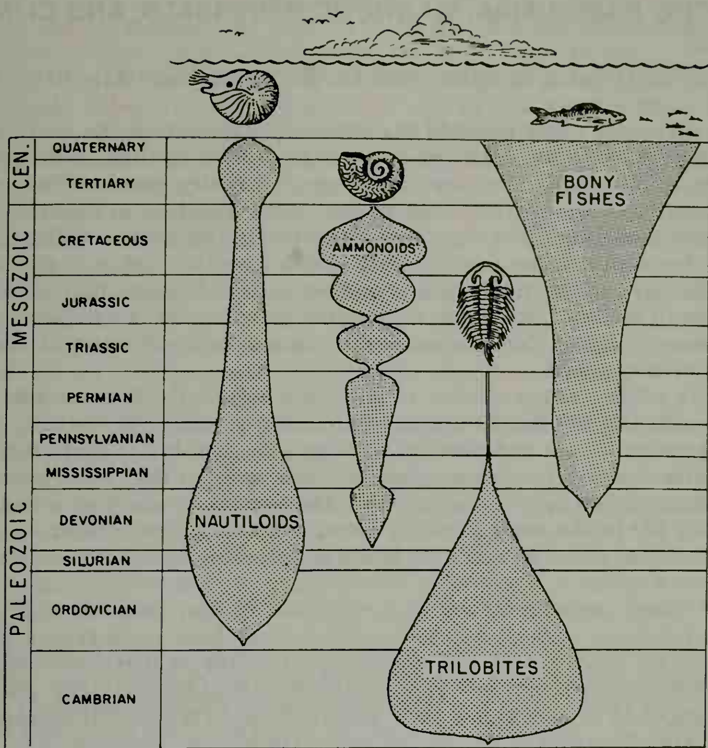
Land plants show remarkable resistance to extinction. The widths of the bands are proportional to the number of genera. Angiosperms have obviously been very successful in recent times.

animals are the consumers, it can hardly be doubted that the great developments in the plant kingdom affected animal evolution, but the history of this relation is not yet understood. (pp. 78-79)

MASS EXTINCTIONS AT THE END OF THE CRETACEOUS PERIOD

Newell, Norman D.; *Science*, 149:922-924, 1965.

I have cited evidence [(Sci. Amer. 208, 76 (Feb. 1963)] that extinctions of the past display a spectrum of patterns ranging from apparently catastrophic revolutions in the faunas of the world to very slow selective and evolutionary replacement. For the former, I have sought general, rather than specific, causes because some of these mass extinctions have involved both terrestrial and marine animals and have recurring rhythms that would seem to eliminate unique causes. Bramlette considers the apparent synchroneity of extinction of land and sea organisms as unproven and possibly a result of circularity in the method of stratigraphic paleontology, in which rocks are dated by fossils and fossils are dated by the rocks that contain them. However, there cannot now be any reasonable



Marine life forms have waxed and waned during geological time, as illustrated by the widths of the bands.

doubt that these and comparable changes in world faunas were compressed into time intervals that were very short as measured on the scale of geologic time. It seems to me reasonable to conclude that worldwide vicissitudes among organisms were the result of recurring general ecological disturbances that destroyed the most fragile populations of both land and marine animals. Extinctions on a massive scale clearly were highly selective among animals, affecting some groups while sparing others, but it is one of the unsolved problems of paleontology that plants were not simultaneously and equally affected by crises in the animal kingdom.

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ANTARCTIC RADIOLARIA, MAGNETIC REVERSALS, AND CLIMATIC CHANGE

Hays, James D., and Opdyke, Neil D.; *Science,* 158:1001-1011, 1967.

Summary. Our study extends the continuous record of the earth's magnetic field to more than 5 million years ago; it defines three new magnetic normal-polarity events and one new normal-polarity epoch. One core (E13-3) has a sufficiently constant rate of sedimentation to enable one to make reliable estimates of the ages of the three new events. The age of the upper boundary of the new polarity epoch is estimated at 5 million years. Because of the many new magnetic events and epochs that will be found through study of deep-sea sediments, we propose a numbering system that may simplify designation and increase the usefulness of marine magnetic stratigraphy.

The rate of deposition of clay in the cores is relatively constant, fluctuations being largely due to variation in amount of biogenic silica.

The cores contain a radiolarian stratigraphy similar to that reported, and they also record disappearances of other species that make possible the definition of two new faunal zones. The upper boundary of one of these zones (Y) is the most striking faunal change yet encountered, occurring at about the same time as evidence of climatic deterioration in other parts of the world.

All the faunal boundaries are time-dependent; four coincide with reversals, or almost so. Change in temperature may have been responsible for some of the boundaries, but not apparently, for at least one. The close correspondence between reversals and faunal boundaries, whether or not changes in temperature were involved, adds a new dimension to the perplexing question of planktonic extinctions.

MASS EXTINCTIONS CORRELATED WITH PERIODIC GALACTIC EVENTS

Hatfield, Craig B., and Camp, Mark J.; *Geological Society of America, Bulletin,* 81:911-914, 1970.

Discussion. We are impressed by the lack of emphasis placed on the periodicity of mass extinctions. As mentioned by Newell and Simpson, the seven most intense mass extinctions, based on percentages of the total known fossil assemblage affected, were late in the Cambrian, Ordovician, Devonian, Permian, Triassic, Cretaceous, and Tertiary Periods; the two most catastrophic extinctions occurred near the ends of the Cambrian and Permian Periods. The late Cenozoic wave of extinctions probably is still in progress and, thus, could also be exceptionally catastrophic by the time of its completion. This yields an average of approximately one significant interval of mass extinction every 80 to 90 m.y. and one exceptionally catastrophic mass extinction every 225 to 275 m.y., if we include the current (late Cenozoic) extinction. Each interval between successive times of exceptionally catastrophic extinctions yielded two significant, but less catastrophic mass extinctions. Thus, the biologic crises of Late Cambrian and Late Permian ages are separated temporally by the less intense extinctions of Late Ordovician and Late Devonian times. Similarly, two ages (Late Triassic and Late Cretaceous) of mass extinction succeeded the Permian catastrophy and preceded the late Cenozoic one.

Beginning with the Late Cambrian extinctions of roughly 500 m.y. ago, the intervals between "times of great dying" have averaged 80 to 90 m.y. and may have ranged from approximately 50 to 100 m.y. in duration. Clearly, there is very low precision in our statement of the lengths of these intervals between extinctions. The limits of precision in radiometric dating are compounded by the facts that each mass extinction occurred over a span of millions of years and is documented by an incomplete fossil record.

If mass extinctions do occur with a degree of temporal regularity, their periodicity should be considered in any postulated cause for the extinctions. Known regular events with such long periodicity are not numerous and, so far as the authors are aware, may be expected only in the realm of astronomy.

Estimates of the time required for one revolution of our galaxy in the vicinity of the sun range from 200 m.y. to 280 m.y. and include intermediate values. During one orbit around the galactic center, the sun completes between two and three vibrations perpendicular to the galactic plane or one oscillation perpendicular to the galactic plane every 80 to 90 m.y. Thus, there is an apparent crude correlation between the galactic position of our solar system and recorded faunal extinctions on earth.

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Conclusions. An apparent correlation between periodic galactic events and mass extinctions in earth history suggests cosmologic control of the amount of radiation incident upon the Earth's surface either directly through change in our position in the galactic distribution of radiation or indirectly through control of the Earth's magnetic field by that of the galaxy.

Earlier conclusions that increases in cosmic radiation would be too small to produce appreciable mutagenic damage may fail to consider the important effect of the time involved in a mass extinction and the immensity of time available for accumulation of deleterious genetic changes.

• Bone Caves and Fissures

THE DELUGE, ITS EVIDENCE AND PROBABLE CAUSE

Key, H. C.; *English Mechanic,* 16:504-505, 1873.

In every quarter of the globe that has been explored by geologists are found bone-caves (now a familiar term); the largest number of these caves hitherto met with in any single country appears to be in Brazil, where M. Lund has examined more than 800. Algeria, Syria, Italy, Sicily, France, Germany, and England, all contain many important examples of these caves, which have been examined by competent geologists. I may instance as especially worthy of mention the Grotta perciata and San Teodoro in Sicily, the Engis and Engihoul caverns in Belgium; in France the caves of Souvignargues, of Lunel-Viel, near Montpellier, of Lherme, of Lombrive, a remarkable one in a hamlet in the commune of Vallieres, the caves of Arcy, and the Brixham caves near Torquay.

These caves contain, generally speaking, three distinct deposits. (1) the first or lowest consists of mud, with pebbles, rolled flints, and pieces of rock; also the remains of Elephas primigenius, Bos prim., elk, horse, cave-bear, hyena, &c., likewise human bones and flint knives. This deposit corresponds exactly with the lower quarternary dilluvial formation known as the Drift, and is of the same period.

(2) The second layer formed in the bone caves consists of altogether different materials, and is of later origin; it consists of argillaceous mud or marl, and contains the remains of the horse, ox, boar, and numerous rein-deer; but those of elephants, bears, and hyenas are not found. The remains of species closely allied to existing ones are found, as well as of animals of the present day, as fox, dog, sheep, &c. In it are also found more perfect human implements and works of art than in the deposit below it. The remains found prove this deposit to be of the same age as the Loess, or alluvial soil of our valleys.

(3) Again, in certain caves is found a third layer, still more recent, in which the remains only of existing animals are met with, and articles of human workmanship, pottery, polished stones, &c., indicating a far more advanced period of art than the remains found in the two lower deposits. This deposit corresponds with the latest formation of the quarternary period called the Red Diluvium.

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A PLEISTOCENE CAVE DEPOSIT OF WESTERN MARYLAND

Gidley, J. W.; *Smithsonian Institution Annual Report, 1918,* pp. 281-287.

In the spring of 1912 there was brought to the United States National Museum, for inspection and determination, a portion of a lower jaw recognized as belonging to an extinct and hitherto unknown species of the wolf kind, together with a few other fossil bones which had been picked up from the bottom of a newly excavated railroad cut about 4 miles northwest of the city of Cumberland, Maryland. These specimens had been sent in and were afterwards presented by Mr. Raymond Armbruster, a local amateur collector of Cumberland, and his uncle Mr. George Roeder, of Swetnan, Virginia. The fossils at once aroused interest, and on invitation of these gentlemen, who reported good prospects of obtaining more such specimens from this recent excavation, a personal inspection was made. The cut is situated on the south side of Wills Creek Valley, where the tracks of the Western Maryland Railway pass westward through a low limestone ridge, or spur, to enter Cash Valley. The material from which the fossil bones had been taken was found to be a true cave deposit, presenting a small exposure, or outcrop, at the base of the almost perpendicular southern wall of the cut which at this point is about 100 feet deep.

This preliminary examination revealed the fact that, while great quantities of the bone-bearing material had been blasted out and carried away by the steam shovel, there still remained a considerable mass which had not been disturbed and which promised to be well worth a thorough exploration. Following the report of conditions and prospects to the museum authorities, a systematic excavation for the careful collecting of the fossil bones was undertaken. The deposit proved to be of considerable depth and extent, and very rich both in quantity and quality of fossils, which were exceedingly varied in kinds of animals represented.

The work, begun in the spring of 1912, proceeded at intervals as the limited available funds permitted, and was not completed until the spring of 1915. A preliminary report of the results of the first two expeditions was published in August, 1913. At this time there had been recognized in the collection, 29 species distributed among 6 orders of mammals. The work of the following two years yielded many more specimens, and among them were the best obtained at this locality. Incidentally these also added many new species to the list reported in 1913, so that the list now includes no less than 45 distinct species or kinds of mammals referable to seven different orders. To these may be added a few species of reptiles, including two snakes, and a species of alligator or crocodile. The actual identity of the latter is not certain, since it is represented by only a single tooth.

The mammals represented constitute a varied and, in some respects, strange assemblage. They range in size from a bat smaller than a house mouse to a mastodon which attained the size of an elephant. Probably none of these except the bats could properly be called cave living animals. Most of the species are now extinct, although many of the extinct forms belong to present day genera, and doubtless very closely resembled their living relatives. Among those animals referable to living genera are bats, shrews, squirrels, porcupines, ground hogs or woodchucks, field or pocket mice, wood rats, beavers, rabbits and picas, bears, wolves, lynx, wolverines, badgers, minks, martens, horse, tapir, deer, and possibly a large species of antelope, big as an ox, which seems to be closely related to the eland now living in Africa. The exact relations of this antelope, however, can not at present be stated with certainty, owing to the fact that two jars, carrying the cheek-teeth and a few scattered teeth and foot bones constitute all the remains now known of it. These differ but slightly in character from the corresponding parts of the eland, with which they were compared and this is why it was provisionally referred to the African genus. A more complete knowledge of the American animal may show that it belonged to an unknown group which is now extinct. Other extinct forms belonging to two or possibly three genera are related but are not ancestral to the living peccaries. The peccaries of the present day are considerably smaller in size and are confined in their habitat to tropical and subtropical America.

Many of the species in the collection are represented by bones of numerous individuals. Some of these are recognized by only a few jaw fragments containing teeth; others by numerous bones, including more or less complete skulls, jaws and other parts of the skeleton; while in all the assemblage only a single animal, and that belonging to one of the extinct species of peccaries, is represented by a nearly complete skeleton.

Most of the big bones and skulls of the larger animals were found broken, and with few exceptions all bones were scattered and indiscriminately mixed throughout the mass of clay and cave breccia. This condition of deposition may be readily understood, when the character of the cavern as it formerly existed is studied. As already stated the fossil-filled chamber, before the railroad cut exposing it to view was made, reposed at a depth of at least 100 feet beneath the surface of the ground, with which it was connected by a small and more or less irregular opening leading almost directly upward. This opening at the surface probably broadened out to form one of those depressions, or "sink holes," so frequently found in limestone regions, and doubtless acted as a natural trap for animals roaming in its vicinity, the cavern far below being the receptacle for their bones when the skeletons had become sufficiently macerated to fall apart and continue their downward journey through the small, irregular chimney-like opening. In this descent of a 100 feet or more it is quite evident how these bones became so broken and separated. The accumulation was probably gradual, extending possibly over hundreds of years, and this time element, in part at least, would account for the indiscriminate mixing of the bones of so great a variety of totally unrelated animals, most of which would not be found directly associated in life.

A critical study of these fossil bones, thus accidentally brought together and again accidentally discovered by man, unfolds a most interesting story of the mammalian life as it existed in the environs of western Maryland during some portion of the so-called "Glacial Period," or "Ice Age." It can not be assumed, however, that these 45 or more species included in the Cumberland Cave collection represent by any means all the different kinds of animals that lived in the locality at that particular period; for, it must be remembered, accident, as just stated, was the chief factor in the accumulation of this deposit, and doubtless many forms then inhabiting the region entirely escaped this pitfall and therefore left no record. Nevertheless, could one, looking backward some 50,000 or 100,000 years to that time, see only those forms represented in this collection as they appeared in life, a remarkable assemblage of creatures would be presented; more remarkable, in fact, than a glance at the list enumerated might at first indicate. One would at once recognize among these animals of the Pleistocene times, as already intimated, certain species very like some of those either living in the vicinity to-day or which have lived there within the history of civilized man. Then many others would be seen to resemble living forms now only inhabiting very far-distant localities; while still others would appear differing from any animal living anywhere in the world to-day.

Among those resembling living or recently extinct species of the neighborhood would be included two or three forms of bats, a small shrew, a wood rat, two or three species of pocket mice, a woodchuck, a "yellow" porcupine, a rabbit, possibly a wolf or two, a black bear, and probably a deer of the Virginia or white-tail variety. Most conspicuous and probably the most interesting feature of this ancient fauna is the large number of species which resembled present-day forms that are now known to inhabit only remote and, in some instances, very far separated localities. Among these may be especially noted the little coney rabbit, or picas, now confined in North America to the highest peaks of the Rocky Mountains; the Canadian porcupine, restricted in range to the western United States and Canada; the wolverine, a strictly boreal or northern animal abundant in the Arctic regions and not known to range farther south than northern Massachusetts, New York, and Michigan; a bear of the grizzly group, not known in recent times to have extended its range east of the great Plains States; a tapir, now confined to tropical zones; a horse, its kind in nature now confined entirely to the Old World; a certain species of bat now living in northern Mexico; and two or three species of wolves now living in the western and northern regions of North America, and in Siberia.

In contemplating this list one must bear in mind that the fossil and living forms compared, with few exceptions at least, are not identical species, but these fossil forms doubtless in life would have closely resembled their present-day relatives in general appearance and probably in habits.

The especially interesting phase of this fauna of the Cumberland Cave deposit, then, is the association of remains of animals whose modern relatives are now living under widely varying climatic conditions, as well as distant geographic ranges. And in referring to the lists enumerated above one might well ask what sort of climate prevailed in the western Maryland region during that portion of the Pleistocene in which this deposit of bones was being formed?

Crocodiles or alligators are not known to have ever existed outside of tropical or subtropical climates, and, moreover, cold-blooded saurians could not have inhabited a locality where the temperature was accustomed to fall much below the freezing point. The present day tapirs and peccaries also are confined to tropical and subtropical localities. The presence of these creatures then, and especially the crocodile, seem strongly to indicate a warm climate for our cave-deposit fauna. On the other hand, the wolverine is always considered a boreal animal, normally associated with cold climate conditions and martens and minks, too, for the most part, now inhabit northern or at least temperate zones, while the little picas or coney rabbits, to-day are found living only in the higher altitudes of the Rocky Mountains or some of the colder regions of Asia and eastern Europe. The presence, therefore, of these animals may be taken as almost equally strong evidence of cold climatic conditions.

How, then, may one account for this intermingling of animals of such widely varying climatic zones? There are at least three possible explanations. The first, and most unlikely perhaps, would be to suppose that the animals of the Pleistocene sufficiently differed in habits from their living relatives as to render comparisons entirely untrustworthy; or, second, that the accumulated fossil bones of this deposit represent a lapse of time sufficient for a gradual local change in climate, from mild subtropic to boreal or arctic, conditions (or vice versa), accompanied by a gradual and appropriate change of faunas; or third, and to me the most likely supposition is that the average temperature of the general region, at least of the lowlands and valleys, was warmer then than now, while the mountain ranges and peaks in the vicinity, being less worn down by erosion were probably much higher and therefore colder, possibly even snow capped.

Such a condition would naturally bring the boreal faunas much farther south than we now find them, while the valleys and lowlands might at the same time be inhabited with a distinctly southern fauna. A contributory cause for a more southern range of boreal forms may be found also in the probable fact that the southern extremities of the great pleistocene ice sheet were at the time not far distant from this particular region. Under these conditions, had they prevailed, a mixture of fossil remains of boreal and subtropic animals such as is indicated in the Cumberland cave deposit is very readily understood and may thus be satisfactorily explained. It might well be that animals of widely varied life habits could inhabit contemporaneously the same general region---the austral species occupying normally the lower, warmer levels, the boreal forms the colder regions of the uplands and mountain tops---while certain animals of each extreme might readily, during the course of seasonal changes, occupy alternately and temporarily an intermediate locality. Moreover, the very nature and occurrence of the fossil remains found in the cave mass suggests just such a possibility, while there was no evidence whatever of a gradual succession or displacement of faunas affecting the entire region which might have taken place during the period of the cave-deposit accumulation.

Nearly coincident with the Cumberland cave discovery, and quite as accidentally, a similar deposit was reported to the National Museum from a locality in West Virginia. This find did not prove nearly so rich as the former one, either in numbers of bones or kinds of animals represented, but is nevertheless of interest since it differs in some important respects from that of the Cumberland locality, while the fossils it contained show it to be about equivalent in age. The deposit was encountered in the course of developing a quarry in the limestone ledge situated on the west side of the beautiful valley of the Green Brier, near the little town of Renick.

Here the rock strata are nearly in their original horizontal position and the small cavern following the general line of stratification extended backward some distance into the side of the ledge with its original opening on the same level with the floor of the cavern instead of directly above, as at the Cumberland locality. This difference in physical structure is reflected, first, in the character of the deposit covering the floor of the cavern, it being a soft, loose cave-clay unmixed with broken stones; and, second, in the much fewer numbers, and less variety of bones found there. The few bones recovered for the National Museum, which include only one well-preserved skull, represent but a single species, and that species, strangely enough, closely related to or possibly identical with one of the large extinct peccaries of the Cumberland cave. Unfortunately, as in the case of the Cumberland find, the greater part of the bone-bearing material had been removed before any steps were taken to preserve the specimens it contained. It, therefore, is quite probable that bones of other animals had also found their way into this deposit, but hardly possible that there was anything like such a varied assemblage of animal remains as was formed at the Cumberland cave; for here there was no natural trap or pitfall to assist in their accumulation, and the bones of the Green Brier deposit seem to have been dragged there by some large carnivorous animal, which in Pleistocene times may have used the small cavern as a den; or possibly these large peccaries may themselves have occasionally sought its entrance for protection or shelter.

Among other notable discoveries in the United States of cave formations containing fossil bones are the Port Kennedy cave deposits of eastern Pennsylvania; the Potter Creek Cave, of Shasta County, California; and the "Conrad Fissure" bone deposit of northern Arkansas.

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In the Old World, and especially in Europe, discoveries of cave deposits containing bones of extinct species of animals have been more frequent than in America. This is probably due, in part at least, to the fact that much of the Old World is more densely populated and has been occupied by civilized man for a much greater period of time. Boyd Dawkins, a noted English scientist and writer has given a good account of these caverns in his interesting book on Cave Hunting, published by MacMillan & Co., London, in 1874.

An especially interesting feature of the European caves is the unmistakable evidence that many of them were inhabited for long periods, especially during the Pleistocene age, by large carnivores, such as hyenas and bears, and these animals were doubtless responsible for the accumulation of bone deposits found there representing many other animals which they had dragged into their dens for food. Many of the caves also show evidences of having been inhabited by early man. A good account of these evidences has been given by Prof. Henry Fairfield Osborn in his book on Men of the Old Stone Age.

THE RECENT BONE-CAVERN FIND AT BISHOP'S CAP, NEW MEXICO

Bryan, William Alanson; *Science*, 70:39-41, 1929.

It seems desirable at this time to make a brief preliminary announcement of what is believed to be an unusually significant bone-cavern find recently made in the lower slope of Bishop's Cap Peak in south-western New Mexico by Mr. Roscoe P. Conkling, of El Paso, Texas.

. . . .

The cave, which is located in carboniferous limestone, opened on the easterly flank of the mountain through a jagged orifice about three by four feet (since enlarged) which led into a dark stone cavern formed by water erosion. The floor was about eight feet below the mouth and was of wind-blown sand some twenty feet or more in irregular diameter. Aside from a few unsuccessful attempts to use the cave as a storm-shelter by an occasional herder, the place had never been a human habitation. A previous unsuccessful attempt to locate treasure in this cavern was made about forty years ago by men still living, who since the discovery have been induced to revisit it.

The work of treasure hunting proceeded without much show of success until at a depth of approximately ten feet below the floor bones were unexpectedly discovered. These were thought by the excavators to be perhaps the bones of a mule that might have belonged to the owners of the supposed buried treasure. As a result the work of excavation went feverishly on, until a fragment of a human skull was exhumed! These bones were brought to the attention of Mr. Conkling, who at once recognized the possible importance of such a find under such circumstances. He then took active charge of the excavations and carefully supervised the further exploration of the cavern.

Early in the work he sent photographs and drawings of his finds to the Los Angeles Museum for verification, with the result that Dr. Chester Stock, curator of the department of vertebrate paleontology, identified certain of the bones uncovered under ten feet of sandy loess deposits as the well-preserved phalanges of a ground sloth; and, as these were found adjacent to and at the same depth as the human skull cap referred to, all excavations since have been made with a view to preserving all available data growing out of the association of the material uncovered, as well as the material itself.

The cavern during the past four months has been carefully excavated to a depth of more than thirty feet without encountering rock bottom, the inference being that it extends much deeper. Except for a slight amount of surface material, and material doubtless falling down from the roof, the entire space is uniformly filled with very fine reddish wind-blown sand which exhibits an ill-defined horizontal laminated bedding, indicating the nature of its slow accumulation.

Eight feet below the occurrence of the skull, i. e., twenty feet below the surface, a hard, compact lens from two to four inches in thickness was encountered. This, while composed of the same material as that which filled the cavern, differed in that it was evidently water laid. Apparently it had settled out of water accumulated in the cavern, as a result perhaps of a cloudburst. The value of this circumstance, however, lies in the fact that it formed a definite undisturbed horizontal diaphragm completely flooring up the cave. The significance of this will be appreciated when it is understood that at about eighteen inches below this floor and more than twenty-one feet below the surface floor of the cavern additional human skull fragments were found!

From the twelve-foot level where the first skull was found, to the bottom of the excavation, i. e., for a depth of eighteen feet, bones of extinct horse, cave-bear, camel and sloth have been excavated in such numbers as to fill five large table type museum exhibition cases, while a bushel or more of small animal and bird bones have been recovered. Practically the complete skeleton of a ground sloth was found in place midway down between the occurrence of the two skull finds, which were almost ten feet apart. The last bones recovered from the bottom of the excavations were the limb bones of a very large camel!

From the foregoing it would seem obvious that we have here the undisturbed occurrence of human remains in direct association with a number of animals regarded as extinct since the Pleistocene period, and all deposited in such a manner as to preclude even the suggestion of their later intrusive burial. It is, therefore, believed that the Bishop's Cap bone-cavern has been a den and trap for wild animals through countless centuries and is a find which fortunately settles conclusively the moot question as to whether man and the sloth, the camel and the cave-bear, for example, were coexistent in America.

At the invitation of Mr. Conkling, the writer visited the cavern during the latter part of April. After very careful study of the occurrence and having had the exhilarating satisfaction of assisting in the removal of the pelvic and lumbar portion of the sloth specimen referred to and seeing its relation to the human remains, I do not hesitate to pronounce the find as probably the most important prehistory discovery ever made in America.

....

BONE-FILLED FISSURES

Rehwinkel, Alfred M.; *The Flood,* Concordia Publishing House, St. Louis, 1951.

The first of this type of evidence I wish to submit is what the geologists call "rubble drift and ossiferous fissures." By "rubble drift" is meant a certain type of deposit or sediment consisting of massive, angular unrolled material tumultuously deposited in local pockets and catchment areas, generally full of shattered bones. And by "ossiferous fissures" are meant great fissures or rents in the earth which were formed by some violent contortion of the surface of the earth.

The evidence of such fissures has been found in many places of the earth, some of them measuring from 140 to 300 feet in depth. They were filled with debris which drifted into them soon after they opened. This probably explains why they did not close again. Such fissures have been found in England, France, southern Spain, Germany, Russia, and elsewhere. The interesting feature of these fissures is the debris found in them, for they are filled with the remains of animals, among them those of the elephant, the rhinoceros, the hippopotamus, the reindeer, the horse, the hog, and the ox. The bones found in them cannot be of animals which fell in alive or were buried there, for no skeleton is complete. They cannot have been brought there by streams, for those who have examined them found no signs on them of having been rolled. Neither could the bones have been exposed to the weather for a long time, for none of them show marks of weathering. That water had something to do with depositing them is indicated by the very general cementing together of the deposits by calcite.

Again, it has been observed by such a competent geologist as Prestwich that these ossiferous fissures are usually found upon isolated hills of considerable height, places on which we might expect animals to gather in seeking safety from an approaching flood. Fleeing in terror and driven by the common danger, the carnivorous and herbivorous alike sought refuge on the same elevation, only to meet even here a common watery grave. A very remarkable classical example of such an isolated hill is found in Burgundy, France, in the valley of the Soane. The hill is about 1,030 feet above the surrounding plain, with steep flanks on all sides. A fissure near the top of the hill is crowded with animal skeletons. No skeleton is entire, the bones are fractured, are thrown together in disorderly fashion, and are unweathered and ungnawed. Again we have the strange phenomenon that bears, wolves, horses, and oxen, animals which are ordinarily not found together as peaceful neighbors, scale an isolated mountain only to die and have their remains preserved in a common grave. Such a flood as is described in Genesis offers the most reasonable explanation for this phenomenon.

Another most spectacular example of an ossiferous fissure is found in the isolated little island of Cerigo, near Corfu, off the coast of Greece. This occurs on a barren mountain, in the form of a fossiliferous deposit, a short distance from the sea. It is called the mountain of bones. It is a mile in circumference at the base, and from the base to the summit is covered with bones. The character of this mountain as well as of those already mentioned is such that animals could not have congregated here to feed, but the most reasonable solution for this phenomenon is the rising of flood waters driving them to this elevation. There they perished and were buried by the same flood water.

According to Prestwich, the rubble deposit in England indicates that the country was submerged to a depth of at least one thousand feet, while on the Continent we find evidence of submergence up to three thousand feet.

Equally interesting examples of this kind of deposits are found in the Rock of Gibraltar, where fissures nearly three hundred feet deep and filled with debris similar to that just mentioned have been discovered.

Animal remains described are practically the same as those found in the hills of France. These fissures on Gibraltar exist at different altitudes. The highest of them has an elevation of eleven hundred feet. In one of them man-made implements are said to have been found.

Similar deposits were discovered in a cavern near Palermo on the Island of Sicily. An enormous number of hippopotamus bones were found there, some of them so well preserved that they could be carved and formed into ornaments. More than twenty tons of bones were shipped for commercial purposes within six months after the discovery of this cavern. The bones were mostly of the hippopotamus, but there were also found among them those of the deer, the ox, and the elephant. The bones were mixed together without order and were broken and scattered in fragments, but again they are described as showing no signs of having been gnawed or weathered.

A large deposit of bones in a cavity of the calcareous beds of the steppes of Russia was discovered in 1847 near Odessa. In this cavity were found 4,500 bones of bears derived from at least one hundred individual animals; with these were found remains of species of the cat family, hyenas, horses, boars, mammoth, rhinoceros, aurochses, and deer, together with remains of numerous insectivores and rodents, such as hares, otters, martens, as well as wolves and foxes. (pp. 179-181)

• Fossil Graveyards and Bone Breccia

FOSSIL CEMETERIES

Obruchev, V. A.; *Catastrophist Geology,* 2:2-3, December 1977.

The history of life on the Earth really shows that during certain periods of time some genera, families, orders and classes of animals and plants came into being, attained their greatest development and distribution and then died out or considerably diminished.

The leading part was played by climatic changes connected with the transgressions and regressions of the sea, the epochs of mountainbuilding and glacial phases. But in addition to these slow transformations of the fauna and flora connected with climatic changes, which can be regarded as catastrophes only with the aforementioned reservations, we find in the annals of the Earth proofs of real catastrophes which in a short time exterminated large numbers of animals and plants. Their remains form whole strata of the earth's crust and may be called fossil cemeteries or fields of corpses.

Cemeteries of reptile corpses of Cretaceous age are known in North America and East Africa. In Mongolia recent expeditions of the Palaeontological Institute of the U.S.S.R. Academy of Sciences have also discovered in various places accumulations of bones of Cretaceous pangolins and even their nests with eggs, and in other places accumulations of remains of Tertiary mammals. Similar cemeteries of Permian reptiles and amphibians are known in South America and in Germany. Accumulations of remains of Tertiary mammals are also found in the U.S.S.R.---Bessarabia, the Taman Peninsula and in Western Siberia near Lake Chelkar-Tengiz in the basin of the Turgai River and near Pavlodar on the Irtysh River. Such cemeteries were recently discovered in the lower layers of the Tertiary conglomerates and sands in the lower reaches of the Chu River, in the Ketmen Ridge near Tashkent, and in the sands of the Kyzyl-Kum. Here the bones of the Cretaceous pangolins, the scutes of turtles and the trunks of trees are badly chipped, rounded and mixed with pebbles representing remains of a vast cemetery of animals and plants of the end of the Cretaceous period which existed in this area and were eroded probably by torrents in the beginning of the Tertiary period.

The cemetery of Permian and Triassic herbivorous and carnivorous amphibians and reptiles discovered by Professor Amalitsky on the Northern Dvina has been known for a long time; the skeletons of these animals have formed a whole gallery, part of which is now on exhibition at the Palaeontological Museum of the Academy of Sciences in Moscow. This cemetery runs from the Unzha River across the Northern Dvina almost to the Kama River and the bones are found in a bed of sandstone with pebbles and sand from 20 centimetres to three metres thick, above and beneath which are mixed marls entirely devoid of remains.

An even greater cemetery, but of the Tertiary period, was discovered in Carnegie Hill and University Hill in the State of Nebraska. Scores of thousands of skeletons of Rhinoceratidae---Diceras, Moropus and Dinoceras, are buried here in a layer only 15-65 centimeters thick. A slab cut out of this layer and measuring 1.65x2m. contains 22 skulls of Diceras and an enormous mass of its bones in a chaotic mixture. According to available figures 164,000 bones belonging to 820 skeletons of rhinoceroses have already been extracted, most of these bones from skeletons of Diceras. Numerous skeletons of a small antelope-like camel were found in two layers of a neighbouring hill. All the bones are very well preserved and exhibit no marks of teeth of predatory animals or rodents. This shows that the corpses did not stay on the surface very long and were buried very soon. So extensive an accumulation of remains of herbivorous animals of few species in one place can be explained only by a catastrophe which rapidly destroyed whole herds of them.

The Bolshoi Lyakhov Island, the southernmost of the Novosibirskiye Islands, is essentially a cemetery of mammoths. Mammoth tusks and sometimes whole corpses of mammoths and other mammals were buried in great numbers in the Quaternary sediments; they have been preserved by the permafrost of the soil. In the coastal slopes washed by the surf the tusks thaw out in summer and fall on to the beach; in the past they were annually gathered in by traders who came from the continent. These abundant remains of large animals on a relatively small island which was unable to provide food for them is accounted for by the fact that as late as the beginning of the Quaternary period the land of Siberia reached much farther north and at the end of the last glacial epoch was broken up, large areas sinking into the sea. The herds of mammoths living on this land sought safety on the areas which remained intact. The Bolshoi Lyakhov Island was one of the asylums where the animals accumulated in large numbers. But it had already been separated from the continent by a wide strait and so become a cemetery for the animals who rapidly starved to death. This was a real catastrophe.

FISH GRAVEYARDS

Price, George M.; *Evolutionary Geology and the New Catastrophism,* Pacific Press Publishing Association, Mountain View, 1926.

Darwin, in his famous chapter on "The Imperfection of the Geological Record," has well shown how scanty and imperfect are the modern fossiliferous deposits. The progress of research has only confirmed and accentuated tne argument there presented on this point. Thus Nordenskiold, the veteran arctic explorer, remarks with amazement on the scarcity of recent organic remains in the arctic regions, where such a profusion of animal life exists, and he concludes with the following language:

"It is strange, in any case, that in Spitzbergen it is easier to find the vertebrae of a gigantic lizard of the Trias than the bones of a self-dead seal, walrus, or bird, and the same also holds good of more southerly inhabited lands."

It is also an expressive fact in this connection that, in spite of the great numbers of cats, dogs, and other domestic animals that are constantly being thrown into rivers like the Hudson or the Thames, dredgings about the mouths of these streams have revealed the surprising fact that scarcely a trace of any such animals is there to be found.

Even the fishes themselves stand a very poor chance of being buried intact. As Dana puts it:

"Vertebrate animals, as fishes, reptiles, etc., which fall to pieces when the animal portion is removed, <u>require speedy burial after death</u>, to escape destruction from this source [decomposition and chemical solution from air, rain water, etc.], as well as from animals that would prey upon them."

If a vertebrate fish should die a natural death---which, of itself, must be a rare occurrence---the carcass would soon be devoured whole or bit by bit by other creatures near. Possibly the lower jaw, or the teeth, the spines, etc., in the case of sharks, or a bone or two of the skeleton, might be buried unbroken, but a whole vertebrate fish entombed in a modern deposit is surely a unique occurrence.

But every geologist knows that the remains of fishes are, in countless millions of cases, found in a marvelous state of preservation. They have been <u>entombed in whole shoals</u>, with the beds containing them miles in extent, and scattered over all the globe. Indeed, so accustomed have we grown to this state of affairs in the rocks we hammer up, that if we fail to find such well-preserved remains of vertebrate fishes, land animals, or plants, we feel disappointed, almost hurt; we think that nature has somehow slighted this particular set of beds. But where, in our modern quiet earth, shall we go to find fish-deposits now forming like the copper-slate of the Mansfield district, the Jurassic shales of Solenhofen, the calcareous marls of OEningen on Lake Constance, the black slates of Glarus, or the shales of Monte Bolca?---to mention some cases from the continent of Europe more than usually famous in the literature for exquisitely preserved fishes, to say nothing of other fossils. Or we might mention the black Onondaga limestones of Ohio and Michigan; the Green River beds, Arizona; or the diatom beds of Lompoc, California, as a few examples from America of strata packed full of splendidly preserved fishes.

Buckland, in speaking of the fossil fish of Monte Bolca, which may be taken as typical of all the others is quite positive that these fish must have "perished suddenly," by some tremendous catastrophe.

"The skeletons of these fish," he says, "lie parallel to the laminae of the strata of the calcareous slate; they are always entire, and so closely packed on one another that many individuals are often contained in a single block.... All these fish must have died suddenly on this fatal spot, and have been speedily buried in the calcareous sediment then in course of deposition. From the fact that certain individuals have even preserved traces of color upon their skin, we are certain that they were entombed before decomposition of their soft parts had taken place."

In many places in America as well as in Europe, where these remains of fish are found, the shaley rock is so full of fish oil that it will burn almost like coal, while some scientists have even thought that the peculiar deposits like Albertite "coal" and some cannel coals were formed from the distillation of the fish oil from the supersaturated rocks.

De la Beche was also of the opinion that most of the fossils were buried suddenly and in an abnormal manner. "A very large proportion of them," he says, "must have been entombed uninjured, and many alive, or, if not alive, at least before decomposition ensued." In this, he is speaking not of the fishes alone, but of the fossiliferous deposits in general.

There is found in all parts of the world a series of strata which used to be called the "Old Red Sandstone," now known as the Devonian. In this, almost wherever we find it, the remains of whole shoals of fishes occur in such profusion and preservation that the "period" is often known as the "Age of Fishes." Dr. David Page, after enumerating nearly a dozen genera, says:

"These fishes seem to have thronged the waters of the period, and their remains are often found in masses, as if they had been suddenly entombed in living shoals by the sediment which now contains them."

I beg leave to quote somewhat at length the picturesque language of Hugh Miller regarding these rocks as found in Scotland:

"The river bullhead, when attacked by an enemy, or immediately as it feels the hook in its jaws, erects its two spines at nearly right angles with the plates of the head, as if to render itself as difficult of being swallowed as possible. The attitude is one of danger and alarm; and it is a curious fact, to which I shall afterward have occasion to advert, that in this attitude nine tenths of the Pterichthes of the Lower Old Red Sandstone are to be found.... It presents us, too, with a wonderful record of violent death falling at once, not on a few individuals, but on whole tribes.

"At this period of our history, some terrible catastrophe involved in sudden destruction the fish of an area at least a hundred miles from boundary to boundary, perhaps much more. The same platform in Orkney as at Cromarty is strewed thick with remains, which exhibit unequivocally the marks of violent death. The figures are contorted, contracted, curved, the tail in many instances is bent round to the head; the spines stick out; the fins are spread to the full, as in fish that die in convulsions.... The record is one of destruction at once widely spread and total, so far as it extended.... By what quiet but potent agency of destruction were the innumerable existences of an area perhaps ten thousand square miles in extent annihilated at once, and yet the medium in which they had lived left undisturbed in its operations?

"Conjecture lacks footing in grappling with the enigma, and expatiates in uncertainty over all the known phenomena of death."

I will not taunt the uniformitarians by asking them to direct us to some modern analogies. But I would have the reader remember that these Devonian and other rocks are world wide in extent.

Surely Howorth is talking good science when he says that his masters, Sedgwick and Murchison, taught him "that no plainer witness is to be found of any physical fact than that nature has at times worked with enormous energy and rapidity," and "that the rocky strata teem with evidence of violent and sudden dislocations on a great scale." (pp. 234-239)

FOSSIL FISH LOCALITIES IN THE GREEN RIVER EOCENE OF WYOMING

Hesse, Curtis J.; *Scientific Monthly,* 48:147-151, 1939.

Few museums in the world, certainly none of the larger ones, are without specimens of the fossil fishes from the Green River shales of southwest Wyoming. These are prize exhibition specimens and no other fossil-bearing formation in North America has produced so many and such characteristic fossils as this great series of lake beds.

....

The section of Green River shale exposed in Twin Creek Valley is about seven hundred feet thick. Toward the top it grades into a brownish zone, less resistant to weathering, which rounds off the top of most of the bluffs of the more resistant oil shale. The fish layer on Twin Creek is about fifty feet below the top of the main bluffs, in the typical part of the section. It is a bluish-white marl, thin-bedded, brittle and not the higher grade oil shale found throughout this formation. Its total thickness is near one foot, and it is divided into a four-inch and an eight-inch member by a thin seam of oil shale.

The method employed by collectors working out a part of this layer is a simple one. A quarry site is carefully chosen, it must be bounded on either side by "settling cracks" which divide the entire face of the bluffs into units of varying size. The layer itself between the settling cracks must show joint cracks clearly, from two to four feet apart. The large settling cracks determine the size of the quarry, and since there is a slight slope to the bluffs, by starting thirty or thirty-five feet above the layer and removing the shale between the settling cracks, a considerable area of the fish layer is exposed. The over-burden is blasted and moved away by hand. Several layers of fishes are encountered, but they are poorly preserved and rotten. One layer seems to be made up of loose scales.

After the fish layer is cleared of overburden, the joint cracks prove their value. They enable the collector to raise the stone between them in blocks not too large to handle. Once the slab is raised and resting on saw-horses, a line of thin chisels is driven into one end of the slab to split it in half. No matter how thin the slabs become they are "halved" if possible. Seldom are the fishes found directly on the bedding planes (along which the rock cleaves) but lie between them covered by a thin film of matrix. The "shadow" of dim outline of the vertebrae and caudal fin may be seen, but an experienced eye is much quicker at this than an amateur.

Once specimens are seen, and they are likely to be numerous, the slab is sawed into convenient sizes for handling with as little damage to the material as possible. The commercial collectors carry the slab down off the cliffs and put them in storage, to be worked out during the winter when the inclement weather prevents activity in the quarries. In the preparation of this material the commercial collectors use an ordinary pocket knife with a rounded blade point and sand paper. Most any museum contains specimens of their skilful workmanship.

Seldom has this quarrying been more than a one-man job, the usual rate is one quarry opened and cleared out in the four summer months.

The most common fishes are those of the genus Diplomystus, a small herring. These are from two to twenty inches long, and the five- to seven-inch size sell for one dollar and fifty cents to three dollars. It is often possible to obtain several of these on one slab; as high as twenty-four fishes have been developed on slabs of less than one square yard. The small Priscacara serrata is the most popular and easily salable of all the types of fishes collected here. Under the name "Sun Fish," five- to seven-inch specimens bring from two to five dollars. Members of this genus are less common than the Diplomystids, and the smaller sizes tend to occur in "schools." Certain quarries will contain many hundreds of them, while in others they are relatively few. Pharodus (Dapedoglossus), a deep-bodied fish with many circumorbital plates, is also fairly common among the larger fishes. Small specimens of this form, twelve to twenty inches long, sell for fifteen to thirty-five dollars; but the still larger specimens run as high as one hundred dollars. The other genera of this fauna are less common, especially the larger sizes. However, every quarry furnishes these in some quantity. The fresh-water sting-ray and the large garpike from these beds are rare. If one specimen of either form is encountered in a quarry, the excavator considers himself lucky. The other elements of the fauna (birds and reptiles) are so rare that probably less than five specimens have been discovered.

....

Fossil fishes are found scattered throughout the entire Green River formation, but so far as known the above localities are the only ones which have produced abundant material. How, then, may the deaths of countless numbers of fishes, at more or less regular intervals, over a great period of time, be accounted for? The sediments of the Green River are, in part, volcanic, but the deposition of this volcanic material was in no sense cataclysmic. There is little to indicate that there were any ash falls, seemingly the volcanic material was more in the nature of dust. The even, laminated deposition of the beds does not suggest that the fishes were suddenly overwhelmed by terriginous matter, such as might occur in times of flood. Nor is there any sign, in the specimens themselves, that might indicate struggling accompanying a violent death.

Bradley, in discussing the varves of the Green River formation, has brought out the high organic content of the sediments of this formation. This organic matter passed through a stage of putrefaction, analogous to the black fetid organic oozes now forming in both fresh- and salt-water lakes. That annual deposits of this organic matter were laid down seems to be proven beyond doubt. Possibly the fishes were killed by the fouling of the water due to deal plankton and algae. Any home aquarist is familiar with the danger of "green water" suddenly turning brown, a change that may take place in a few minutes, killing all the fishes in the tank.

Some such explanation as this seems logical to the writer to account for the Green River fish layer. However, the varves extend throughout the entire two thousand feet of the formation, while the fish layer is only fourteen inches thick, near the top of the section. Nor is that layer seemingly one rich in organic matter derived from the sapropel. Why fish layers are not common in the entire section I am at a loss to explain.

A MIOCENE CATASTROPHE

Jordan, David Starr; *Natural History*, 20:18-22, 1920.

A great many years ago, in round numbers let us say about 2,000,000 B.C., in the age called Miocene, the coast line of California was in a formative stage. Great deposits of sand and clay were being rolled up and folded as mountain chains, and their nascent peaks and ridges formed an archipelago of islands with sheltered bays. Here were developed immense masses of diatoms, microscopic plants, each with a fine shell of silica, most of them having the form of a flat disk, adorned with thimble-like depressions and spinules of complicated sorts. The number of these creatures must be beyond conception for, in the locality mentioned below, they are piled up solidly to the average depth of fourteen hundred feet over a territory two and one-half miles long, and more than a mile and a half in breadth.

In this locality the deposits are free from sand, which shows that no fresh water came in; but in other places, over dozens or hundreds of miles, from Kern County to Orange, the diatom masses are interspersed with sand and clay and at times completely buried under them. From above these buried masses exudes the oil called petroleum. It is known that each diatom when alive secretes a minute droplet of this oil. But this is a theory; now to a concrete fact.

In a little bay on the north side of the Sierra Santa Ynez in Santa Barbara County, just above the present town of Lompoc were measureless masses of diatoms, covering the bottom at first to a depth of about 950 feet. For some reason this bay was chosen as the spawning ground for a herring of those days, known now by the name of Xyne grex. This fish was much like a modern herring, except that its surface bones were covered with enamel, a ganoid fashion of those Miocene years long since gone out of date, so far as herrings are concerned. This species had, moreover, a row of sharp enameled spines along the edge of its belly. Something like this still persists in many forms of herring---as the menhaden and other so-called "saw-bellies," but these are plain nowadays, the enamel all off.

Into the bay at one time came millions on millions of these herring---all of a size---six to eight inches long, doubtless for spawning purposes. But they covered the whole bottom of the bay---four square miles---and very evenly at that. That is the marvel, and now comes the catastrophe. For none ever got away; they all lay down and died and were promptly buried under the diatoms---350 feet of diatoms at least. But the erosion of the years has cut into these masses in different places, laying bare the strata in which the Xyne lie. And whenever one strikes that horizon, there are the fish, all in the same stratum, none below, nor for many feet above. The skeletons are all well preserved, not much crowded, and the organic part of the skeleton is carbonized so that the bones are all dark brown or black.

The accompanying photograph [not reproduced] shows a slab of diatom rock, twenty inches by sixteen, with thirteen of these fishes upon it, besides parts of others. This seems to be a fair average for the whole stratum, and indicates that the total number in the bay on the day of the holocaust was about 1,337,195,600, a mighty school of fish!

About six feet above this deposit of Xyne, throughout the basin, there lies a thin layer of transparent volcanic glass. Again, long after this was deposited, the whole area was thrown together into low folds. The Xyne deposits now stand at an angle of about thirty degrees in the place where this slab was obtained.

Above the Xyne lie further deposits of pure diatoms, to the depth of 350 feet. In the upper stretches are many fossil fishes, of about twenty kinds, so far as observed, largely broken into fragments. Four kinds of Spanish mackerel, two kinds of porgy, a big seabass, three species of flounder, two rock-cod, two kinds of croaker, and others are present. Among these are two species of herring, one of them being Xyne. This, however, nowhere except in the one great layer, exists in mass or in large numbers. All these fishes of the upper regions are mainly molds, imprints of a fish skeleton, replaced by diatoms. None of the herring skeletons is black or carbonized, like those taken in the great layer below. In the upper strata occur also a species of Mergus (fish duck), a heron, a porpoise, and a whale. Above the whole diatom mass lies in places a coarse angular conglomerate, with many inchoate bones, mostly of whales, teeth of a man-eater shark, and here and there masses of limestone filled with Pecten shells and other Miocene mollusks.

These hills are now occupied by quarries, the diatom masses being sold under the patented trade name of "Celite." The material is used as non-conducting packing for hot pipes ("Sil-o-Cel") and for filtering liquids ("Filter-cel"). The siliceous crusts of the diatoms are insoluble in ordinary liquids, and by pouring them into a fluid and then filtering, everything in suspension is caught by the diatoms.

Two problems remain, both probably insoluble. Why was this bay crowded with a billion individuals of Xyne to the exclusion of all other fish? Why did they all die instantly, quietly, with no sign of agony, and how were they hermetically sealed before going to pieces in decay?

Heat, poison gas, earthquake disturbance---you may answer. But no one knows, and anyone's guess is as good as yours or mine.

AN AMPHIBIAN GRAVEYARD

Romer, Alfred S.; *Scientific Monthly,* 49:337-339, 1939.

Living amphibians---the frogs, toads, salamanders and their kin---are forms of modest size which are relatively unimportant in the animal life of modern times. In the Triassic period, some 150 millions of years ago, their role was a more prominent one. The oldest amphibians, of the late Paleozoic, had been of major evolutionary importance as the first vertebrates to emerge from the fish stage of evolution and become four-footed animals. By Triassic times many of their descendants had reached the still higher reptilian stage of evolution, and dinosaurs, mammalian ancestors and other reptiles dominated the scene. The older amphibian groups still survived, however, in the form of labyrinthodonts. Many of these were of large size, and were roughly comparable to the modern crocodiles and 'gators in appearance and habits. But they were a degenerate stock, with flattened heads and bodies and tiny legs, which indicate that they were incapable of emerging from the water.

Such amphibians have been found in almost every region of the world. In North America, however, they are far from common. Despite extensive exploration of the Triassic, our museums contained perhaps but two dozen skulls of "native" members of the group.

It was thus of interest when, in 1936, Mr. and Mrs. R. V. Witter, while engaged in a "scouting" expedition for fossil reptiles and amphibians for the Museum of Comparative Zoology, saw fragments of amphibian bone washing down the side of a small hill in Triassic deposits 16 miles south of Lamy, New Mexico. The fragments were found to come from a bone layer extending some distance along the slope of the hill. Such excavation as could be done in a limited time resulted in the discovery that the layer consisted of a nearly solid mass of bones, almost all of them pertaining to a single species of amphibian, Buettneria perfecta. Time was lacking to do more than obtain a few skulls.

Two years later the Witters returned to the site, accompanied by Dr. T. E. White and undertook the complete excavation of the deposit, a project sponsored by Dr. Thomas Barbour, director of the museum. The rich bone layer extended 50 feet or more along the face of the exposure and some distance back into the hill. It was covered, however, with a six-foot overburden, including a two-foot sandstone layer, which made the task of reaching the fossils a difficult one. The sandstone was broken up with picks and a few judicious shots of dynamite. The overburden was removed with a slip attached to the faithful, though decrepit, expedition flivver, and the bone layer exposed throughout.

From the excavation about half a hundred good skulls were recovered, as well as large quantities of the prominent dermal plates of the shoulder girdles (clavicles and interclavicles) and numberous isolated elements of the backbone and limbs. Fragmentary remains of skulls indicated the presence in the area of a total of about 100 individuals. It seems certain that the deposit is but a remaining margin of a much larger area of deposition which before erosion must have contained the closely packed skeletons of many hundreds if not thousands of these large amphibians.

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This deposit is an excellent example of "mass death" a phenomenon discussed by Weigelt, and of which a second (and geologically much more recent) American example is that of the Agate Springs (Nebraska) fossil quarry. Slabs from the Agate deposit are displayed in a considerable number of American museums. These are derived from a bone layer entirely underlying a small hill, in which are contained the tightly packed and disarticulated remains of thousands of mammals, most of them the twin-horned rhinoceros "Diceratherium." Matthew has suggested that the

Agate deposit represents a quicksand near a water-hole, in which animals were bogged.

The explanation of the present deposit must be of another nature. The bone layer is thin---but two to four inches thick---and is surely not a quicksand. More probably it represents the last remnant of a large area of water in which the amphibians dwelt. In Triassic times western Texas and New Mexico must have been a well-watered lowland, with numerous streams and pools. Presumably, however, it was subject to recurrent droughts---geologically ancient predecessors of "dust bowl" conditions. Under such circumstances the lagoonal areas in which the amphibians lived would have become greatly restricted. Since these animals were, as we have said, confined to the water, the gradual drying up of the pools would have resulted in crowded conditions in the remaining lagoons. Their food supply of fishes and other water-dwelling animals would have been rapidly exhausted, and starvation would have followed. Our deposit represents the last scene in the drama of drought---a shrinking residual pool, tightly packed with these amphibian monsters, starving survivors struggling about through the mass of rotting corpses of their weaker brothers. Eventually all would become quiet in the pool.

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LANCEFIELD SWAMP AND THE EXTINCTION OF THE AUSTRALIAN MEGAFAUNA

Gillespie, R., et al; *Science*, 200:1044-1048, 1978.

Abstract. Excavations into the Australian swamp of Lancefield show that a bone bed dated at 26,000 years ago contains perhaps 10,000 giant extinct animals. Associated artifacts suggest that humans were in the area, but the direct cause of death of the animals is, on present evidence, not explicable. Such a recent date for the classic megafauna shows that it was living together with humans for at least 7000 years in southeast Australia. This enduring association argues against a catastrophic and rapid overkill in the Australian Pleistocene.

ANIMAL GRAVEYARDS

Anonymous; *Science News Letter*, 14:293, 1928.

Travelers in the Andean highlands of South America have often reported areas in which the two types of camels, the llamas and guanacos, repair when death approaches, there to leave their mortal parts, often undisturbed by predatory animals. These "dying-places" are said to be desolate places which none but the sick and the aged seek out.

Fossil animals of considerable antiquity are thought by scientists to have had a similar custom. In the sides of a large hill in northwestern Nebraska many skeletons of a small, graceful camel, slightly larger than a greyhound, have been found in such situations as to suggest an ancient practice of the custom of seeking out "dying places" far back in the history of the camels. The fossil animals, called Stenomylus, lie extended, in groups and singly, with no part of the body disturbed. Their slender leg bones are about as slender and as fragile as glass tubing. There in the sand, long since converted into rock, these early camels lie in precisely the same attitudes which they had assumed at death in a time when the races of mammals were young. Disease and injury have played no part in the mortality of these ancient camels who had voluntarily selected this spot as their last resting-place.

PIT WEAR IN LA BREA TAR PIT BONES

Anonymous; *Science,* 69:sup xiv, September 28, 1928.

The asphalt pits at the Rancho la Brea at Los Angeles, once filled with skeletons of a score of species of mammals long since extinct, were for thousands of years constantly a slightly mobile and shifting mass. Huge bubbles of gas, slowly working their way upward through the mass of bones, tar, sand, dirt and trash, caused slight, discontinuous movements which by the contact of bone on bone or bone on teeth, produced great changes in the skeletal parts which is known to museum workers as "pit wear." Nowhere else in the world has such a phenomenon been known. Large, strong limb bones have been cut smoothly in two parts; teeth are curiously worn; skulls queerly scratched and abraded and thousands of skeletal parts worn into curious forms.

BONE BEDS AND CRINOIDAL SANDS OF THE DELAWARE LIMESTONE OF CENTRAL OHIO

Westgate, Lewis G., and Fischer, Richard P.; *Geological Society of America, Bulletin,* 44:1161-1172, 1933.

Introduction. Middle Devonian limestones of central Ohio consist of two formations: below, the Columbus limestone, equivalent of the Onondaga limestone of New York State, 80 to 105 feet thick; above, the Delaware limestone, 35 to 40 feet thick. A bone bed, distinctly visible in the quarries west of Columbus, but absent or recognized with difficulty outside of Franklin County, has been considered the boundary between the Columbus and the Delaware limestones. A second bone bed occurs near the top of the Delaware limestone in the abandoned quarries northwest of the Chesapeake and Ohio Railway station at Delaware, but has not been seen elsewhere. These two bone beds will be referred to as the lower and the upper bone beds. The present paper aims to show that these bone beds, together with certain crinoidal layers in the Delaware limestone, are shallow-water, mechanical sediments.

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The lower bone bed is well shown west of Columbus in the extensive quarries on both sides of the Scioto River at Marble Cliff. This bone bed was thought by Orton to be the boundary between the Columbus and the Delaware limestones and was not definitely assigned to either formation.

Recently, it has been considered the topmost bed of the Columbus limestone. The physical features to be described show it to be the lowermost bed of the Delaware limestone.

The following quotations from Newberry contain descriptions of the bed and interesting suggestions as to its origin. Conditions at the bone bed level, with the occurrence of ripple marks in the Columbus limestone a short distance below, preclude deep-water accumulation. The suggestion that the rounding of the material may be due to mastication is interesting.

"The stratum in question is only from two to four inches in thickness, but it extends over an area of many square miles. It is almost entirely composed of fragments of plates, teeth, spines, and dermal tubercles of Ganoids, Placoderms, and Elasmobranch fishes. Unfortunately most of them are so much broken and worn that they are difficult and disappointing objects of study; but the deposit is one of peculiar interest from its mode of formation and from the comprehensive view it gives of the Devonian fish fauna.

"Here we have the assemblage of millions on millions of generally imperfect but mostly recognizable organs or fragments of the bony structure of the forms of fish life most characteristic of the Devonian age. There are many entire teeth and dermal tubercles, but these are always detached and scattered. Most of the fragments are worn and rounded, and have evidently been subjected to some sort of triturating agency. They have the aspect of having been beach-worn, but the mass is almost entirely organic, and it is difficult to understand how it could have accumulated along a shore line without some intermingling of sand or pebbles. It forms a thin layer in a thick sheet of organic sediment, which must have been deposited in comparatively deep water, for no land wash of any kind is associated with it. It has seemed to me not impossible that this fish bed was made up of excrementitious matter, and that it represents the hard and indigestible parts of fishes which have served as food for other and larger kinds. On this supposition the fragmentary and worn appearance of the bones would be attributable to the crushing, maceration, and partial digestion which they have suffered. If this is the true history of the deposit, it accumulated in some nook or bay, perhaps bordering a coral reef, where large and small fishes congregated age after age until their 'kjokkenmoddings' formed a sheet some inches in thickness all over the sea bottom. [p. 30.]

"The bone-beds of the Corniferous limestone, in which the remains of millions of marine fishes of middle Devonian age are strewn over the old sea bottom, contain numerous stud-like, often highly ornamented dermal tubercles, and occasionally fragments of the pectoral spines of Machaeracanthus, but almost no teeth of cartilaginous fishes. Many teeth of Onychodus are there, often broken and sometimes worn, as though having suffered trituration; but the limestone in which they lie was deposited in comparatively deep and still water, and they could only have been broken and worn by violence or the digestive energy of the fishes which swallowed them" [p. 24.]

• Fossils in Concretions

AMMONITE ACCUMULATIONS IN THE CRETACEOUS MOWRY AND ASPEN SHALES

Reeside, John B., Jr., and Cobban, William A.; *Science,* 119:355, 1954.

The formations are noted for their well-preserved but scattered scales and bones of fishes; other fossils are very rare. At a few places abundant pelecypods, with few ammonites and gastropods, are preserved in porcellanite. Completely flattened molds of ammonites, mostly in porcellanite, have long been known, but because of their preservation are difficult to evaluate. Unflattened ammonites were known from a few localities in northern Wyoming and Montana, but were erroneously attributed to other formations; recent field work has shown that these annomites are also from the Mowry shale.

The unflattened ammonites are all in calcareous concretions that are alike in certain features. They are usually in a stratum with many others that are nearly barren of fossils, as are also the enclosing rocks. They contain, in parts of the concretions, fish remains so abundant that they form the matrix of the invertebrates. They also contain carbonized wood and a few isolated bones of pterodactyls and marine reptiles.

The ammonites are unoriented and unsorted. Variant shells, from slender costate to stout spinose, are associated, and immature forms 10 mm in diameter are mingled with others 50 mm or more in diameter. In most specimens the living chamber that in life contained the soft parts is missing or crushed, and in many the septate part has been damaged. A phenomenal number of ammonites is present in some of the concretions. One found near Winnecook, Mont., yielded 1300 specimens of gastroplitid ammonites (the largest 270 mm in diameter) and 230 engonoceratids. A second, from Teigen, Mont., yielded 3800 gastroplitids (the largest 400 mm in diameter) and 400 engonoceratids. And a third, from Cody, Wyo., produced 2400 gastroplitids (to 400 mm in diameter) but no engonoceratids. For none of these concretions (each about 6 ft in diameter) is the collection probably as much as half the original content of the concretion. In view of the rarity of the scattered specimens of flattened ammonites in the ordinary beds of the Mowry and Aspen shales, what conditions would produce in a single concentration a mass of unflattened ammonites, fish remains, and carbonized wood? And why would no fossils be found in the many other concretions nearby at that level? The persistence of fossil wood suggests currents that could sweep the shells together, but there has been little sorting, such as currents might produce, and it is difficult to see why all the shells would be concentrated by currents in the small area of one concretion. If ammonites lived in swarms, the mass annihilation of a swarm by some sudden volcanic event could perhaps result in its preservation in one restricted spot, but surely there would be a few stragglers somewhere in the vicinity. To us the most attractive speculation is that these concentrations are aggregations of the fecal matter of some large carnivore (reptile, fish, or cephalopod), a thesis that would explain the damage to the shells, the lack of complete individuals, the lack of sorting, and the disarticulated condition of the fish remains. It would be necessary to postulate that the carnivore fed almost entirely on ammonites and fish and perhaps that, as the living octopus, it frequented a sort of lair, to which it carried its prey for leisurely consumption and in which the mucus-bound fecal matter could accumulate.

THE ARCTIC MUCK: GRAVEYARD OF THE MAMMOTH

The famous "frozen mammoths of Siberia" represent a special case of possible biological extinction. Around the Arctic Ocean thousands of square miles are covered with a thick layer of muck containing immense jumbled concentrations of bones, partially decayed flesh, tree trunks, and other biological remains. While many biological extinctions are as abstract as the squiggles on the charts of the paleontologists, the Siberian mammoths (and many other animals) died within the time of man. If they succumbed to some catastrophe; man could hardly have gone untouched. Only the bone caves and bone-filled fissures have conjured as many visions of recent terrestrial catastrophe.

Do the facts really indicate catastrophism? Was there a sudden freeze that has not moderated for thousands of years? Was there some planetary convulsion that piled up hundreds of feet of life-laden muck in a few terrible hours? Few geologists believe that catastrophism need be invoked. Rather, slowly acting forces could account for all the data. Catastrophists group the facts into two categories:

1. Preserved organic matter that catastrophists say would have decayed long ago if it had not been quick-frozen.
2. The sheer extent and turmoil of the circumpolar biological trash heap that militate for a catastrophic origin.

Almost all catastrophic theories rely upon the mammoths and the muck that buried them for support. Pole shifts, the Deluge, cometary impact, and near-misses by celestial interlopers are typical of the hypotheses found in the sensational literature. So wild have been the claims of the catastrophists that most geologists have instinctively felt safer with the uniformitarian, slowly acting forces produced by the Ice Ages.

• Anomalous Geological Features of Mammoth Graveyards

THE MAMMOTH IN SIBERIA

Howorth, Henry; *Geological Magazine*, 2:7:491-501 and 550-561, 1880

The existence of remains of Mammoths preserved with their flesh intact was known in Europe as early as the seventeenth century. Witsen, in his work, Noord en Oost Tartarye, edition 1694, p. 413, cites the finding of many Mammoths' teeth in Siberia, and mentions that numbers of people were engaged in searching for them. He also says that occasionally whole Mammoths were found, which were of a brownish colour, and emitted a great stench. Witsen was not alone. Isbrand Ides, who was sent as an envoy from Peter the Great to China in 1692-1695, met on his way through Siberia a man who was engaged every year in collecting fossil ivory, and who told him he had once seen the head of a Mammoth projecting from the frozen ground, which, with the help of some companions, he cut off. The inside of the head had decayed, but he secured the teeth, which he says were placed before his mouth like those of an elephant. He also took some bones out of its head, and cut off a foot of the girth of a man, of which he took a portion to Trugan (i. e. Turuchansk). The bones of the head were somewhat red, as if coloured with blood. Isbrand Ides knew these elephants were found imbedded in the frozen banks of the rivers, and he reports that the Russians ascribed them to the Noachian deluge, a view in which he concurred (Isbrand Ides' Travels, pp. 25, 26).

Lawrence Lange, who went as an envoy to China in 1715, after speaking of the stories of the Mammoth (which he calls the Mamant or Behemoth) living under ground, goes on to say that what convinced him most that its bones were those of a beast which still existed was that several people worthy of credit had assured him they had seen the horns (sic), skulls and bodies of the animal with flesh and blood still remaining, adding that if it were thought necessary it would be easy without much difficulty to collect together a perfect skeleton (Journal de Laurent Lange, in Nouveaux Memoires sur l'etat present de la Grande Russie ou Moscovie, vol. ii. pp, 110, 111).

Muller, the author of the famous collections on Russian history, who wrote in the first half of the last century, in his Memoir on the Manners and Customs of the Ostiaks, reports how he had been told by several people that they had seen these animals beyond the Beresowa in the caverns in the high mountains of those districts. They reported them as eight or ten feet in height, and about eighteen feet long, of a grey colour, with a long head, broad forehead, and having a horn on either side just below the eyes, which they could move about, and cross one over another as they pleased. It was said that when walking they could stretch themselves considerably, and could also shrink into a small space. Their legs in size were like those of the bear. After criticizing these stories, which clearly point to their relators having seen some Mammoth carcases intact, he goes on to discuss the opinion of those who merely deemed the bones lusus naturae. This he contests, on the ground that many times it had been noticed that the bones were bloody when the roots were broken, and that a cavity filled with clotted blood was often to be seen near the end.

Laptef, who travelled along the northern coast of Siberia during the reign of the Empress Anne, 1739-1743, writes: "On the banks of several rivers on the Tundra, whole Mammoths with their tusks are dug out with thick hides on them. Their hair and bodies are however rotten, while the bones, except the tusks, are also decaying." He describes the heads of the animals as like those of a Horse, while their teeth were thick, flat, and not longer than three inches, a description which made Middendorf suppose he had seen the heads of the fossil Rhinoceros, which are like those of a Horse.

It is probable he confused the two animals, of which he had heard or seen specimens.

The next notice we have of the finding of one of these preserved animals refers to the Rhinoceros tichorhinus, and not the Mammoth. A head and foot of the Rhinoceros were taken to Pallas, when he was at Irkutsk in 1772. The complete animal had been found in the preceding December at Wiljui, about 64 versts below Yakutsk, and it had then begun to putrefy. The head and three feet were sent to Irkutsk, and the fourth foot to Yakutsk. One of the feet was destroyed by being dried too quickly; the other remains were described in a famous memoir by Pallas, and later by Brandt. They are still to be seen in the Zoological Museum at Petersburgh. Pallas did not himself visit the site where the body was found, but was told by the person who had sent him the remains that the carcase was half buried in the sand a fathom from the water of the river, and four fathoms from a high steep bank. It was covered with a thick hide, over which were some scattered tufts of hair. The beast had clearly not been long where it was found, and had probably been detached from the bank in the spring floods of the years 1769 or 1770, and the sand in which it was found buried was probably a portion of the matrix which surrounded him in his grave. (Pallas, de reliquiis animalium per Asiam borealem, etc., Nov. Comm. St. Peter. Acad. vol. xvii, p. 576).

In 1787, Sarytschef, who accompanied Billing in his well-known journey through Siberia, was sent in company with Dr. Merk and others from Sredne Kolymsk to Yakutsk. At Alaseisk, a small station on the river Alaseya, about 100 versts down the river, and in its sandy banks, he was told there was the body of an animal of the size of an elephant. It was still whole and covered with its hide, and here and there had long hair on it. Sarytschef unfortunately did not visit the spot, which was a good deal out of his way.

About the same time, or even earlier, a Mammoth covered with hair was found at the mouth of the Lena, for when Adams' specimen was discovered, the Tungus told him that their fathers had told them that one of their number had seen a similar animal, and had then immediately died with all his family. The new discovery he deemed an evil omen, and fell ill.

In 1805, when Tilesius was on his way to Kamstkatka with Krusenstern's expedition, he was told by Patapof, who was carrying provisions from Okhotsk, that he had a short time before seen a Mammoth with a hairy skin, on the shore of the Polar Sea, and as evidence he sent Tilesius a bunch of its hair, which he in turn sent on to Blumenbach. Adams speaks of another similar find two years before his own discovery on the banks of the Lena a long way from the sea.

We now arrive at the famous Mammoth with which the name of Adams is so associated. Adams was a botanist, who was at Yakutsk in 1806, when he heard that a Mammoth with its flesh, skin, and hair intact, had been found on a peninsula at the mouth of the Lena. On going there he learnt that a Tungus chief named Ossip Schumakhof, in a journey to the borders of the peninsula of Tamut in 1799, saw a hummock or lumpy hill. In 1801 this had melted away partially and disclosed the side of a large animal with a tusk projecting out. The following summer proved a very cold one and the animal melted very little. In 1803, the ice between it and the cliff melted, and it subsided on to a bank of sand lower down. In March, 1804, Schumakhof returned to the Mammoth, detached its tusks, and bartered them for goods of the value of 50 roubles. The Tungus drew a picture of the animal, which Adams said was very incorrect. It had pointed ears, very small eyes, feet like a Horse, and a line of bristles along the back, and looked like a cross between a Pig and an Elephant. The merchant Boltunof, who saw the carcase in 1803, before it had decayed, mentions that it had a long snout between its tusks (i.e. a trunk). Adams did not see it till 1806. In the meantime the dogs of the Yakuts and the wild animals had eaten its flesh, and Adams found little more than the skeleton, of which one of the fore-limbs was lost. The bones were still united by thin ligaments, the skin on the head was dried up, and a bunch of hair remained on one ear. In the left eye he thought he could distinguish the pupil.

The skin of the side on which the animal had lain was still covered with thick hair. Adams secured a portion of this hide, which was so heavy that ten men with difficulty dragged it on to the bank. He also collected a pood of long hair, which lay scattered about the ground round about. These remains are still in the Zoological Museum at Saint Petersburgh. When Adams found the remains, they were about 100 paces from the steep bank from which they had slid down. This bank was from 35 to 40 fathoms high, and the Tunguses reported that they lay at first under seven fathoms from the surface. Adams reported that the remains were found imbedded in a stratum of clear ice.

The delta of the Lena has undergone considerable alterations, but the site of the discovery may still be made out. It is on an island marked as a peninsula in Wrangell's map, but which is now an island, as appears from the staff survey map of the Russian government issued in 1855. It lies in the Polar Sea opposite the little station of Kumak Surka on the Lena. Its northern point is called Myss Bykofskoi, and its southern one Myss Mostach (the Manstai of Adams).

During Schrenck's journey across the Samoyede steppe in 1837, he heard of the discovery of two skeletons of pachyderms in the great peninsula of Karakhaiskaya which separates the Kara Sea from the Gulf of Obi. One of them was found on the left bank of the river Yerumbei or Yerubei, four or five years before Schrenck passed that way. It was described to him as being as big as a walrus, but without tusks. Schrenck suggests that it was the skeleton of a rhinoceros, but it may be that the tusks had been previously broken off and carried away. It had apparently lain exposed a considerable time, and the bones were of a brown colour. Another skeleton not quite so perfect had been found ten years before on the same peninsula, and was well known to the Samoyedes.

In 1840, an entomologist named Motschulsky was at Tobolsk, where he was told by the Samoyedes that the spring of the previous year had been very wet. This had washed away a portion of the bank of the river Tas, a tributary of the Yenissei, and exposed the body of a frozen Mammoth. They had seen its head and one of its tusks, the latter of which they had detached and sold at Obdorsk. They reported that from the jaws of the animal there projected a tongue as long as that of a one year old reindeer, by which they no doubt meant the trunk of the animal. Some difficulty has arisen about the exact locality of this Mammoth, as no such river as the Tas falls into the Yenissei, and Baer suggests that the Samoyedes may call the wide outlet of the latter river by that name. At all events, a merchant of Berezof, named Trofimof, undertook to bring the remains to Obdorsk, which he did, and they were found by him not far from the Yenissei, about 70 versts from its outfall into the sea near a cliff. This skeleton was removed to Moscow, and still remains in the museum there. Portions of hair and of the flesh still remained on it, upon which Professor Glebof has written.

In 1843, Middendorf found the remains of a Mammoth near the river Taimyr, only 50 versts from the Polar Sea, in about 75° N. L. He describes the animal as but half grown. Its flesh had nearly decayed away, and the bones were soaked through from the great moisture of the clay in which they lay. They still retained their form however, and it was clear the flesh had decayed away on the spot, from there being found there two inches thick of a dark brown mud, which surrounded the bones, which had a strong ammoniacal smell, and was clearly a decayed animal substance. The banks of the river were about six fathoms high, and consisted of coarse sand containing boulders of various kinds of stone from the size of a nut to that of a man's head. Some of these boulders were taken home by Middendorf and were classed by Keyserling as granite, white felspar, gneiss containing garnets, black mica slate, and a peculiar breccia formed of pieces of anthracite welded together by white carbonate of lime. Halfway up the cliff in the otherwise unstratified sand, was a layer an inch thick of fine-grained peat mixed with coarser sand. Higher up, and five to seven feet below the surface, lay the remains of the Mammoth in a layer of sand mixed with clay. The boulders did not apparently reach so high. The animal lay on its left side.

A Mammoth was found some time between 1840 and 1850 in the circle of Yakutsk. It was mentioned in a notice by Herr Schtschukin, who had lived long in Yakutsk, and was afterwards in correspondence with the place. It was probably the same animal of which a foot is preserved at Irkutsk, and was mentioned by Schrenck. It was well preserved when found, and the animal had a mane of long hair reaching from the neck to the tail. Like most of the others it was found in the bank of the river, which had been undermined by floods. The Archbishop of Yaroslaf reported that the animal had been found by a missionary named Khitrof, who reported that it had a shaggy mane, and that its head was covered with hair; remains of its food between its teeth consisted of twigs of trees. It seems this Mammoth was found on the banks of the Kolyma.

Baer was told by the doctor, Alexander Golubef, who had practised long in Yakutsk, that about 1860 or 1862 the Yakuts had found a huge beast covered with skin on the banks of the Wiljui, where it falls into the Lena, which they reported to the Yakutsk merchant, Ivan Platonovitch Kolessof.

A Yurak, who was looking for his reindeer on the Tundra, near the bay of Tas, noticed projecting from the ground a horn (so they call the Mammoths' tusks found in Siberia). In order to secure this he scraped away as much as he could of the earth, and disclosed the head of a great beast. Having drawn or broken off the tooth, he detached also a portion of the hide as evidence, which he gave to the village elder of Dudinsk, Athanasius Koschkarof, who passed it on to the overseer, Sotnikof, who showed it to Ivan Maksimof, an engineer on one of the steamers on the Yenissei, who again communicated the important news to M. Stephen Gulayef, and he to the Russian naturalist, K. E. von Baer. The news was communicated in a letter from Karl Maximovitch to Stephen Gulayef, dated Barnaul, 30th November, 1865.

On the receipt of this news, the Imperial Academy nominated a Commission, consisting of the well-known names of Brandt, Helmersen, Schrenck, and Baer, and it was determined to send an expedition to recover, if possible, the skeleton and other remains of the Mammoth, and to take a plaster cast of his shape. This expedition was put under the command of F. Schmidt, who was ordered to set out in February, 1866. When he arrived in Siberia, he found that the carcase he was in search of had decayed. Kaschkaref had visited the place in the spring of 1865, and found some bones and a piece of decayed hide only. The place where the remains were found was on the Yambu, a small lake from which springs the river Gyda, about 100 versts to the north-west of Maksimof Myss. The tundra about there is quite naked, alder bushes and grass grow apparently near the rivers. Schmidt describes the land of the Yuraks as a veritable mine of Mammoths' remains, and affirms his belief that the specimen in the Moscow Museum came from there, from the Simovie Krestowskaya close to the Polar Sea. Schmidt heard of another skeleton of a Mammoth with hair still remaining on its head, which lay on the Swamskian tundra, and exposed to the air. He eventually secured a number of the bones, and a quantity of the hair of the former specimen.

In the summer of 1867 another Mammoth, with its flesh and hide intact, was found about 100 versts from the Polar Sea, between the rivers Indigirka and Alaseya, and on a small river called Kovschetschaja, whose mouth is about 50 to 60 versts from that of the Alaseya. It was found by a Tungus named Foka, who spent the summer there in search of Mammoth bones. Its flesh, it was reported, had been eaten by wild animals. This discovery was very important, from the place where it was made, which was about the same meridian as New Siberia; it was one and a half day's journey north of the limit of trees, and about five days' journey from the Polar Sea. Schrenck says that the Mammoth's body referred to by Sarytschef as having been found in 1787 was found on the Alaseya; while Kosmin, a companion of Wrangell, who made a journey in 1821 along the Polar Sea from the Kolyma to the Indigirka, passed the River Uschiwaja, called Pila by the Jukagirs, which is about half-way between those two rivers, found a collection of Mammoths' bones which had been washed out of the banks by the undermining of the river.

A Yakut, who was sent by the Baron Von Maydell to find the remains of this Mammoth, found only a leg, with one end sticking in the ground, but without flesh or hide, covered with skin only on the hoof; he also found a piece of the hide with hair still on it the size of half a horse's skin.

Meanwhile news arrived at Nishni Kolymsk of the discovery of another Mammoth's body. Of this but the skeleton remained; it lay some fathoms from the right bank of the River Kolyma, 200 versts above Nishni Kolymsk, out on the open ground.

Maydell noted the spot where the first of the three Mammoths had been discovered, but when he went he found only a number of Mammoths' bones. On his way to it he heard of a third find. A Yakut told him that on a stream not far from the Kovschetschaja, where a former Mammoth had been found, he had seen the leg of a great beast, with flesh and hide upon it, sticking out of the ground. This was in the summer of 1870. This he had detached by moving it backwards and forwards. The site of this find was on the tundra between the Indigirka and the Alaseya, which is very prolific in Mammoths' remains, so that a number of men are annually engaged in searching for ivory there. It is watered by a number of small rivers, the most eastern of which is the Kovschetschaja, where the second of the above-named Mammoths was found. Forty versts west of this was another river named the Schandran, where the third Mammoth was found. Maydell visited both places. In the first he found a number of bones, and a piece of the hide four arshins long and one and a half broad, covered in places with yellowish short hair, and longer hair of a brown-red colour. He then went on to the second site, where he recovered the leg which had been detached the year before by the Yakut. It was broken off at the knee, and, according to Maydell, seemed to have been detached long before, as the exposed parts of the bones seemed weathered, and of a brown colour. There was no flesh remaining, but the hide was intact, and ended in a rounded foot with a horny sole. He succeeded in finding another similar limb, and a mass of earth mixed with Mammoth hair, but nothing more; the rest of the animal had been dispersed either by being dragged away by wild animals, or by being broken and washed away by the water or otherwise. (pp. 492-498)

THE NEW MAMMOTH AT ST. PETERSBURG

W., A. S.; *Nature,* 68:297-298, 1903.

(So much sensational literature exists describing the frozen Siberian mammoths that this matter-of-fact account is refreshing. WRC)

The new mammoth just mounted for exhibition in the Zoological Museum at St. Petersburg, is a triumph of the taxidermist's art. The frozen skin has been cleaned, softened, and prepared. The skeleton, and as many of the surrounding soft tissues as possible, have been carefully removed from its interior and preserved separately. The animal has been actually stuffed like a modern quadruped, and placed in the attitude in which it originally died. The skin of the head and the ears are artificial, copied from the famous old specimen obtained a century ago by Adams. A model of the base of the proboscis has also been added. The skin of the trunk and limbs, however, is nearly complete, only embellished in parts by the addition of a little wool and hair from other specimens; and some deficiencies are covered by the surrounding mount, which represents the morass into which the animal slipped. The well-preserved tail is especially noteworthy, and bears a large tassel of long black hair at its tip. The animal is a young male of rather small size.

The hopelessly-struggling aspect of this mammoth is very striking, and reproduces exactly the attitude of the carcase as it lay buried in the Siberian tundra. In fact, the chief value of the specimen depends upon the circumstance that it was scientifically disinterred, photographed at various stages in the excavation, and carefully preserved by the best modern methods. Great credit is due to Dr. Otto Herz, the leader of the expedition organised by the St. Petersburg Imperial Academy of Sciences, who undertook the arduous task of securing the carcase and transporting it to the Russian capital. His are the only photographs hitherto obtained of a mammoth buried in the tundra, and they throw important new light on the question of the conditions under which these large quadrupeds were destroyed and entombed. Some of Dr. Herz's photographs have lately been presented by Dr. Salensky to the British Museum, and two of them are reproduced in the accompanying figures.

The carcase in question was exposed by a landslip on the bank of the River Beresowka, an affluent of the Kolyma, in the Government of Jakutsk, in latitude 67° 32'N. The head was entirely uncovered, so that the foxes and other carnivores ate its soft parts, while the inhabitants of a neighbouring village removed a tusk. The Governor of Jakutsk, however, succeeded in keeping the remainder of the specimen undisturbed until the arrival of the expedition from the Academy. It was buried partly in ice, partly in frozen sand and gravel, and there was a sufficient covering of earth to prevent its naturally thawing.

According to the general report published by Dr. Herz, he began to excavate the specimen from the front. In this manner he soon discovered the two fore limbs spread widely apart, and sharply bent at the wrist. Proceeding backwards on the left side, he unexpectedly met with the hind foot almost at once, and it gradually became evident that the hind limbs were completely turned forwards beneath the body. Dr. Herz then removed the skull, and found the well-preserved tongue hanging out of the mandible. He also noticed that the mouth was filled with grass, which had been cropped, but not chewed and swallowed. Further examination of the carcase showed that the cavity of the chest was filled with clotted blood. It is therefore natural to conclude that the animal was entrapped by falling into a hole, and suddenly died from the bursting of a blood-vessel near the heart while making an effort to extricate itself. As shown by the recent researches of Dr. Tolmatschow, the ice surrounding the carcase was not that of a lake or river, but evidently formed from snow. It is thus quite likely that the mammoth was quietly browsing on grassland which formed the thin covering of a glacier, and fell into a crevasse which was obscured by the loose earth. On this subject, however, much more information may shortly be expected, when Mr. Ssewastianow publishes an account of the geological researches which he made in the neighbourhood of the Beresowka last summer.

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FLESH REMAINS OF ANCIENT ANIMALS DUG UP IN ALASKA

Anonymous; *Science News Letter*, 55:403, 1949.

Russian scientists did do it first, but their monopoly has been broken. Officials of the American Museum of Natural History in New York announced that the actual flesh remains of prehistoric animals discovered in Alaska are on display. Included is the body of a young muskox which died some 15,000 years ago and was preserved in a natural deep freeze in Alaska.

These specimens are among the first ever found on the North American continent, though Russian scientists have been digging up this sort of thing in Siberia for years.

FROZEN MAMMOTHS AND MODERN GEOLOGY

Farrand, William R.; *Science*, 133:729-735, 1961. (Copyright 1961 American Association for the Advancement of Science)

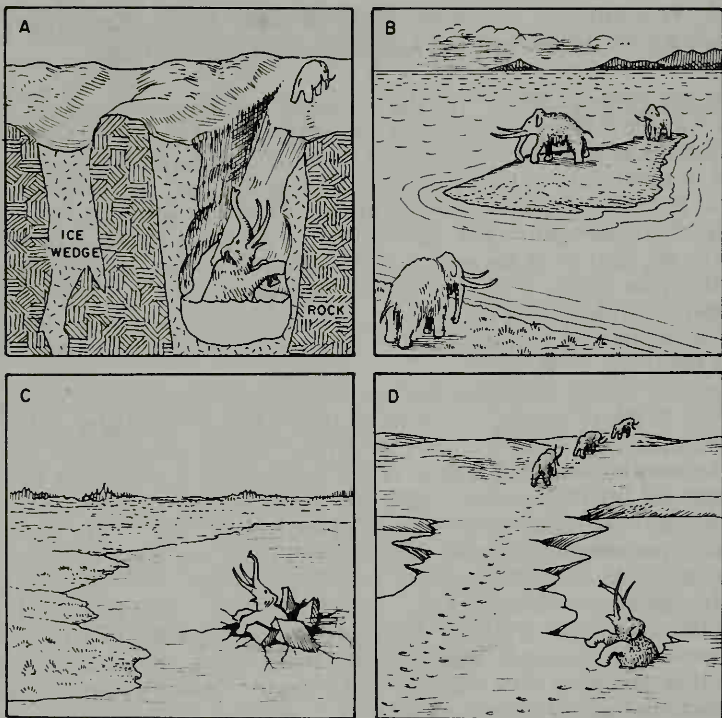
Death and Preservation. All the evidence now at hand supports the conclusions of previous workers that no catastrophic event was responsible for the death and preservation of the frozen woolly mammoths. The cadavers are unusual only in that they have been preserved by freezing; the demise of the animals, however, accords with uniformitarian concepts. The ratio of frozen specimens (around 39) to the probable total population (more than 50,000) is of the order of magnitude expected among terrestrial mammals on the basis of chance burial. Furthermore, the occurrence of nearly whole carcasses is extremely rare (only four have been found), in spite of the numerous expeditions for fossil ivory and other exploration in northern Siberia.

There is no direct evidence that any woolly mammoth froze to death. In fact, the healthy, robust condition of the cadavers and their full stomachs argue against death by slow freezing. On the other hand, the large size of their warm-blooded bodies is not compatible with sudden freezing. In addition, all the frozen specimens were rotten and, in most cases, had been somewhat mutilated by predators prior to freezing. This is attested to by many first-hand accounts. Although some of the flesh recovered from the cadavers was "fibrous and marbled with fat" and looked "as fresh as well-frozen beef or horsemeat," only dogs showed any appetite for it; "the stench...was unbearable". Histological examination of fat and flesh of the Berezovka mammoth showed "deep penetrating chemical alteration as a result of the very slow decay," and even the frozen ground surrounding a mammoth had the same putrid odor, implying decay before freezing. Furthermore, the stories of a banquet on the flesh of the Berezovka mammoth were "a hundred per cent invention."

Soft parts of other fossils are not unknown in the geologic record, but sudden or catastrophic changes of climate have not been postulated to explain the preservation of these parts. Skin and hair of Pleistocene ground sloths are known from nonglacial areas. From more remote times we have mummified skin of Mesozoic dinosaurs and muscle fibers of Devonian sharks, still showing individual fibers and cross-striations. Such fossil evidence implies preservation of these soft parts for a considerable period of time---at least as long as was required for lithification of the enclosing sediments.

The only direct evidence of the mode of death indicates that at least some of the frozen mammoths (and frozen woolly rhinoceroses as well) died of asphyxia, either by drowning or by being buried alive by a cave-in or mudflow. As stated above, sudden death is indicated by the robust condition of the animals and their full stomachs. Asphyxiation is indicated by the erection of the penis in the case of the Berezovka mammoth and by the blood vessels of the head of a woolly rhinoceros from the River Vilyui (Siberia), which were still filled with red, coagulated blood.

The specific nature of deposits enclosing the mammoths is not known well enough to be very helpful as an indicator of the mode of death or burial. Most of the remains are associated with river valleys and with fluviatile and terrestrial sediments, but whether the mammoths bogged down



Many noncatastrophic death scenarios have been proposed for the mammoths: (a) falling into an ice shaft; (b) starvation after being stranded by rise in sealevel; (c) falling through ice and drowning; and (d) drowning after eroding lake shore collapses. (Adapted from Smithsonian Magazine, *8:61-68, December 1977.)*

in marshy places or fell into "riparian gullies" or were mired in and slowly buried by sticky mudflows is not clear. Perhaps all three of these agencies and several others were involved. One point of fact helpful in this problem is the specificity of the frozen animals: In Siberia only mammoths and woolly rhinoceroses have been found frozen and preserved, and the former have been found in much greater numbers than the latter.

So far no other members of the contemporary Eurasian fauna---stag, horse, reindeer, antelope, musk ox, and so on---have been found frozen and well preserved. That only the bulky and awkward "giants" of the fauna are so preserved points to some peculiarity of their physique as a contributing factor. The low-slung rhinoceros would have trouble negotiating marshy ground and snow drifts. Similarly, the mammoth, with his stiff-legged mode of locomotion, would have difficulty on such terrain and, moreover, would probably not be able to cross even small gullies. It would be nearly impossible for him to extricate himself if he had fallen into a snow-filled gully or had been mired into boggy ground. A modern elephant is unable to pass over any trench which barely exceeds his maximum stride because of the pillar-like leg structure which is required to support his vast body. Also, the mere weight of the mammoth's body would have been a dangerous attribute if the animal happened to graze too near the edge of a river bluff which had been softened by the summer sun.

The stomach contents of the frozen mammoths indicates that death occurred in the warm season, probably in late summer or early fall, when melting and solifluction would have been at a maximum and, accordingly, locomotion would have been difficult.

The several theories of entombment, which have been alluded to above, generally reflect the theorist's particular experiences or impressions in the mammoth-bearing terrain. Digby was impressed by "countless riparian gullies" which would have been ideal mammoth traps when filled with snow in the winter. Vollosovich was himself trapped in a slowly moving stream of very sticky mud and had to be rescued by his guides. He theorized that an animal so trapped might fall on its side and act as a dam, being slowly buried and suffocated by mud. The Berezovka mammoth is commonly regarded as having fallen as a cliff slumped beneath it; its broken bones attest to such a fall. Presumably it then suffocated as it was buried alive by the caving bluff. Popov believes the Mamontova mammoth perished in a bog while grazing on the floodplain of the ancient Mamontova River. Quackenbush believed that his specimen from Alaska perished on a floodplain and that most of the flesh rotted away before the corpse was naturally buried by floodplain sediments. Another possibility is drowning by breaking through river ice. All of these theories are credible and can be accepted as possibilities. There appears to be no need to assume the occurrence of a catastrophe. (pp. 733-734)

THE CATASTROPHIC DEEP-FREEZE OF THE BERESOVKA MAMMOTH

Dillow, Jody; *Creation Research Society Quarterly*, 14:5-13, 1977.

Abstract. It is commonly held in historical geology that Pleistocene extinctions were a gradual process lasting over thousands or millions of years. However, frozen mammoth carcasses found buried in the tundra muck give evidence leading to a different conclusion. Of particular interest is the carcass of the Beresovka Mammoth (1901). An analysis is presented of the temperature drop necessary at the time of its death to leave the mammoth in the state of preservation in which it was found. By using

thermodynamic models of the mammoth, it is demonstrated that the animal must have frozen to death in mid-summer by being suddenly overcome by an outside temperature below -150°F.

• Unusual Preservation of Organic Matter

THE MAMMOTH IN SIBERIA

Howorth, Henry; *Geological Magazine*, 2:7:491-501 and 550-561, 1880.

I am not aware that the contents of the stomach of any Siberian Mammoth have been hitherto examined, and we are reduced as to actual evidence of food to the results obtained from an examination of the fissures of the teeth of the Rhinoceros. This has been made by several observers. Brandt found bits of coniferous wood and remains of a seed. C. A. Meyer found the seed of an Ephedra. Mercklin distinguished the wood of a willow. The most elaborate examination of such frail debris was made in 1876, by M. Von J. Schmalhausen; he found in some brown matter scraped from a Rhinoceros teeth from Irkutsk remains of monocotyledons and dicotyledons, and recognized traces of a graminaceous plant, and of an ericaceous one, the latter probably Vaccinium Vitis Idaea. Among the remains of coniferae were those of a Picea (? obovata), of an Abies (? sibirica) of a Larix (? sibirica), of a Betula, of a Salix, and of an Ephedra, all plants still thriving in Southern Siberia. The a priori evidence therefore is overwhelming, that when the Mammoths and their associated animals lived in Siberia, the climate was much more temperate. Let us now adduce such experimental evidence as we possess. We cannot of course take our thermometer with us to those days, but we can do something very like it, we can examine the debris of vegetation that has survived from those times. Plants at all events cannot migrate; they must stay the winter through, and they afford us therefore a good thermometer to mark where ancient isothermal lines passed. Fortunately remains of such plants have survived. These consist of two series, those which are the result of drift, and those which clearly grew on the spot. The shrewd observers who live in Siberia long ago discriminated between these kinds, and gave the name of Noashina to those which have drifted, and of Adamshina to the indigenous timber, and this division is supported by Goppert, who separates the trunks of timber found in Northern Siberia into a northern series with narrow rings of annual growth and a southern with wider ones. The latter, as Schmidt says, doubtless floated down the rivers, as great quantities do still, while the former probably grew here with the Mammoth.

Describing the fresh-water deposit in which the Mammoths' remains occur on the Lower Yenissei, Schmidt says: "It consists generally of clay alternating with layers of vegetable matter, consisting, like the similar layers of vegetable matter on the banks of the Tundra lakes, of water-mosses, grass, roots, leaves, pieces of branches, and layers of low weeds, which are covered in the spring floods with fresh layers of clay... Where the lakes on the Tundra have grown small and shallow, we find on and near their banks a layer of turf, under which in many places are remains of trees in good condition, which support the other proofs that the northern limit of trees has retrogressed, and that the climate here has grown colder. I found on the way from Dudimo to the Ural Mountains, in a place where larches now only grow in sheltered river valleys, in turf on the top of the Tundra, prostrate larch trees still bearing cones. We also found on the Tundra under the turf near Sselakim, stems over half a foot in diameter; similar ones are only now found occasionally on slopes with a southern aspect. Lopatin found similar trees still more to the north in the cliff of Nikandrowskie Jary in 70-1/2° N. L., while 11 versts above Krestowkoje, in 72° N. L., he found in a layer of soil covered with clay on the upper edge of the banks of the Yenissei, well-preserved stems like those of the birch, with their bark intact, and sometimes with their roots attached, and three to four inches in diameter. Professor Merklin recognizes them as those of the Alnaster fruticosus, which still grows as a bush on the islands of the Yenissei, in lat. 70-1/2° N. While on the Tundra, near Swerevo, in 71° N. L., its present northern limit, it creeps along the ground with a stem but the thickness of one's finger. With the branches and roots of the Alnaster, Lopatin found a mass of fine twigs or branches, which shows it was not drift timber.

In the deposit where the Mammoth on the Gyda lay, Schmidt found some Hypnum mixed with the leaves of Salix retusa, var. rotundifolia and Salix glauca, which still live in the neighbourhood, and small bits of wood an inch thick and three to four inches long, and roots which Professor Merklin recognizes as larchwood. No remains of larch were found in the layers above. "That the larch grew here" (where there is now only a bare Tundra) "is most probable. We have no reason to believe the Gyda ever sprang further north than it does now, while drift wood and rolled pebbles do not occur here."

Schmidt, in another letter, reports that he was told by a native of Heligoland, named Bolting, who had lived for twenty years at Yenisseisk, that at Dudimo, just at the limit of the woods, he had seen in a miserable larch wood, the lower part of a stem sticking in the ground apparently rooted, which was three feet in diameter.

Turning from Western to Eastern Siberia, we find Hedenstrom, who crossed the Tundra from the Indigerka to Ulsiank in 1810, saying, "On the Tundra, equally remote from the present line of forest, among the steep sandy banks of the lakes and rivers, are found large birch trees, complete, with bark, branches, and roots. At the first glance they appear to have been well preserved by the earth, but on digging them up they are found to be in a thorough state of decay. On being lighted they glow, but never emit a flame; nevertheless, the inhabitants of the neighbourhood use them as fuel, and designate these subterranean trees as Adamovshtshina, or of Adam's time. The first living birch tree is not found nearer than three degrees to the north, and then only in the form of a shrub."

On the same journey he says he observed on Lake Chostag, which is fourteen versts long and six broad, that every autumn it throws up a quantity of bituminous fragments of wood, with which its shores in many places are covered to the depth of more than two feet. Among these are pieces of a hard transparent resinous substance, burning like amber, though without its agreeable perfume. It is probably the hardened resin of the larch tree. The Chostag Lake is situated 115 versts from the sea, and 80 versts from the nearest forest.

In another place he mentions how, in a cliff from 30 to 35 feet high, beyond the Malaya Kuropalasik Vaga, and consisting of ice-clay and black earth, he drew out some interspersed roots, and found them to be birch, and as fresh as if only just severed from the trees. The nearest woods were 100 versts distant.

Samukof, we are told, found on the island of Kililnoi the skulls and bones of Horses, Buffaloes, Oxen, and Sheep in such abundance that these animals must formerly have lived there in large herds. At present, however, the icy wilderness produces nothing that could afford nourishment, nor would they be able to endure the climate. Samukof concludes that a milder climate must formerly have prevailed here, and that these animals may therefore have been contemporary with the Mammoth, whose remains are found in every part of the island. Another circumstance, whence he infers a change of climate, is the frequent occurrence, here, as well as in the island of New Siberia, of large trees partially fossilized.

Erdmann says: "It cannot escape notice, that as we go nearer to the coast, the deposits of wood below the earth, and also the deposits of bones which accompany the wood, increase in extent and frequency. Here, beneath the soil of Yakutsk, the trunks of birch trees lie scattered, only singly, but on the other hand they form such great and well-stored strata under the Tundras, between the Yava and the Indigerka, that the Yukagirs there never think of using any other fuel than fossil wood. They obtain it on the shores of lakes, which are continually throwing up trunks of trees from the bottom. In the same proportion the search for ivory grows continually more certain and productive, from the banks of the lakes in the interior to the hills along the coast of the icy sea. Both these kindred phenomena attain the greatest extent and importance at the furthese chain of the islands above mentioned (i.e. New Siberia, etc.), which are separated from the coast of the mainland by a strait about 150 miles wide, of very moderate depth. Thus in New Siberia, on the declivities facing the south, lie hills 250 or 300 feet high, formed of drift wood; the ancient origin of which, as well as of the fossil wood in the Tundras, anterior to the history of the earth in its present state, strikes at once even the most uneducated hunters."

Herr von Ruprecht reported to Brandt that at the mouth of the Indiger, in 67° 39' N.L., on a small peninsula called Chernoinos, where at present only very small birch bushes grow, he found rotten birch trunks still standing upright, of the thickness of a man's leg and the height of a man. In going up the river he met with no traces of woods until he reached the port of Indiga. Here he noticed the first light fir-wood growing among still standing but dead bushes. And higher up the river still, the woods fairly began.

Trees are not the only debris of the life contemporary with the Mammoth which could not migrate, and which may be accepted as a kind of thermometer. In the fresh-water deposits in which the bones are found there are also fresh water and land shells which tell the same story.

Schmidt found <u>Helix Schrencki</u> in fresh-water deposits on the Tundra below Dudimo and beyond the present range of trees. Lopatin found recent shells of it with well-preserved colours, 9° further south, in lat. 68° and 69°, within the present range of trees at the mouth of the Awauka. The most northern limit hitherto known for this shell was in lat. 60° N., where they were found by Maak in gold washings on the Pit.

In the fresh-water clay of the Tundra by Tolstoi Noss, Schmidt found Planorbis albus, Valvata cristata, and Limnoea auricularia, in a subfossil state; Cyclas calyculata and Valvata piscinalis he found thrown up on the banks of the Yenissei, and on a rotten drifted trunk, Amare agrestis. Anodonta anabora he also found on the banks of the Yenissei as far as Tolstoi Noss, but no further. Pisidium fontinale still lives in the pools on the Tundra, as does Succinea putris, on the branches of the Alnaster on the Breschof Islands.

Again, he says, speaking of his journey from Tolstoi Noss to Dudimo, "On the top of the Tundra is often found Noah's wood and peat moss with Planorbis, Limnoea, and a large species of Helix which I have never found here alive."

The evidence then of the debris of vegetation and of the fresh-water and land shells found with the Mammoths' remains, amply confirm the a priori conclusion that the climate of Northern Siberia was at the epoch of the Mammoth much more temperate than now. It seems that the botanical facies of the district was not unlike that of Southern Siberia, that the larch, the willow, and the alnaster were probably the prevailing trees, that the limit of woods extended far to the north of its present range, and doubtless as far as the Arctic Sea; that not only the mean temperature was much higher, but it is probable that the winters were of a temperate and not of an arctic type, and roughly we may conjecture that Lithuania, where the bison still survives, and where so many of the other contemporaries of the Mammoth still live, probably presents to us a not unfaithful picture of what Northern Siberia must have been like from the Urals to Behrings Straits, and that it was probably in such a condition of things as prevails in Lithuania that the Siberian Mammoth thrived the best. (pp. 557-561)

THE GLACIATED GRAVE OF THE MAMMOTH IN SIBERIA

Anonymous; *Current Opinion*, 61:330, 1916.

The whole of northeast Siberia is one vast graveyard filled with the bones of animals that have perished within comparatively recent times. Little does the traveler think, says the physical geographer, Doctor D. Gath Whitley, that the ground under him only a few feet below his sled is packed full of the bones of enormous animals which have perished in some mysterious manner since man appeared upon the earth.

The whole of northern Siberia, from the Ural Mountains to Bering Strait, is one vast graveyard filled with animal remains. The bones, teeth and skulls are those of elephants, rhinoceroses, buffaloes and musk-oxen. These bones occur everywhere. They are found on the banks of the rivers, in the plains, on rising ground and in frozen cliffs. On the shores of the Arctic Ocean there are sloping banks of ice. These are split and furrowed in all directions with deep chasms. As the traveler looks down into their dark depths from above. he sees that the lower portions of these icy chasms are filled with tusks, bones and skulls in countless abundance. We quote from Chambers's:

"In other places on the northern coast of Siberia fronting the Arctic

Ocean the low cliffs which rise above the beach and are formed of earth and clay are full of the bones of elephants and rhinoceroses. In the brief summer, which hardly lasts for six weeks, portions of these earthy cliffs thaw and fall on the beach below. Then it is that the traveler who walks along the shore witnesses an astonishing spectacle. Not only does he observe icebergs stranded on the beach but he also sees the tusks, bones, and teeth of elephants (the mammoth) lying on the shore and whitening the beach for long distances! If he leaves the Arctic Ocean behind and journeys inland, the same sights constantly meet his astonished gaze. He comes, it may be, to a plain where for perhaps half a mile the whole ground seems to be formed of masses of tusks, teeth, and bones of elephants and rhinoceroses welded together in one confused mass in the frozen soil. These mighty beasts must have been destroyed in herds, but how they perished no one knows.

"Still more amazing is the fact that the islands in the Arctic Ocean north of Siberia are equally full of the tusks and bones of elephants and Rhinoceroses; and on the shores of these islands in the Polar Sea the tusks of elephants can be seen sticking up like trunks of trees in the frozen sand!

"Stranger still, actually the very bodies of these great elephants, with flesh, fur and hair perfect, are seen standing upright in the frozen cliffs.

"When the cliffs thaw, the bodies of these great elephants fall to the ground and are so perfect, after being entombed for thousands of years, that the wolves eat the flesh!"

ORIGIN OF THE MUCK-SILT DEPOSITS AT FAIRBANKS, ALASKA

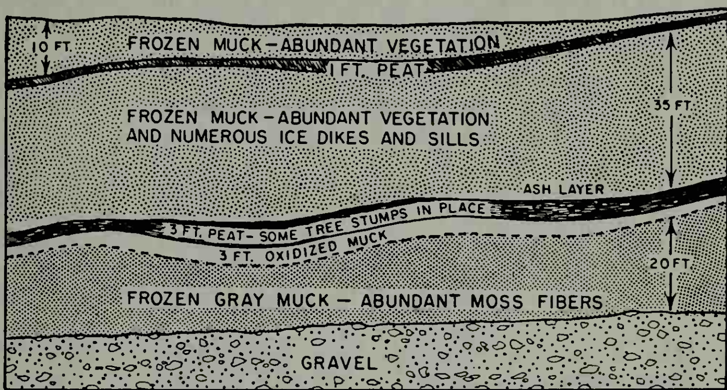
Tuck, Ralph; *Geological Society of America, Bulletin,* 51:1295-1310, 1940.

Muck. The muck covers the valley bottoms of all the streams in the district, with the exception of the Tanana River where gravel flats are exposed. From the surface, where it is covered only by the present-growing vegetation, it extends to depths ranging from a few feet on the headward portions of the valleys to 150 feet on the lower portions of the large streams. The base of the muck horizon that mantles the surface does not extend more than a few feet below the elevation of the Tanana Valley. However, deep drilling indicates that close to the Tanana flats there is a lower muck horizon separated by gravel from this upper surface one.

Uniformly fine mineral grains, of which more than 98 per cent will pass through 200-mesh screen but of which there are practically no clay sizes, make up the inorganic material in the muck. The mineral grains are subangular and are predominately quartz and mica, with lesser amounts of feldspar, hornblende, rutile, garnet, epidote, and other accessory minerals.

The amount of organic material varies from a trace to almost 100 per cent---where it forms peat---but the typical muck contains from 20 to 50 per cent. Practically all the organic material has come from grasses, mosses, alder, spruce, willow, cottonwood, and birch---a vegetation identical with that growing at the present time. The rude bedding, imparted to the muck by the vegetation, is usually horizontal or at a low angle conforming with the slope of the valley, except where it is locally highly contorted by ice dikes. Much of the vegetable material is in place, with the stumps of trees still embedded and upright; in one 20-foot section, six horizons of residual vegetation were plainly evident. In other localities, the heterogeneous accumulation of tree trunks and branches indicates that it was washed in. Occasionally there is evidence of soil flows.

Ash layers several inches thick mantle some of the horizons of vegetation. Where the vegetable material of these horizons is in place, the inorganic material of the muck is always slightly oxidized, indicating that the surface was exposed to weathering for some time.



Generalized section of muck on Engineer Creek, Fairbanks, Alaska.

Vertebrate remains---usually bones, both sometimes almost complete skeletons, and occasionally bones or skeletons with skin and flesh adhering---occur throughout the muck. These remains include living species such as moose, caribou, and many smaller types, and extinct species such as mammoth, mastodon, sabre-toothed tiger, super-bison, and camel. The occurrence of most of the remains indicates that they have been washed, or slid, into their present location, but a few are found in place. Usually where one fossil is found there are many, suggesting the possibility of a water-hole where they congregated or a boggy spot where they may have been entrapped. The finding of complete skeletons indicates that the remains are where the animals died, and, when flesh and hide are still adhering, that freezing and covering must have occurred shortly after death. Rodents' nests are common and are always found a few feet below the horizons of residual vegetation. Organic material is so abundant in the muck that the odor from its decay is noticeable half a mile or more from the open-cuts.

All the muck is frozen, and three types of ice are recognizable: (1) One type is that inherent in the muck, occupying the pore spaces, which was formed contemporaneously with the muck itself. This type forms about 50 per cent of the total mass, which corresponds to the porosity of the inorganic material under close packing. (2) The second type of ice is in sills, a few inches to 10 feet thick, which conform with the bedding of the muck. The sill ice contains a small amount of organic and inorganic material whose rude bedding conforms with that of the main muck mass. The sill ice is believed to be contemporaneous with the muck and to be caused by the freezing of the overflow of creeks in winter and the subsequent covering with silt and vegetation in the spring. A similar process may be observed at the present time. (3) The third type occurs as dikes of clear ice cutting across the sill ice and the bedding of the muck and distorting the latter. The most probable explanation of the dikes is that they represent tension fractures in the frozen muck that have become filled with water---either ground or surface---which subsequently froze, thereby distorting the bedding of the muck.

The muck is always very dark because of the presence of frozen organic material, but upon exposure the vegetable material oxidizes, and the muck assumes a light color identical with that of the silt.

When the muck directly overlies gravel, the latter is always frozen. The contact between the two is usually sharp but sometimes is a gradational zone of interbedded muck, sand, and fine gravel. At the valley heads, the muck may lie directly upon bedrock, which is then usually frozen for several feet. The muck sometimes lies directly upon silt, in which case the contact is usually sharp and the silt is frozen back for 10 or 15 feet.

In the large valleys the muck has many irregular topographic features, such as small ridges and hummocks, and elliptical and circular depressions occupied by small lakes. The irregular depressions are probably due to subsurface thawing of the frozen material by circulating ground water and consequent subsidence of the surface. The elliptical and circular depressions are always surrounded by a muck ridge from 5 to 20 feet high, which is broken at one end. The perpetually frozen subsoil serves as an impervious layer, so that much of the ground water is under a considerable head. These depressions have probably been caused by hydrostatic pressure doming up the frozen layer, which subsequently collapsed upon the release of pressure, leaving a ridge around the depression that was breached at one end by the outflowing water. (pp. 1299-1301)

MUCH ABOUT MUCK

Anonymous; *Pursuit,* 2:68-69, October 1969.

In a fine report on a highly informative talk given by a Mr. E. M. Benson, Vice-President of the North American Producing Division of the Atlantic Richfield Oil Company, to the Long Beach Petroleum Club of California on the new oilfield in northern Alaska, there appeared a rather noteworthy quote. This read:---"Drilling down through the 1000-foot thick frozen earth can produce some surprises. One of our wells brought up an 18-inch long chunk of tree trunk from almost 1,000 feet below the surface. It wasn't petrified---just frozen", the oil company executive said. The reason this statement is noteworthy is not because the reporter seems to have been impressed but rather that a man of Mr. Benson's experience---and he started as a worker in the fields---should use the word "surprise" in this case.

We are going to hear a lot about this frozen earth or "muck" from now on because of this vast oil strike on the Arctic shores of the Alaskan peninsula. It is indeed full of surprises; but a tree trunk in it, and even at a depth of a thousand feet, is not at all surprising. What surprise there was on this occasion was probably due to the fact that it came to light in an area devoid of trees today and hundreds of miles from any forest growth. The nature of muck is not generally understood, and the theories on its origin are even less widely known.

Frozen soil, as diammetrically opposed to ice on the one hand and rock on the other, constitutes one of the greatest mysteries on our earth's surface. What is more it covers no less than one seventh of the land surface of the earth, and all of it encircles the Arctic Ocean and lies within the Arctic circle at what we consider the top side of our planet. Actually it is a form of 'rock', despite its very mixed composition, at least to the extent that a tillite or pudding-stone may be. The reason for stating this is that the material that binds it is water, and water in its solid form as ice is also technically a rock and behaves as such. When this frozen soil melts it results in an appalling and often stinking sort of soup composed of goo with silt, sand, pebbles, and boulders, often with masses of preserved, semi-decayed, or fully decayed vegetable and animal matter. This is what is called "Muck".

A world map of the distribution of this frozen soil and muck reveals several very interesting things, the most outstanding aspect being that it lies on low, level plains or tablelands. Unless it was caused by some cosmic forces that we have not yet detected, it would appear to be a subaerial deposit derived from massive erosion of higher grounds and with steeper slopes. However, its depth in some places, and over enormous areas, has always caused even the most open-minded geologists to boggle. The Russians, who own the major land areas covered by this substance, have conducted prolonged studies on it for half a century and have in some places drilled down to over 4000 feet but still without reaching solid rock. The conundrum is, of course, how do you get that thickness of what is manifestly surface-derived material if it is the result of mere run-off? To this there would appear to be but one answer.

First, the lands now blanketed with this material must at one time have been much higher above sealevel, so that stuff could be deposited upon them, rather than running on beyond and out into the sea. Alternatively, the sea level would have to have been much below that of today; but in this case are we asked to suppose that universal sealevel was not too long ago, geologically speaking, more than 4000 feet lower? If neither of these situations pertained when the first, and lowest layers of this muck were laid down, just what were the conditions, since no such strata could be laid down even under shallow, tranquil coastal seas? To suggest that the uplands from which this stuff came were much once higher and had a steeper run-off is begging the question, and doesn't help at all. Yet, there is the bloody muck lying all over the lot and to enormous depths. It has to be accounted for.

Let us next turn back to Mr. Benson's remark. This was to the effect that finding a section of a fair-sized tree trunk a thousand feet down in this frozen muck was a 'surprise'. It may indeed be to the average person who has not had cause to investigate or read about this incredible natural phenomenon, but it comes as no surprise at all to geologists who have specialized in the surface constitution of the Arctic regions. A mere section of tree trunk is a mild relief compared to some of the things that the muck has yielded. In the New Siberian Islands, for instance whole trees have turned up; and trees of the family that includes the plums; and with their leaves and fruits. No such hardwood trees grow today anywhere within two thousand miles of those islands. Therefore the climate must have been very much different when they got buried; and, please note, they could not have been buried in frozen muck which is rock-hard, nor could they have retained their foliage if they were washed far north by currents from warmer climes. They must have grown thereabouts, and the climate must have been not only warm enough but have had a long enough growing period of summer sunlight for them to have leafed and fruited.

Ergo, either what is now the Arctic was at the time as warm as Oregon, or the land that now lies therein was at that time elsewhere. Geophysicists don't go for an overall warming of this planet to allow such growth at 72 degrees north; otherwise everything in the tropics would have boiled! Thus, we are left with the notion that either the whole earth's crust has shifted, or bits of it have drifted about. But then comes another problem ---the Time Factor.

Along with the plum trees, and other non-arctic vegetation there are found associated animal remains of many kinds. One of these is the famous mammoth. Now, everybody has somehow got the totally erroneous idea that these great hairy beasts are found in ice. Not one has ever been found in ice: they are all in this frozen earth or muck. Then, just because of their layer of fat and their covering of long hair everybody likewise thinks that they were arctic types. A moment's consideration will disclose just how ridiculous an idea this is. A large elephantine needs some half a ton minimum of fresh green food a day to maintain itself, and there were apparently (at least according to the number of their bones and bodies that have been found in the muck) hundreds of thousands of them up till only a few thousand years ago. For a minimum of eight months out of the year there is nothing for such large animals to eat north of the tree line in the Arctic, though some Barren Ground Caribou and a few Muskox get along by scratching through the shallow snow to get at tundra moss and lichens. Therefore these elephantines must have migrated far south for the winter or the climate must have been much milder than it is today, or the lands they lived in were elsewhere.

But not even this pinpoints the reason for the muck or explains just how all the junk that is found in it, even down to thousands of feet, got there. Mr. Benson's tree trunk may not have been a surprise but it is still a mystery in one way. And we should contemplate the many aspects of this mystery in order to be ready for the many more enigmas that we are going to be told about as our technicians slice into the far north.

• Anomalous Dates for Mammoths

BABY MAMMOTH CARCASS 44,000 YEARS OLD

Anonymous; *New Scientist,* 77:215, 1978.

Radio carbon dating studies of the baby mammoth found near Magadan in eastern Siberia last summer have revealed its age to be nearer 44,000 years than the 10,000 to 15,000 years first estimated. Leningrad scientists are now working on a protein analysis of the mammoth. They had hoped to carry out a microstructural analysis of the animal's soft tissues, but unfortunately both its muscle tissue and its brain cells have turned out to be too poorly preserved.

ON THE EXISTENCE OF THE MAMMOTH IN RECENT TIMES IN NORTH AMERICA

Anonymous; *Geological Magazine,* 2:8:373, 1881.

In his Report for 1880, Prof. John Collett, Ph.D., State Geologist of Indiana, says:---Of the thirty individual specimens of the remains of the Mastodon (Mastodon giganteus) found in this State, in almost every case a very considerable part of the skeleton of each animal proved to be in a greater or less condition of decay. The remains have always been discovered in marshes, ponds, or other miry places, indicating, at once, the cause of the death of the animal and the reason of the preservation of the bones from decay. Spots of ground in this condition are found at the summit of the glacial drift or in "old beds" of rivers which have adopted a shorter route and lower level, consequently their date does not reach beyond the most recent changes of the earth's surface; in fact, their existence was so late that the only query is, Why did they become extinct? A skeleton was discovered in excavating the bed of the canal a few miles north of Covington, Fountain County, in wet peat. The teeth were in good preservation, and Mr. Perrin Kent states that when the larger bones were cut open the marrow, still preserved, was utilized by the bog cutters to "grease" their boots, and that chunks of sperm-like substance, 2-1/2 in. to 3 in. in diameter (adipocere), occupied the place of the kidney fat of the monster. During the past summer of 1880, an almost complete skeleton of a Mastodon was found six miles north-west from Hoopston, Iroquois County, Ill., which goes far to settle definitely that it was not only a recent animal, but that it survived until the life and vegetation of to-day prevailed. The tusks formed each a full quarter of a circle, were 9 ft. long, 22 in. in circumference at the base, and in their water-soaked condition weighed 175 pounds. The lower jaw was well preserved with a full set of magnificent teeth, and is nearly 3 ft. long. The teeth, as usual, were thickly enamelled, and weighed each from four to five pounds. The leg bones, when joined at the knee, made a total length of 5-1/2 ft., indicating that the animal was not less than 11 ft. high, and from 15 to

16 ft. from brow to rump. On inspecting the remains closely, a mass of fibrous, bark-like material was found between the ribs, filling the place of the animal's stomach; when carefully separated, it proved to be a crushed mass of herbs and grasses, similar to those which still grow in the vicinity. In the same bed of miry clay a multitude of small fresh-water and land shells were observed and collected, which were kindly determined by Dr. F. Stein, as follows:---1. Pisidium, closely resembling P. abditum, Haldeman. 2. Valvata tricarinata, Say. 3. Valvata resembling V. striata. 4. Planorbis parvus, Say. The shell-bearing animals prevail all over the States of Illinois, Indiana, and parts of Michigan, and show conclusively that, however other conditions may differ, the animal and vegetable life, and consequently climate, are the same now as when this Mastodon sank in his grave of mire and clay.

A GIGANTIC MASTADON

Anonymous; *Scientific American,* 26:264, 1872.

The farm of Mr. Arden Mitchell of Otisville, Orange county, New York, has become suddenly famous by the recent discovery, in a swamp upon the premises, of the entire skeleton of one of the largest mastodons that ever tramped the earth. According to the New York Times, the discovery was made by a laborer who had been hired to dig muck.

The man had excavated to the depth of four feet when he came upon an enormous bone, shaped like a rib. He stopped work and informed Mr. Mitchell of his discovery, who, thinking it must have belonged to some monstrous animal, directed that deeper and more extended digging be done. At a depth of fifteen feet, the pelvis, head and other large bones were found. Search has been continued until almost the entire skeleton has been exhumed. It is said to be much larger than the famous remains in the Boston Museum, which were also found in Orange county, and which were the largest known specimen of these extinct mammalia. The upper jaw and main portion of the head of this new marvel weighs about five hundred pounds, and measures three feet seven inches across the top. There are four teeth in the upper jaw, two on each side. The back teeth extend seven inches along the jaw bone, and are four inches across. The openings where the tusks have been are three feet and eight inches deep and eight inches in circumference. The vertebra was found in forty pieces, but lying all together, while the pelvis was taken out whole and uninjured. The channel where the spinal cords lay when the monster was alive is five inches in circumference. Among the missing bones are the tusks, the lower jaw bone, and those of the hind legs. One bone of a leg that has been found weighs alone over 350 pounds. When the skeleton is reconstructed, it will measure fourteen feet from the bottom of its feet to the top of its head, and over twenty-five feet from head to tail.

A singular incident connected with the skeleton is that in its stomach was found a quantity of undigested matter. Among it were fresh looking and very large leaves, of odd form, and blades of strange grass, of extreme length, varying from an inch to three inches in width, and looking as if freshly cropped from the earth.

[The remarkable feature of both of the preceding reports is the presence of plant material with the mammoth remains. In one instance the vegetation appears fresh, just as it does with some of the supposedly quick-frozen Siberian mammoths.]

STRANGE SURVIVALS

The older scientific literature contains dozens, perhaps hundreds of accounts of torpid toads discovered imprisoned inside rocks and other geological cells apparently locked eons ago. The testimony is profuse and generally rather consistent. Of course the laws of biology and geology unite to disclaim such evidence; the hapless toads being sort of subterranean UFOs. The toad finders were mistaken or lied. Toads and other amphibians and reptiles do have marvelous powers of hibernation and suspended animation, but survival over millions of years? Impossible! Nevertheless, in the spirit of bibliographic completeness we do not discard these unbelievable data.

In the same vein, the reported revival of fossil bacteria found in billion-year-old rocks seems equally incredible. Such announcements are repeatedly refuted but still crop up from time to time. They are on a par with equally numerous "creations" of life with electrical apparatus and claims of spontaneous generation. Biological contamination of equipment and samples is always blamed for such phenomena.

• Reports of Live Animals in Rocks

ACCOUNT OF A TOAD FOUND ALIVE IMBEDDED IN A SOLID MASS OF NEW RED SANDSTONE

Gooch, T. L.; *Report of the British Association, 1835*, p. 72.

The following is an abstract of the statements contained in this communication.

In the excavations for the London and Birmingham Railway, in the Park Gardens at Coventry, the earth was opened to a depth of eleven feet on the 16th of June 1835; the section presented soil eighteen inches, mixed sand and clay three feet, masses of red sandstone, somewhat severed by 'backs' and fissures, but requiring the use of iron bars, and occasionally powder. One of these masses, near the bottom of the excavation, having its three dimensions eighteen, fifteen, and five inches, being lifted and thrown towards a wagon, fell on the ground and broke nearly through the centre; the divided parts lay about an inch asunder. One of these fragments having been thrown into the wagon, a Toad was observed in a cavity or cell in the face of the remaining fragment, and was projected thence in consequence of the workman kicking the stone. The other fragment of stone being reapplied to its fellow, it was found that an oval cavity existed in the centre, which had no visible communication to the surface.

The cavity of the stone in which the Toad is said to have been imbedded was lined with a thin black deposit; on one side of the cavity, which was more rounded than the other, this deposit was most visible.

The colour of the Toad was at first bright brown; in ten minutes it had grown almost black: it seemed oppressed, and gasped frequently; was rather under the usual size, but plump, and apparently in good condition, but seemed to have been injured on the head. It was replaced in the hollow of the stone, the crack having been stopped with clay, and died in four days.

OCCURRENCE OF A TOAD IN A BLOCK OF IRON ORE

Evans, John; *Zoologist,* 10:3632, 1852.

On Monday last, September 20, while some workmen were engaged in getting iron ore at a place called Paswick, in the North of this county, they came upon a solid lump of ore, which, being heavier than two men could lift, they set to work to break with their picks, when, to their surprise, in a cavity near the centre of the stone, they found a toad alive. The cavity was much larger than the toad, being nearly six inches in diameter, and was lined with crystals of what I suppose to be carbonate of lime. The stone was about four yards from the surface of the ground; it is now in the possession of Mr. Haywood, of Derby, by whose men it was found: but unfortunately the toad was not preserved after its death, which took place almost immediately on its exposure to the atmosphere.

A MUMMIFIED FROG

Shufeldt, R. W.; *Science,* 8:279-280, 1886.

Not long ago Mr. James Stevenson of the U. S. geological survey visited me for a day or two at Fort Wingate, and while here invited my attention to an interesting specimen that had fallen into his possession during a recent trip he had made in the coal regions of northern Pennsylvania. The specimen consists of a mummified frog taken from the coal-mine of McLean county, Penn., and the following account of it is from a local newspaper loaned me by Mr. Stevenson for the present purpose. I quote the short notice in full; and the writer of it says, "One of the most curious finds unearthed lately in this region, and what may yet prove a valuable fact in the study of science and history, was singularly found by Eddie Marsh, the fourteen-year-old son of Mr. D. B. Marsh, a book-keeper for Stevenson Brothers, hardware dealers. Eddie, becoming impatient at the fire in the stove, which was not burning vigorously, took the poker and began punching it. A large lump of coal lay smouldering, and he determined to break it; and, after punching at it for a moment, the lump burst open as if by explosion, and a number of pieces flew out of the stove. One piece he caught, and he was in the act of casting it back into the stove, when its lightness attracted his attention. On viewing it, he saw that it was nothing less than a perfectly formed frog. On last evening a large number of persons viewed the little curiosity. It had been embedded in the centre of the large lump of coal, and its bed was plainly discernible when the lump was laid open. The lump of coal came from the third vein of coal in the McLean county coalshaft, which is 541 feet under ground. The curiosity apparently was not petrified. Apparently it had been mummified instead. It was shrivelled until it is about half the size of a full-grown frog, and it is light and soft. Its shape is perfect, and the warty protuberances of the skin are very plain. Its limbs are regular and properly shaped, including the finger-like toe of its feet, and its eyes and mouth are natural. There can be no doubt of its being a mummified frog, and now various and tough questions arise regarding it: How did it get that far under ground? How did it become embedded in that chunk of coal, which probably had been blasted from the centre of a thick vein? How many thousands of years had it been buried? and various other queries, which we will leave for the scientist to unravel and explain."

Mr. Stevenson tells me that he is personally acquainted with all the parties concerned in the discovery of this specimen, and has carefully examined the piece of coal whence the mummy was taken, and says, further, that it came from the vault, and not from either the sides or the floor of the mine.

He has done me the honor to turn the specimen over to me for diagnosis, as well as to take such steps as I saw fit to ascertain if there be any similar cases on record, and, finally, how geologists or paleontologists explain such finds as this. The specimen is now before me, and I at once recognized it as a species of Hyla, though I am unable to say which one. It apparently agrees in all its external characters with a specimen I have of Hyla versicolor, kindly diagnosed for me by Professor Cope last summer, though it is rather smaller. As will be seen from the life-size figure I have made of it, which illustrates this letter, it is in nearly a

A mummified frog reportedly found in a lump of coal.

natural position; its feet, however, are somewhat drawn up under it. I have figured it as viewed directly from above. It is completely mummified, and in a wonderfully perfect state of preservation, being of a dark, snuff-brown color, somewhat shrunken, and, in short, reduced to a condition, that, if properly excluded from the air, would keep for an indefinite length of time. I am aware that these tree-frogs very often climb into some of the most unheard-of places; but it struck me that it would be interesting to have someone tell us if they ever heard of a Hyla finding its way to the vault of a coal-mine 541 feet under ground, and climbing into the solid coal-bed after getting there.

TOADS IN ROCKS

Anonymous; *Scientific American*, 63:180, 1890.

Many well authenticated stories of the finding of live toads and frogs in solid rock are on record, and that such things are possible was demonstrated here recently, when the workmen engaged in Varley & Everill's lime rock quarry, north of the city, broke open a large piece of rock which had been blasted out, and a frog hopped out of a pocket in the center of the stone, says the Salt Lake Herald. Of course, the occurrence created a tremendous sensation among the workmen, and operations at the quarry were for the time suspended, and the movements of the frog were watched with great interest. The animal was somewhat smaller than the ordinary frog, and was perfectly white. Its eyes were unusually large and very brilliant, but the frog was apparently blind. Where the mouth should have been there was only a line, and on the feet was a dark, horny substance. Mr. Everill at once took charge of the curiosity and put it in a tin can but the frog died the next morning. He brought it down town, and it was examined with interest by a large number of people, and it was afterward presented to the museum, where it will be preserved in alcohol.

TOADS AND FROGS IN STONES

Anonymous; *Nature*, 83:406-407, 1910.

The old myth of the occurrence of live frogs and toads enclosed in blocks of stone or of coal is not yet dead, but ever and again shows signs of life in the way of vigorous assertion of supposed cases of the phenomenon. We have received a communication from a resident in Leicestershire in which the writer states that, while recently breaking a lump of coal, "from the centre a live half-grown toad, fell out on its back. I called the attention of my neighbours to it, and I thought it was dead; but in a few minutes it began to move about, so I took care of it, and have it now as well as the piece of coal. There is the cavity in the coal where it laid. I can vouch for its genuineness. Is it of any value as a curio to naturalists or geologists? I have had several amateurs to see it." It matters little to tell the reporters of such occurrences that the thing is absolutely impossible, and that our believing it would involve the conclusion that the whole science of geology (not to speak of biology also), is a mass of nonsense. Why that is so it would be difficult to make them understand, for at present, with the exception of the comparatively few professional and amateur geologists, the general public, even some of the most educated, are as ignorant of the most elementary facts of geology as they are of the Chinese language. All popular beliefs, however, rest upon some basis of fact, though the facts may be imperfectly observed and erroneously interpreted. The true interpretation of these alleged occurrences appears to be simply this---a frog or toad is hopping about while a stone is being broken, and the non-scientific observer immediately rushes to the conclusion that he has seen the creature dropping out of the stone itself. One thing is certainly remarkable, that although numbers of field geologists and collectors of specimens of rocks, fossils, and minerals are hammering away all over the world, not one of these investigators has ever come upon a specimen of a live frog or toad imbedded in stone or in coal. Why are these alleged occurrences testified to only by those having no knowledge of geology, and, indeed, for the most part by uneducated workmen? It would indeed be an epoch-making event in the history of science if, for instance, a member of the Geological Survey should lay before us a genuine case of a live frog enclosed in stone!

• Revival of Fossil Organisms

FOSSIL ALGAE BROUGHT BACK TO LIFE?

Anonymous; *New Scientist*, 16:187-188, 1962.

Last year the scientific world was startled by the suggestion from the United States, which is still in dispute, that curious bodies in meteorites were the remains of life from another planet. Now an equally surprising claim has been made by a Soviet scientist, Dr. N. Chudinov. He reports that he has successfully brought to life fossil algae that previously lived about 200 to 350 million years ago.

The organisms in question---red and yellow species of algae---were, according to Dr. Chudinov, identified during a search for the cause of the colour staining of salt deposits in the foothills of the Urals, and it seems that they are present to a total extent of hundreds of millions of tons weight. The deposits consist of alternating layers of sodium, potassium, and magnesium chlorides. It is from the latter two kinds of salt that the scientists at the laboratories of the Berezniki Potassium Combine, assisted by the Palaeontological and Botanical Institutes of the USSR Academy of Sciences, say they have made their discovery.

Their report explains that, when they dissolved away the salt, they found that the coloration was due to species of algae entombed in the salt that they could not classify with any known kinds. They were then amazed to find that the algae began to show signs of life: they transferred them to various culture media, until they began to reproduce and to form large colonies. Moreover, bacteria associated with the algae also apparently came to life again. The experiments were repeated on a large number of samples from different salt deposits and, according to Dr. Chudinov, strict precautions were taken against contamination with contemporary species.

In recent years there have been several unsubstantiated claims concerning "living fossil" micro-organisms---for example reports of finding live bacteria in oil wells, or of organisms in salt deposits found by American and West German researchers. But in previous instances the numbers of individuals found have been small and open to the objection of being possible contaminants introduced by drilling or mining. The sheer volume of the Soviet material, if indeed it all contains viable algae, would seem to be a point in favour of its credibility.

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NEW CLAIM TO HAVE REVIVED "FOSSIL" BACTERIA

Anonymous; *New Scientist,* 23:575-576, 1964.

Bacteria found in salts taken from the Zechstein layer---a 250 million-year-old limestone formation in the Permian System of Germany---have been revived, according to H. J. Dombrowski of Freiburg University, West Germany. Claims made to this effect a few years ago were greeted with considerable scepticism, and Dr. Dombrowski has therefore taken great care to exclude the possibility of the samples being contaminated by fresh bacteria. He maintained absolutely sterile conditions during his experiments and carried out "control" tests on other salts treated in the same way. In view of this, he concludes that the living bacteria, which he found in every second sample, can only have come from the ancient deposits themselves.

The samples were obtained by boring into zones which it was certain had remained undisturbed since their formation, ensuring that any organism found was the same age as the rock itself. Microscopic examination of thin sections of the samples showed, moreover, that the bacteria were, in fact, embedded in the salt, rather than in the thin cracks that opened in it during the process of boring. The oldest deposits from which living bacteria are claimed to have been extracted are about 600 million years old.

....

DOUBT CAST ON ANTQUITY OF BACTERIA FOUND IN COAL

Anonymous; *Science News Letter,* 22:196, 1932.

Bacteria found inside lumps of hard coal are not necessarily as old as the coal, in the opinion of Prof. Homer G. Turner of Pennsylvania State College. They may be of quite recent origin, and have been carried into the coal through pores or crevices by water.

Prof. Turner has examined anew the evidence advanced by Prof. C. B. Lipman of the University of California, for the great antiquity of bacteria which he found within lumps of anthracite.

The coal seam from which Prof. Lipman's samples came, Prof. Turner reports, is closer to the surface than was at first considered to be the case. Moreover, it slopes upward to a surface outcrop, through which water can filter, and conceivably carry bacteria with it. As a further possibility of bacterial contamination from the outside, Prof. Turner points out the constant presence of bacteria carrying air and water in the mine itself. He also suggests the improbability of the delicate living protoplasm of bacteria surviving the terrific pressure and the probable high temperatures of the earth.

BIOLOGICAL EVIDENCE OF EXTREME SEA-LEVEL CHANGES

Raised terraces, drowned estuaries, and wave-planed guyots are common topographic indicators of sea-level changes. (See Chapter 2.) The distributions of some fossils and living organisms support these morphological observations of substantial alterations of sea level. Small changes---plus or minus a few feet---are bypassed here in favor of data suggesting more profound changes.

Examining submergence first, buried forests and shallow-water shells dredged up from the continental shelves testify to recent encroachments of the sea. Fossils of Pleistocene animals and even human artifacts are often found in samples scooped up from depths of 100 meters and more. Generally, these relatively recent elevations in sea level are attributed to the waning of the Ice Ages and the melting of immense quantities of ice.

More startling are the discoveries of shallow-water fossils on sea mounts now several thousand meters beneath the waves. Although the sea mounts themselves may have subsided, it is also possible that the sea level was drastically depressed in relatively recent geological times---not just hundreds of meters but thousands. Submarine canyons and some evaporite deposits support the latter interpretation.

No one disputes that sunken lands have risen from the sea to several kilometers elevation in the distant past, for sedimentary strata decorate the Canadian Rockies and other mountain ranges. More recent and modest recessions of the sea are inferred from whale skeletons and marine fossils found near the surface kilometers inland and at elevations of hundreds of meters. In addition, some present fresh-water lakes support marine organisms that were seemingly stranded when the sea retired to its present beaches. More controversial are reports of recent marine fossils and low-altitude plants among the peaks of the Andes. Live sea horses were once reported from Lake Titicaca, only to be refuted. But there is other evidence that the Andes have risen thousands of meters in very recent geological times.

• Buried Forests

THE BURIED FORESTS OF NEW JERSEY

Anonymous; *Scientific American*, 59:265, 1888.

An industry the like of which does not exist anywhere else in the world furnishes scores of people in Cape May County, New Jersey, with remunerative employment, and has made comfortable fortunes for many citizens. It is the novel business of mining cedar trees---digging from far beneath the surface immense logs of sound and aromatic cedar. The fallen and submerged cedar forests of Southern New Jersey were discovered first beneath the Dennisville swamps 75 years ago, and have been a source of constant interest to geologists and scientists generally ever since. There are standing at the present day no such enormous specimens of the cedar anywhere on the face of the globe as are found embedded in the deep muck of the Dennisville swamps. Some of the trees have been uncovered measuring six feet in diameter, and trees four feet through are common.

Although ages must have passed since these great forests fell and became covered many feet beneath the surface, such trees as fell, according to the scientific theory, while they were yet living trees are as sound to-day as they were the day of their uprooting. Such trees are called "windfalls" in the nomenclature of the cedar mines, as it is thought they were torn up by the roots during some terrible gale of an unknown past. Others are found in the wreck that were evidently dead trees when they fell, and to these the miners have given the name of "breakdowns." The peculiar action of the wind and water in the swamp has kept these breakdowns in the same stage of decay they were in when they fell, as the same agency has preserved intact the soundness of the living trees.

The theory of those who have made this mysterious collection of buried cedar trees a study is that they in some unknown age formed a vast forest that grew in a fresh water lake or swamp that covered this portion of New Jersey, the properties of the soil of which were necessary to the forest's existence. According to Clarence Deming and Dr. Maurice Beasely, eminent geological authorities in Southern New Jersey, the sea either broke in upon the swamps or the land subsided and the salt water reached the trees. This destroyed the life of many of them, and subsequently some prehistoric cyclone swept over the forest and leveled it to the earth. The heavy trees gradually sank into the soft soil of the swamps until they reached the substantial earth or rock beneath it, where they reposed, unknown and undisturbed, until their presence was accidentally discovered in 1812. Ever since then the logs have been mined, and have been an important factor in the commercial and business prosperity of South Jersey.

The buried forest lies at various depths in the swamp, and the uncovering of the trees or working the "cedar mine" is done in a very simple and easy manner. The log miner enters the swamp and prods in the soft soil with a long, sharp iron rod. The trees lie so thickly beneath the surface that the rod cannot be pushed down amiss on its testing errand, for the prodding is not so much in search of a tree as it is to test whether the tree is a "windfall" or a "breakdown." When the prod strikes the log, the miner chips off a piece with the sharp point of the tool, which brings the chip or splinter to the surface when drawn out of the muck. By the appearance and order of this chip the miner can tell at once whether the tree he has tested is a sound or a dead one. If the former, he quickly ascertains the length of the trunk by prodding along from one end of it to the other.

That ascertained, he proceeds at once to raise the log from its hidden bed. He works down through the mud a saw similar to those used in sawing out ice in filling an ice house. With this he saws the log in two as near the roots as he cares to. The top of the tree is next sawed off in the same way, and then the big cedar stick is ready to be released from its resting place. A ditch is dug down to the log, the trunk is loosened by cant hooks, and it rises with the water to the surface of the ditch. A curious thing is noticed about these logs when they come to the surface, and that is that they invariably turn over, with their bottom sides up. After mining, the log is easily "snaked out" of the swamp and is ready for the mill or factory.

These ancient trees are of a white variety of cedar, and when cut have the same aromatic flavor intensified many degrees that the common red cedar of the present day has. The wood is of a delicate flesh color. One of the mysterious characteristics of these long-sunken trees is that not one has ever been found to be waterlogged in the slightest. It is impossible to tell how many layers deep these cedars lie in the swamps, but it is certain that there are several layers, and that with all the work that has been done in constantly mining them during three-quarters of a century, the first layer has not yet been removed from the depths. At some places in the Dennisville swamp the soil has sunk in for several feet and become dry, and there the fallen cedars may be seen lying in great heaps, one upon the other. No tree has ever been removed from the Dennisville swamp from a greater depth than five feet, but outside the limits of the swamp they have been found at a great depth, which shows the correctness of the deep-layer theory. Near the shore of the Delaware, eight miles from Dennisville, white cedar logs have been exhumed from a depth of 12 feet. At Cape May, 20 miles distant, drillers of an artesian well struck one of the trees 90 feet below the surface. It was lying in an alluvial deposit similar to the Dennisville swamp. Another log was found at Cape May 20 feet below the surface, and a third at a depth of 70 feet. These deeply buried logs were among the largest ever brought to light, and their location so far away from the Dennisville marsh indicates the great extent of that ancient forest area.

. . . .

RATES OF SUBMERGENCE OF COASTAL NEW ENGLAND AND ACADIA

Lyon, C. J., and Harrison, W.; *Science,* 132:295-296, 1960.

Abstract. Altitudinal and carbon-14 age determinations of in-place Pinus strobus stumps of drowned forests at Odiorne Point, N.H., and Grand Pre and Fort Lawrence, Nova Scotia, yield apparent average rates of submergence of 3.1, 14.5, and 20.3 feet per 1000 C^{14} years, respectively. Rate differences are assessed in terms of eustatic rise of sea level, crustal movements, and tidal effects.

....

The drowned forest at Odiorne Point, N.H., near lat. 43°2' N., long. 70°44' W., consists of the remains of a coniferous stand whose stumps and fallen trunks are found within a protected cove measuring about 500 feet in diameter. The stumps are rooted in a firm woodland peat, ranging from 2 to 4 feet in thickness, that overlies till and bedrock.

The famous drowned forest at Fort Lawrence, N.S., near lat. 45°50' N., long. 64°17' W., has now lost most of its exposed soil and the stumps rooted in it. The site can be reached by following Dawson's directions. Samples of the forest soil, described by Dawson as "black vegetable mould, resting on a white, sandy subsoil", proved to be clay loam colored with forest humus to a depth of 6 inches. The "white" layer is underlain by 8 to 9 inches of red sandy loam, which in turn rests on till.

At Grand Pre, N.S., the remains of a forest extend over at least 100 acres of mud flats exposed at low tide on the north side of Boot Island (lat. 45°8' N., long. 64°17'W.), near the south shore of the Minas Basin. Stumps are rooted in 15 to 18 inches of gray clay soil that rests upon a pale-red clay layer varying in thickness from 12 to 24 inches, underlain by stony till.

....

DEEP-SEA REMAINS OF TREES

Anonymous; *English Mechanic,* 35:424, 1882.

The Panama Star of June 8th, gives some news which should be of considerable interest if true. In repairing the cable of the West Coast of America Telegraph Co., the break was found some 400 nautical mile south of Chorillos, off Point Pescadero, in a depth of about 800 fathoms. The cable, when grappled, brought up great masses of trunks, roots, and branches of trees, and the question is, how came the trees there? as Indian tradition, like history, is silent as to any great convulsion.

(The preceding item, if true, may concern vegetable debris washed out to sea by floods rather than in situ growth. The plant material buried deeply in the drift, as in the following excerpts, seems to represent extensive flooding rather than marine submergence. Whale skeletons, however, are also found in the drift signifying marine incursions; so this item is included here rather than in the section on the drift in Chapter 1. WRC)

VEGETABLE REMAINS IN THE DRIFT DEPOSITS OF THE NORTH-WEST

Winchell, N. H.; *American Association for the Advancement of Science, Proceedings*, 24:43-56, 1875.

Vegetation in the Drift Deposits of Illinois. Jersey County, borders on the Mississippi. In this county fragments of wood, and even trees of considerable size are often met with in sinking wells or in making other excavations in "the plastic clay." By "the plastic clay" is here meant the lowest portion of the northern drift. It is overlain by a layer of twenty or thirty feet of gravel and sand, with boulders. This last is overlain by about twenty feet of yellowish-brown clay rising to the surface.

Marion County. Mr. Henry Englemann reports pieces of brown wood in a well at Patoka, thirty feet below the surface. This occurs in blue clay with sand and pebbles, the clay itself being thirty feet thick.

....

In St. Clair County, Mr. Worthen found bits of wood in a coarse quicksand near the bottom of the drift, over eighty feet below the surface. This was below the mass of blue and reddish clay, which was fifty feet in thickness.

....

In Woodford County a layer of rotten driftwood or peaty matter occurs at the depth of about sixty-five feet, below a thickness of fifty feet or more of bluish clay, or hardpan, exposed in a ravine of Richland Creek, as reported by Mr. H. A. Green. This deposit here is said to resemble peat, but embraces fragments of wood well enough preserved to be recognized. From this locality Prof. Lesquereux identified the following species: American white birch, black or double spruce, American larch or tamarack, and one variety of cedar.

The "true drift" in Grundy County, is said by Mr. Frank H. Bradley, to consist of a tough, blue, "boulder-clay," with pebbles and boulders, sometimes also including fragments of wood, overlaid but slightly, or not at all, with gravel, and underlaid, so far as known, with a bed of hardpan, and a water-bearing quicksand, which has thus far prevented any knowledge of the underlying materials.

McLean County. At the city of Bloomington, a coal mining shaft passed through 254 feet of drift materials, including two separate layers of black mould and vegetation, between which, according to the report of Mr. H. M. Bannister, were eighty-nine feet of hardpan and clay. The first layer was thirteen feet thick, and a hundred and ten feet beneath the surface. The lower was but six feet thick.

In Tazewell County, according to the last named writer, a bed of black vegetable mould was met in wells in the vicinity of Pekin, where it tainted the water of wells to such an extent as to render them almost unfit for use.

In Menard County, Mr. H. M. Bannister reports near Athens, a shaft that struck pieces of coniferous wood at the depth of about one hundred feet below the general level of the country, taken out in a tolerable state of preservation.

In the extreme northeastern part of Morgan County, a shaft passed through eighty-five feet of drift materials, the greater portion of it bluish hardpan, and near the bottom encountered a log eighteen or twenty inches in diameter. Logs and driftwood are reported to have been frequently found in the clays, etc., of the drift in this county, according to Mr. Bannister, but seldom as deep as in this instance, at the very base of the formation.

In reference to McHenry County, Mr. Bannister says: "In the central and western portions of the county, the mass of the drift appears to consist of clay and hardpan, with occasional boulders. We have, however, in this county, accounts of logs of wood and other vegetable remains being found at various depths in these deposits, a feature which appears to be wanting, or extremely uncommon in Lake County. One such instance of the finding of a cedar (?) log seven inches in diameter, at the depth of forty-two feet below the surface, is reported on the eastern line on Sec. 13, township 44, range 6. Other instances are reported in various parts at depths varying from fifteen to fifty feet or more." (pp. 45-47)

• Recent Fossils Found at Great Depths

ANCIENT OYSTER SHELLS ON THE ATLANTIC CONTINENTAL SHELF

Merrill, Arthur S.; *Science,* 147:398-401, 1965.

Abstract. Shells of long-dead Crassostrea virginica are reported at 71 stations in depths of 14 to 82 meters. The depths exceed those of the estuaries where the species flourishes. Radiocarbon measurements indicate that the oysters were alive 8000 to 11,000 years ago. It is concluded that the oysters lived in lagoons or estuaries which became submerged when the sea level rose at the end of the latest glacial epoch.

ELEPHANT TEETH FROM THE ATLANTIC CONTINENTAL SHELF

Whitmore, Frank C., Jr., et al; *Science,* 156:1477-1481, 1967.

Abstract. Teeth of mastodons and mammoths have been recovered by fishermen from at least 40 sites on the continental shelf as deep as 120 meters. Also present are submerged shorelines, peat deposits, lagoonal shells, and relict sands. Evidently elephants and other large mammals ranged this region during the glacial stage of low sea level of the last 25,000 years.

EVIDENCE OF INSTABILITY IN THE PACIFIC BASIN

Revelle, Roger; *Geological Society of America, Bulletin,* 62:1510, 1951.

Recent geophysical and geological investigations of the floor of the deep Pacific indicate that this area has been the scene of large-scale geologic activity during relatively late stages of earth history. Both seismic and paleontologic evidence suggests that Bikini Atoll began to form on a volcanic base in Mesozoic or Early Tertiary time. Shallow-water fossils from dredgings on the Mid-Pacific Mountains show that the tops of the seamounts which form the summit of this range now at depths of 2500 to 6000 feet, were near the sea surface during Early Tertiary or late Cretaceous time. The lower slopes of many deep topographic highs rising above the level of the sea floor appear to consist of talus unburied by sediment. Volcanic ash layers in cores from different areas indicate local submarine volcanism during the Pleistocene. Finally, the apparently slight thickness of deep-sea sediment suggests that relatively rapid deposition did not begin until the Mesozoic.

A DROWNED MIOCENE TERRACE IN THE HAWAIIAN ISLANDS

Menard, H. W., et al; *Science,* 138:896-897, 1962.

Abstract. A highly fossiliferous sample dredged in September 1961 from a submerged terrace at a depth of 500 to 520 meters off Honolulu contains a reef fauna suggesting deposition at depths of 10 meters or less. The corals and pelagic foraminifers indicate a probable Miocene age. The Hawaiian rise was in existence prior to that time, and the submarine terrace and associated reef were subsequently submerged to their present position.

UPLIFT OF THE CONTINENTAL MARGIN AND POSSIBLE CONTINENTAL ACCRETION OFF OREGON

Byrne, John V., et al; *Science,* 154:1654-1655, 1966.

Abstract. Sedimentary rocks collected from the continental shelf and slope off the central coast of Oregon contain fossil benthic foraminifers of Pliocene and Miocene age. These fossils indicate water depths much greater than those from which the rocks were collected, implying that the rocks have been uplifted as much as 1000 meters since their deposition. Uplift of this magnitude near the edge of the continent is interpreted as representing an early stage of continental accretion, possibly as a result of compression normal to the continental margin. The average maximum horizontal component of this accretion would be about 16 kilometers.

DEEP SEA LEG 48

Anonymous; *Science News,* 110:71, 1976.

Leg 48 of the internationally sponsored Deep Sea Drilling Project has shown that an ancient mountain range, which has now sunk to a depth of 4,000 feet below the sea surface, once existed between Greenland and Europe. Project scientists also discovered that the edge of the European continent, near Spain, was once bounded by a hitherto unknown swamp and shallow sea, abounding with coral reefs. Both are now 10,000 feet below the Bay of Biscay.

The drilling was done by the research vessel Glomar Challenger, which ended Leg 48 of its ongoing mission July 13. Recent cruises have concentrated on finding out why the edges of the continents are as we see them today, and on understanding how the forces that caused continental drift apparently raised and lowered mountain ranges like the one just discovered.

DEEP-SEA RESEARCH BY MANNED SUBMERSIBLES

Heirtzler, J. R., and Grassle, J. F.; *Science,* 194:294-299, 1976.

The New England seamounts extend for 2000 kilometers from the East Coast of the United States. In 1968 two dives were made on Bear Seamount, which is closest to the coast, and we had our first direct look at the tops of others only within the last 2 years, when dives were made on seven others. The seamounts are extremely rugged and have several types of topographic features not previously seen on the sea floor. On Mytilus, one of the seamounts closer to the continent, dead coral that had lived in water no more than 100 m deep has been sampled from Alvin at a depth of 3000 m. These dives are our first brief look at an area nearly as large as the continental United States. The base of the seamounts and the great abyssal plains are so deep that they can be reached by only one submersible---the Archimede. (Excerpt)

• Living Marine Life in Inland Waters

ON THE ORIGIN OF THE MARINE (HALOLIMNIC) FAUNA OF LAKE TANGANYIKA

Hudleston, W. H.; *Victoria Institute, Journal of the Transactions,* 36:300-345, 1904.

The history of the recognition of the halolimnic fauna is important as tending to show what were men's views from time to time as each step in the progress of discovery was made. It will be remembered that Lake Tanganyika was discovered by Burton in 1857, and that his companion, Speke, picked up a few dead shells from the shores and brought them to England. The well-known conchologist, Dr. Sam. P. Woodward (Proc. Zool. Soc., 1859, p. 348, Pl. XLVII) was struck with the peculiar forms of some of the gasteropods, which he considered had a certain marine look about them. Subsequently when further supplies were procured, Mr. Edgar Smith (Proc. Zool. Soc., 1881, p. 276), in a paper on a collection of shells from Lakes Tanganyika and Nyassa, expressed an opinion that they might turn out to be the relics of a former sea. The subsequent discovery of medusae in Lake Tanganyika seemed to confirm these views as far as that lake was concerned. Hence before Mr. Moore appeared upon the scene, most of those who had paid attention to the subject had expressed themselves as favouring the view of the marine origin of this peculiar fauna.

Mr. Moore, as a result of his first journey in 1896, found "that in Nyassa and Shirwa there were no jelly-fishes, nor anything except purely fresh-water forms; while in Tanganyika there were not only jelly-fishes, but a whole series of molluscs, crabs, prawns, sponges, and smaller things, none of which appeared in any of the lakes he then knew, and all of which were distinctly marine in type. Further than this, however, he found that none of these strange marine looking animals were to be compared directly with any living marine forms, yet, in their structure, some of them certainly seemed to antecede a number of marine types in the evolutionary series, and, in consequence, they appeared to hail from the marine fauna of a departed age. The most definite result of the first Tanganyika expedition, therefore, appeared to be that the sea had at some former time been connected with the lake, but when or how remained a mystery."

The above are Mr. Moore's own words in explanation of his views after the termination of his first expedition. It should be borne in mind that at this period, viz., in 1898, when his inferences were laid before the Royal Society (Proc. Roy. Soc., vol. 62), there was an idea then partially and perhaps generally prevailing, that owing to the peculiar structure of the Rift Valley system and its obvious physical connection with the great Red Sea depression, that the "halolimnic" fauna might have entered Lake Tanganyika from that quarter, and would consequently be found in some of the Rift-Valley lakes to the northwards, and especially in Lake Kivu, with which at the present day Tanganyika is hydrographically connected through the River Rusizi. It was therefore indeed a surprise when Mr. Moore had to announce as the result of his second expedition, commenced in the spring of 1899, that no trace of the "halolimnic" fauna had been discovered in any of the lakes, such as Kivu, the Albert Edward, or the Albert Nyanza, which lie to the northward of Tanganyika in the western arm of the Rift-Valley system. Nay, more, it would seem that no such thing as the halolimnic fauna was to be found in the great upland basin of the Victoria Nyanza, nor in the chain of lakes associated with Lake Rudolf (Basso Narok), which lie towards the northern termination of the eastern arm of the Rift-Valley system.

To quote Mr. Moore's own conclusions on this point: "It has been shown that throughout Equatorial Africa, as in other great continents, there is a normal fresh-water fauna which has nothing peculiar about it. . . . Subsequently, the fauna of L. Tanganyika has been examined in detail, and it has been shown that this lake, like all other great lakes of Central Africa, contains the ordinary fresh-water fauna of the continent; but that in Tanganyika, and in Tanganyika alone, there are a number of organisms possessing definitely marine and somewhat archaic characters. Along with these, the halolimnic members of the Tanganyika fauna, there are others, such as the prawns, sponges and protozoa which, although not like the previous types, unique in being found in Tanganyika for the first time as fresh-water forms, are notwithstanding probably portions of the same group, for they are peculiar to Tanganyika, and are not characteristic of the general fresh-water fauna of the African continent." He further suggests that the African ganoids and certain other members of the African fish fauna may be portions of the "halolimnic" fauna. Lastly, he points to the significance of the similarity which subsists between the shells of the halolimnic gasteropods and "the remains of those found in the deposits of the old Jurassic seas."

Thus for Mr. Moore. When we ourselves attempt to face the Tanganyika Problem, it is obvious that it will have to be considered both from a zoological and a geological point of view, and the question is which shall we consider first, the zoology or the geology? We are dealing with an exceptional fauna, occurring under peculiar conditions and in what was, until quite recently, a most out-of-the-way place. Perhaps the first question we should ask ourselves is this: Do we consider that there is sufficient evidence of the marine origin of the halolimnic fauna? This fauna is placed by Mr. Moore himself under two different categories. (1) The halolimnic gasteropods, which are thought to be homaeomorphic with certain shells from beds of the Inferior Oolite formation in Western Europe, and are thus inferentially regarded as descendants of those forms. (2) A fauna, not so thoroughly exceptional as the halolimnic gasteropods, made up of prawns, sponges, protozoa, etc., which are archaic in type and may be portions of the same group of marine derivatives. The presence of Medusa also is held greatly to strengthen this view. As regards the portion of the argument relating to the fishes, it has been stated by a competent authority that the fishes described by Mr. Boulenger in Mr. Moore's beautiful book are all essentially present day types, and do not in any way represent survivors from the seas of the Mesozoic period. (pp. 303-305)

MOUNTAINS FROM MOLEHILLS

Garner, H. F.; *Geological Society of America, Bulletin,* 74:195-196, 1963.

Dresch (1958) and Cotton (1960) have cited undocumented and hearsay evidence in support of post-Pliocene uplift of the Andes Mountains. The data were originally recorded by Welter (1947) and concern a sea horse (Hippocampus sp.) which reputedly inhabits Lake Titicaca (3804 m elevation) and beaches (3000-3500 m elevation) on the western Andean flank. Both features supposedly reflect marine conditions when these places were at sea level. Dresch (1958) and Cotton (1960) assign a Pliocene age of emplacement to these relics; they advocate a drastic "sensibly uniform upheaval" of the range (at least 12,000 feet) since that date.

In their extensive summaries of available structural data Harrington, Ahfeld, Cristi, Lewis, and others (in Jenks, 1956) emphasize the varied and intermittent character of Andean orogeny extending back to at least Mesozoic time. Physiographic evidence recorded and summarized by

Garner (1959) is also strongly opposed to Quaternary uplift of thousands of feet. Paleontologic data cited by Jenks (1956) suggest that the most recent seaways in the Andean Cordillera relate to the middle or even early Tertiary at various points along the range. All these relations diminish the probability of late Tertiary marine encroachment into the central Andes. Welter's (1947) paleontologic data which Dresch (1958) and Cotton (1960) emphasize accordingly merit close scrutiny. Other ideas advocating drastic recent Andean uplift are based on geomorphic and erosional theories and uplift rates related to these which Garner (1959) noted to be subject to alternative explanations.

Because of the great significance of the matters at stake Welter's (1947) original statements are reproduced from the South American journal in which they appeared. With regard to the 3000-3500 m high "beaches" which Dresch (1958, p. 147) and Cotton (1960, p. 476) hail as Welter's "discovery" the latter states,

> "Between Jaqui and Yauca quebrada there are preserved small insignificant patches of Pliocene marine sand irregularly distributed in small depressions on a plain [of supposed marine-abrasion origin] (2300 m[1]). There I collected two shells of Pliocene age, <u>in any case of an age older than Quaternary</u>, but which I have not determined exactly through lack of a paleontologic library. The fossils have shapes which are thick and typical of the surf zone of the ocean."

Note that the reputed age was not precisely designated, and that this age and the supposed marine origin were ascertained without even phyletic identification of the specimens. Thick shelled fresh-water mollusks are common in rivers and lakes. Vague comments as to shell thickness therefore signify little. Also, the writer has noted isolated valves of the marine clam <u>Venus mercenaria</u> near rivers as much as 100 miles inland in nearby Ecuador where they may have been carried by man. The inferred extension of the "beaches" from 2300-3500 m elevation is based on the unsubstantiated idea that the shells are marine, and hence that the subjacent plain is one formed by wave erosion. The same surface is discontinuous and has been referred to by Bowman (1916) and Garner (1959) as a remnant of a peneplain or pediplain respectively. In any case the marine origin of the surface is as dubious as the unidentified shells on which it is based, and the age of both remains doubtful.

References to a sea horse in Lake Titicaca have an even less secure basis than the aforementioned features. Welter (1947, p. 9) states, "A fish <u>Hippocampus</u> which normally is an inhabitant of the Pacific Ocean also lives in the slightly salty water of Titicaca." However, neither he nor any of the local inhabitants he cites to confirm the occurrence are willing to state that they have personally observed living specimens extracted from the lake. Welter (1947, p. 9) maintains that a Senor Poznansky of La Paz, Bolivia, received a dried example of <u>Hippocampus</u> from an Aymara Indian but neglects to state its origin. Welter adds that a Sr. L. Sundt believes that the sea horse occurs in Lake Titicaca, whereas a Sr. G. Steinmann disbelieves this occurrence. Welter (1947, p. 9) adds nothing more positive than that 27 years earlier he observed" . . . at least 20 examples [of <u>Hippocampus</u>(?)] in the wharf area of the Bolivian village of Guaqui," where that place borders Lake Titicaca. He fails to mention whether the specimens were dried or freshly caught and the instance may parallel relations in curio shops and markets in inland areas all over the world. Welter (1947, p. 9) seems to attach little importance to the failure of a British scientific expedition under Moon (1941) to achieve its major purpose of collecting specimens of Hippocampus from from Lake Titicaca.

There is little point in raising arguments of any kind against unverified marine beaches of unknown age. Conjecture about a "hearsay sea horse" also smacks of "jousting with windmills," but at least it should be noted that there is a potentially sound contemporary basis for such an occurrence. Following the lead of Welter (1947, p. 10), Dresch (1958, p. 147) and Cotton (1960, p. 478) contend that the sea horse must have entered Lake Titicaca when, ". . . in the Pliocene, it was at sea level." These statements take no note of the frequent invasion of elevated fresh water bodies by marine organisms or of the present "marine" fauna of fresh Amazon River waters near Lake Titicaca. Price (1952, p. 15), speaking of the Amazon and its tributaries states, ". . . two thousand miles and more upriver [well inside Peru] may be found such ocean dwellers as the shark, the tarpon, the sawfish, the swordfish, the porpoise, and the manatee." Lake Titicaca may have had outlets to the sea during the times of accentuated rainfall and overflow, cited by Newell (1949, p. 14, 17) and Garner (1959, p. 1361). These would permit quasi-recent occupation of Lake Titicaca by marine forms of life at elevations not differing greatly from those of the present. The same associations render quite unnecessary the orogenic gymnastics required to rapidly raise a large water body 12,000 feet vertically without mortally disturbing the inhabitants or spilling the contents.

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• Marine Fossils at High Elevations

WHALE BONES 330 FEET ABOVE SEALEVEL

Anonymous; *Nature,* 38:134, 1888.

At a recent meeting of the Scientific Society of Upsala, Dr. C. Aurivillius read a paper on the skeleton of the so-called Swedenborg whale (Eubalena svedenborgii, Lillj.), discovered last November in the province of Halland, in a layer of marl 50 feet above the sea. Remains of this species of whale have only been found once before, viz. early last century, when some parts of one were discovered in the province of Western Gothland, 330 feet above the sea, and 70 miles inland. It was at first believed that they were the bones of some giant, but it is said that Swedenborg discovered their true nature. The skeleton has been presented to the Upsala Museum.

WHALE SKELETONS IN MICHIGAN

Anonymous; *Science,* 72:sup xiv, November 7, 1930.

Excellently preserved fossils of sea-going whales which visited the Michigan peninsula during the ice age have been discovered in two localities, according to an announcement made by Professor Russell C. Hussey, of the department of geology of the University of Michigan. Some twenty to thirty thousand years ago the whales swam inland by way of the St. Lawrence or the Hudson waterway, through the prehistoric glacial lakes and into shallow rivers at the edge of the retreating ice sheet which then covered northern North America. The whales caught in the rivers could not turn around and find their way out, and Professor Hussey believes they must have died of starvation. Their bones were cast upon the beaches of those times and are found to-day in gravels. As found at both localities, one ten miles south of Ann Arbor and the other in Oscoda County in the northern part of Michigan, the bones are bleached white with backbone and ribs perfectly preserved. The University of Michigan hopes to acquire one skeleton for exhibition purposes.

WHALE REMAINS IN GLACIER ICE

Dineley, D. L., and Garrett, P. A.; *Nature,* 183:272, 1959.

The preservation of Pleistocene or Recent land mammals in the Siberian permafrost has long been known, but the literature does not appear to include mention of marine mammals preserved in ice. Particular interest, therefore, is attached to the discovery in 1958 of part of a whale carcass entombed in the ice-cored moraine of Sveabreen, Ekmanfjord, in Vestspitsbergen. The north-eastern lateral moraine of Sveabreen projects into the fjord about two miles beyond the ice-front, and the find was made by members of the Birmingham and Exeter Universities' Spitsbergen Expedition near the seaward tip.

The ice-core of the moraine rises to about 20 ft. above the high-water mark and the dirt cover probably about 3 ft. thick. Near the top of the ice-core, and within the adjacent moraine, the bones and (now decomposing) flesh and skin of a whale were found. Melting of the ice and the removal of moraine seem to be uncovering more of the carcass each year and, from what could be seen, much of the body behind the shoulder region appears to remain. Several of the posterior vertebrae are exposed on the upper surface of the moraine so that their dorsal surfaces have suffered some damage. The head and shoulders have been carried away during present-day erosion of the moraine, which consists here largely of water-worn pebbles and small boulders and muck containing "raised beach" fossils typical of the "Mytilus horizon", that is, of the Sub-Recent period. Weathered-out vertebrae and ribs were found on the shore. The length of the existing part of the animal is about 30 ft. so that its length when complete must have been about 60 ft.

The question of how and when the animal became entombed is a difficult one. One would expect a dead whale to float and hence decompose during the summer months, even if it died in the winter. It is suggested, therefore, that this specimen was trapped beneath ice, possibly the floating ice-front of Sveabreen, and held there. Advance of the ice pushed the whale, together with sediment and the enclosed shelly fauna, from the fjord floor to the position where the moraine so formed is now situated. The long axis of the whale is more or less parallel to the length of the moraine. It may be fortuitous that it lies at the top. As long as it remained in the permafrost the animal would not decompose. It is surprising that the body remained intact during the movement.

A regional recession of the ice in the Arctic had been taking place during the past 200 years and certainly Sveabreen has retreated some two miles during the past 45 years. The whale must have reached its present position at least before the recession began and probably during the previous major advance of the ice, which occurred as a result of a severe deterioration of the climate in Sub-Recent times. Ahlmann suggests that this advance may have occurred about 2,500 years ago. Since then and with the further recession of the glaciers, isostatic recovery has raised the Sub-Recent littora deposits on the Ekmanfjord coast 2-3 m. above sea-level and with them the overlying ice-cored moraine. Thus it may be surmised that the carcass of the whale reached its present site most probably more than 200 years ago but not more than 2,500 years ago. This time-interval is a large one; but radiocarbon dating would perhaps narrow the likely limits within which the whale died.

MUMMIFIED SEAL CARCASSES IN THE MCMURDO SOUND REGION, ANTARCTICA

Pewe, Troy L., et al; *Science,* 130:716, 1959.

Mummified carcasses of the "crabeater" seal (Lobodon carcinophagus) lie scattered over the land surface 1 to 30 miles from the sea and up to 3000 feet above sea level in the ice-free areas of the McMurdo Sound region, Antarctica. A few such carcasses were noted on land many miles from the sea in this area almost 60 years ago by scientists of the early British antarctic expeditions. We noted 90 mummified seal carcasses during the 1957-58 field season. No doubt many others exist in the Mc Murdo Sound region, and probably in other parts of Antarctica. The occurrence of these carcasses on the surface of the ground so far from their natural habitat raises the questions of why they are there, how long they have been there, and how they got there. Two carcasses have been shipped to the United States for anatomical and histological study. This paper represents a preliminary report of our observations.

All except one of the identifiable carcasses are of the crabeater seal. One is a Leopard seal (Hydruga leptonyx). A fairly well-preserved carcass of an Adelie penguin was found lying on the ground 15 miles from the sea near seal carcasses on the west side of the sound.

The leathery dry carcasses are in various states of preservation; some are relatively well-preserved, and others are merely old, twisted, wind-dissected fragments of tissue. The well-preserved ones range in length from 3-1/2 to 7 feet and in diameter from 1 to 1-1/2 feet. They are dry and hard, and they have hair only on the side in contact with the ground; this side is generally flat and has a strong smell.

We found seal carcasses in every ice-free area we visited in the Mc Murdo Sound region except Black Island and Ross Island. Twenty-five percent of the remains were found within a mile of the sea, but scattered groups of 2 to 19 specimens were found as much as 17 miles inland. The carcasses in each group were spaced 10 to 100 feet apart.

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The age of the mummified seal carcasses in the ice-free land of the McMurdo Sound region is intriguing. The remains have been thought to be perhaps 100 years or so old, because the arid and cold climate of the area is ideal for retarding organic decay. Radiocarbon analysis of one carcass showed that it is between 1600 and 2600 years old; another is being analyzed.

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We believe that the antarctic seals, which occasionally wander inland, find no food in the fresh or alkaline lakes and therefore die. The cold, arid climate preserves their carcasses an incredible length of time, and the remains of seals and other animals that have wandered inland during the last 2000 years probably still exist to attest the animals' last journey.

MUMMIFIED SEALS OF SOUTHERN VICTORIA LAND

Dort, Wakefield, Jr.; *Antarctic Journal,* 6:210-211, 1971.

One of the more puzzling of the many interesting features of the dry valleys of southern Victoria Land is the presence there of numerous seal bodies well preserved by desiccation or mummification in the cold, dry environment. These unusual remains were first discovered when land exploration of the region commenced with Captain Scott's first antarctic expedition of 1901-1904. Since 1957, literally dozens of bodies have been observed by the many parties that have undertaken field studies in the area.

Available information is not sufficiently detailed to permit computation of an accurate total of the number of carcasses present. A minimum of 210 seal bodies have been observed in the three main dry-valley systems; an additional 70 reported sightings may, at least in part, represent duplication of discoveries. However, the University of Kansas field parties recorded the locations of 106 carcasses in Taylor Valley alone. Additional finds were reported from the Ferrar Glacier by members of the Scott expedition and from smaller ice-free coastal valleys east of the Royal Society Range by several parties, especially those of Pewe, who discovered 20 carcasses in and near Garwood Valley.

In the Victoria, Wright, and Taylor Valley systems, mummified seals have been found as far as 66 km inland from McMurdo Sound. Most bodies are on or near the valley floors, especially against easterly facing escarpments or other topographic situations that form cul de sacs impeding easy westward travel. A few seals, however, succeeded in climbing steep slopes or even isolated peaks before dying at elevations ranging up to 1,200 m above sea level.

The occurrence of the remains of seal bodies at inland locations in southern Victoria Land is not duplicated elsewhere in Antarctica. Carcasses observed by Soviet parties, for example, have all been at or very near the coast. This may be a consequence of either the dearth of inland ice-free areas or the lack of intensive exploration along most of the periphery of the continent. In 1966, a remarkable sighting and capture of a live crabeater seal pup at an elevation of 920 m occurred in Marie Byrd Land 113 km from the coast.

A distinctive pattern of cusps on the cheek teeth provides a means of ready identification of crabeater seals. The skulls of many of the seal bodies in southern Victoria Land have been removed by souvenir collectors or normal ice and sand abrasion. However, 95 percent of those bodies still retaining cheek teeth are of crabeater seals. Body lengths indicate that almost all of the carcasses, whether complete or not, are of pups not more than 6 months old; some were hardly more than newborn.

There is an extremely wide range in the degree of preservation of the seal bodies. Some are complete even to whiskers, the pelt soft and pliable, body fluids still exuding. The majority are dried and shrunken, truly mummified, and have suffered erosion of upper surfaces by wind-blown ice crystals and sand. Others have been reduced to a few bare bones still articulated by remnants of ligaments. Close juxtaposition of seals showing sharply contrasting preservation suggests that there is a considerable range in the ages of the carcasses. Determination of these absolute ages is a problem yet to be completely solved.

A seal found on the ice of Lake Bonney in November 1966 is believed to have died within the preceding week or two. The trail it left on the gravel surface was readily traceable from Nussbaum Riegel to the lake, a distance of 3 km. During 1966 and 1970, three other seal trails were found in the middle part of Taylor Valley. Comparison with manmade trails and other features of known age indicated that a trail is easily visible for only a year or two and will disappear after 5 years.

Radiocarbon analysis of specimens obtained from mummified seals in southern Victoria Land has yielded ages ranging from 615 to 4,600 years. However, antarctic sea water has significantly lower carbon-14 activity than that accepted as the world standard. Therefore, radiocarbon dating of marine organisms yields apparent ages that are older than true ages, but by an unknown and possibly variable amount. Therefore, the several radiocarbon ages determined for the mummified seal carcasses cannot be accepted as correct. For example, the apparent radiocarbon age of the Lake Bonney seal known to have been dead no more than a few weeks was determined to be 615 ± 100 years. A seal freshly killed at McMurdo had an apparent age of 1,300 years.

On the basis of all data available from repeated field observations between 1965 and 1970, the writer believes that the slightly desiccated seals have been dead only a few years, that the mummified remains that still have intact or nearly intact pelts are no more than 20 to 30 years old, and that none of the bare skeletal remnants are more than 200 to 300 years old.

RECENT CHANGES IN CIRCUMPOLAR LANDS

Howorth, Henry H.; *Nature,* 5:162-163, 1871.

(That changes in sealevel have occurred in circumpolar lands is not controversial. How much and when are at issue now. Howorth, a proponent of the Deluge, infers that the changes are large and recent. WRC)

The question of the upheaval and subsidence of different areas of the earth's surface, as it is going on at the present moment, is of very great importance in geology, and yet few subjects have been more neglected. A few facts have been here and there collected; but even the best authorities treat the matter in a jejune fashion. According to them the areas of upheaval and subsidence are scattered over the earth's surface in an irregular manner, without any definite law or rule. I believe that with very slight local exceptions there is a very distinct law which governs the subject.

Putting aside altogether the southern hemisphere for the present, I wish to prove that the area of upheaval is confined to the land bordering the Polar Sea, and to the Polar Sea itself; that it is perfectly continuous all round the earth, and that it is greatest near the Pole, and gradually diminishes until it disappears about the 57th parallel, leading to the conclusion that the focus of upheaval is the Pole itself.

Of course, my observations are entirely confined to what is taking place <u>now</u>, and are not to be confused with the facts of any other period, historical or geological.

Commencing with Scandinavia, we have the remarkable testimony of Pliny, Mela, Solinus, and others, to the fact that Scandinavia was considered by the Roman geographers, whose authorities were bold and expert seamen, to be an archipelago. Ptolemy speaks of the Scandian Islands. The very name Scandinavia is evidence that those who used it looked upon it as an island. This implies that a great deal of dry land must then have been under water. In 1834 Sir Charles Lyell wrote his Bakerian lecture, in which he brought forward overwhelming evidence to prove that Scandinavia was then being gradually upheaved. Celsius, who wrote in the 17th century, had affirmed it, and calculated the rise at forty inches in a century. In 1807 Von Buch wrote that all the country from Frederickstadt, in Sweden, to Abo, in Finland, and perhaps as far as St. Petersburg, was slowly rising. Other authorities concurred, and lastly Sir Charles Lyell, who had approached the subject as a sceptic, was fully convinced after an exploration of the ground. At Stockholm he found striking proofs of change since the Baltic acquired its present tenants, Testacea found there seventy feet above the sea level being identical with those found in the adjacent sea. At Soderleige, a little farther south, and in a bed ninety feet above the sea level, besides the shells were found several buried vessels, made of wood, and joined with wooden pegs. In another place an iron anchor and nails were found. At Upsala brackish water plants were found in meadows where there are no salt springs; a proof that the sea had only recently retired. At Oregrund, forty miles to the north, the land had risen five inches and a half since 1820, and at Gefle were low pastures, where the inhabitants' fathers remembered boats and even ships floating. Experienced pilots in the Gulf of Bothnia estimated the fall of the waters at two feet in thirty years. Since Sir Charles Lyell's lecture both the Russians and the Swedes have made experiments all proving the same fact.

To the east of Scandinavia we have Finland, exhibiting all the characteristics of a recently-emerged land. It is a mere congeries of lakes and swamps, separated by moss and sand. The level of the lakes is constantly falling. In 1818 Lake Sovando was suddenly lowered; its waters escaped into Lake Ladoga, and much of its bottom was exposed. Similar traditions about low meadows but recently crossed by boats and ships to those existing in Sweden prevail here also, and there seems good ground for believing that in the days of the Norsemen the White Sea and the Gulf of Finland were joined by a considerable strait. Farther east, again, we have the experience of Murchison and his companions, who found on the banks of the Dwina and Vaga recent shells still retaining their colour, and of the same species as those found in the Arctic Sea. In Spitzbergen, Mr. Lamont reports (see vol. xviii. of the "Quarterly Journal of the Geographical Society") that he discovered recent bones and drift wood several miles inland and high above high-water mark, skeletons of whales thirty to forty feet above the sea level. The seal fishers told him the land was rising, and that the seas thereabouts were now too shallow for the right whale, which had forsaken the Spitzbergen coast. This is confirmed by Malmgren (see Petermann's Mittheilungen, 2, 1863). Farther east we have the Tundras between the Karen Sea and the Gulf of the Obi presenting bare desolate flats that look as if they had only recently emerged. Middendorf describes the surface of the great Siberian Tundra as coated with fine sand like that now being deposited by the Polar Sea. Von Wrangel has many useful remarks to prove my position. He tells us that Diomed Island, mentioned by Laptev and Schalaurov, is now joined to the mainland; the coast of the Swatoi Ness, which they describe as very indented and ruinous, is now straight. The Bear Islands are mere heaps of ice and stones, evidently but recently covered with water; and shoals and banks now occupy what was tolerably deep water in 1787 when Captain Sarypchew was there.

Herdenstrom, in 1810, found large birches scattered about the Tundra, 3^{o} to the north of any known Siberian forest; probably drift wood such as Wrangel himself found drifting in the Polar Sea. Whales have now almost deserted the Siberian shores, where in the eighteenth century they were common. This is, no doubt, due to the shallowing of the water, as is the case in the Spitzbergen Sea. The shores of the Polar Sea, from the Lena to Behring's Straits, are for the most part low and flat. In winter it is hard to say where land ends and sea begins. A few versts inland, however, a line of high ground runs parallel with the present coast, and formerly, no doubt, constituted the boundary of the ocean. This belief is strengthened by the quantity of drift wood found in the Upper Level, and also by the shoals that run out, and will, no doubt, become dry land (Vide Wrangel's Introduction). "At several places along the coast we found old weathered drift wood at the height of two fathoms above the present level of the sea, whilst the lower drift wood lay at a level, indicating a change of level." Moving farther east again across Behring's Straits, we find Captain Beechey describing the coast as a high cliff, now separated from the sea by low flats with bones, &c., on them. I cannot speak with the same confidence of the vast archipelago that bounds America on the north, nor about the northern shores of America, my researches having been confined to Asia, but evidence must abound in the Arctic voyages. Drift wood and bones of whales are mentioned on high ground by several of them. If it be permitted to quote the works of M. Reclus as an authority, and I believe it to be a most sound book, he says, page 628, numerous indications of the phenomenon (i.e. of the upheaval of the circumpolar land of North America) have been recognised in the Arctic islands, scattered off the coasts of the Continent. At Port Kennedy Mr. Walker found shells of the present period at a height of 557 feet above the sea; a bone of a whale lay at a height of 164 feet. Again, page 651, after saying that Southern Greenland is being depressed, he continues, "On the north of Greenland, from lat. 76^{o}, and in Grennell's land, &c., the directly contrary phenomenon is taking place." Hayes discovered on all the coasts the existence of ancient sea-beaches which had gradually risen to the height of 100 feet.

I have thus shown good ground for entertaining the notion that the land at present rising about the Pole is a continuous area, and is not rising merely in detached masses as M. Reclus's and Mr. Murray's maps (Geographical Distribution of Mammals) would lead us to suppose. I believe, further, that this area, bounded on the south by about the 57th parallel of latitude, <u>is the only area in the Northern Hemisphere which is at present undergoing upheaval</u>. I should feel grateful to any of your correspondents who would point out where there is another area (of course excepting local disturbance immediately round a volcanoe); or would direct me to any authorities throwing light on the question I have advanced, which for anything I know may be an old theory, or even an exploded heresy.

Not only is the land around the Pole rising, but there is evidence to show that the nearer we get to the Pole the more rapid the rise is. This has been shown most clearly in the case of Scandinavia by Sir Charles Lyell, who most carefully gauged the rise at different latitudes from Scania, where the land is almost stationary, to the northern parts of Norway, where the rise is four feet in a century. While in Spitzbergen and the Polar Sea of Siberia, if in the memory of seal fishers and others the water has shallowed so fast as to have excluded the right whale, we may presume that the rate of emergence continues to increase, until it reaches its focus at the Pole, as it certainly diminishes until it disappears towards the south between the 56th and 58th parallels of latitude. The subject is one of paramount importance to those who are trying to work out the history of the earth, and I once suggested at the British Association that it should be made the work of a special report, but I was snubbed. I appeal with more confidence to you, sir, to help me to ventilate it. The question of the subsidence of other areas, and of the correlated climatic change, I will reserve for another letter.

CIRCUMPOLAR LAND

Howorth, H. H.; *Nature,* 5:420-422, 1872.

Having strengthened my former paper by instances of upheaval in other points, and I hope satisfied your readers of the justice of the generalisation about the rise of circumpolar land, it is natural to ask if this remarkable fact is paralleled in any way at the southern pole,---whether we can show that both in the Arctic and Antarctic seas there is a bulging out of the land, and a displacement of the sea at present in progress. Our knowledge of the lands immediately about the southern pole is very scanty; but fortunately we have unmistakeable evidence at the various points of those better known austral lands which approach the antarctic seas, from which we may be justified in drawing a sound conclusion, South America, New Zealand, Australia, Tasmania, and Southern Africa.

To begin with South America, I cannot quote a better authority than Mr. Darwin:

"Everything in this southern continent has been effected on a grand scale: the land from the Rio Plata to Terra del Fuego, a distance of 1,200 miles, has been raised in mass (and in Patagonia to a height of between 300 and 400 feet) within the period of the now-existing sea shells. The old and weathered shells left on the surface of the upraised plain still partially retain their colours. . . . I have said that within the period of existing sea shells, Patagonia has been raised 300 to 400 feet; I may add that within the period when icebergs transported boulders over the upper plain of Santa Cruz the elevation has been at least 1,500 feet" (Naturalists' Voyage p. 171). Again, "M. d'Orbigny found on the banks of the Parana, at the height of 100 feet, great beds of an estuary shell now living 100 miles lower down nearer the sea, and I found similar shells at a less height on the banks of the Uruguay; this shows that just before the Pampas was slowly elevated into dry land the water covering it was brackish. Below Buenos Ayres there are upraised beds of sea-shells of existing species, which also proves that the period of elevation of the Pampas was within the recent period" (p. 130). So much for the East Coast. Now for the West. Speaking of the Hacienda of Quintero, in Central Chili, he says: "The proofs of the elevation of this whole line of coast are unequivocal. At the height of a few hundred feet old-looking shells are very numerous." Again, speaking of Northern Chili, he says: "I have convincing proofs that this part of the continent of South America has been elevated near the coast at least from 400 to 500 feet, and in some parts from 1,000 to 1,300 feet, since the epoch of existing shells, and further inland the rise may have been greater." In Peru, about Callao, he also found evidences of rising land; but here we come to one of the horizons where rising and sinking land meet. If it be necessary to supplement the account of Mr. Darwin, I have the authority of Mr. Baxendall for stating that he found numerous skeletons of whales and seals stranded above high-water mark on the coast near Africa, where a tide (as is well known to be the case in all the Eastern Pacific) is almost unknown.

Having satisfied ourselves of the rise of the southern portion of South America, we must now shortly state the reasons for making it very recent. Speaking of the earthquake of 1822, which caused a general upheaval of the land, Mr. Darwin says, "The most remarkable effect of this earthquake was the permanent elevation of the land; the land round the Bay of Conception was upraised two or three feet, at the island of Santa Maria (about thirty miles distant) the elevation was greater. On one part Captain FitzRoy found beds of putrid mussel-shells still adhering to the rocks 10 feet above high water-mark; the inhabitants had formerly dived at low-water spring tides for these shells" (p. 310). Again, two years and three-quarters afterwards Valdivia and Chiloe were again shaken, and an island in the Chonos Archipelago was permanently elevated more than 8 feet. At Valparaiso within the last 220 years the rise has been somewhat less than 19 feet, while at Lima a sea beach has certainly been upheaved from 80 to 90 feet within the Indo-human period (id, passim). Eighty-five feet above the sea level in an island in the Bay of Callao he found on a sea beach some Indian corn and pieces of Indian thread, similar to those found in Peruvian tombs, a parallel find to that made by Sir Charles Lyell in Scandinavia, which I previously referred to.

Having examined the evidence for South America, we will now turn to the other great southern continent, Africa. I will quote a few passages. "There cannot be the slightest doubt that the upheaval of the country is still going on; for along the whole coast of South Africa from the Cape to Durham Bluff, and still farther north, even as far as Zanzibar, modern raised beaches, coral reefs, and oyster banks may everywhere be seen. At the Izinhluzabalungu Caves is such a point, where the rising of the coast is plainly visible, recent oyster-shells are now 12 feet and more above high-water mark. The same can be observed on the whole line of the Natal Coast. Van der Decken has observed the same thing at Zanzibar, and is of the same opinion as myself, viz, that the Eastern Coast is rising early in the present year (i.e., 1870). I had the opportunity of observing at the Bazanito Islands about ninety miles north of Inhambane, on the east coast of Africa, a series of raised coral reefs round the island of Marsha containing many living shells and quite recent oyster-banks." (Griesbach, Geology of Natal, Quart. Journ. Geol. Soc. xxvii. part ii. p. 69.) Mr. Griesbach also mentions that he saw implements of early man, which were obtained by Richard Thornton and others in old raised beaches of Natal, near Inanda, and at the mouth of the Zambesi River.

Mr. Griesbach is confirmed by Mr. Stow in his papers on the Geology of South Africa in the same Journal (see vol. xxvii. p. 526 et seq.), where bones and teeth are found mixed with shells, quite in a recent state, about Port Elizabeth, &c.

In regard to Tasmania, I quote the following from Mr. Wintle's paper on the Geology of Hobart Town (Mine Journal, vol. xxvii. p. 469):---"Until a very recent period in the geological annals of this island, a great portion of what now constitutes the site of this city was under water. This is proved by the extensive deposits of comminuted shells, all of recent species, which are met with for miles along the banks of the Derwent. Some of these deposits are at an elevation of upwards of 100 feet above high-water mark, and from 50 to 100 yards from the water's edge, plainly showing thereby that a very recent elevation of the land has taken place."

In New Zealand the evidence is the same. M. Reclus says the port of Lyttelton has risen 3 feet since it was occupied by the settlers. Mr. Forbes says that proofs of upheaving of the land are even now obvious to any intelligent traveller. Some of these changes have been witnessed by the present generation. Again, in the Middle Island upheaval of the land is observable in a marked manner through the entire length of the western coast from Cape Farewell to Dusky Bay. Some of the most extraordinary changes in these regions have taken place within the last few years.

This has been confirmed by Dr. Haast, who, however, found some signs of depression at the north-western extremity of the lands. In Australia our evidence is ample:---the north-east, if not the whole of the east coast of Australia, is slowly rising, as proved by the gradual shoaling of the Channel between Hinchinbrook Island and the mainland, due to all appearance neither to silting up nor growth of coral water-worn caves, now well above high-water mark in the sandstone cliffs of Albany Island, and those of the mainland opposite, and in the existence along many parts of the coast, especially towards the north of the peninsula, of extensive tracts of level country now covered with sand dunes, bearing a scanty vegetation, stretching inland 10, 15, and 20 miles off, but which once bordered the sea" (Rattray, Geology of Cape York Peninsula, Australia, Mine Journal, vol. xxv. p. 297).

"An immense portion of the continent of Australia is known to be uprising. . . . The whole coast round to a distance of several miles inland is covered with recent shells; the drainage of the country is apparently altering. Lakes known to have been formerly filled with salt water are now filling up with fresh or becoming dry. The lagoons near the coast are filled with salt and brackish water, and their banks are filled with marine shells with their colours in many cases preserved. Reefs of rocks are constantly appearing in places where there were none formerly. At Rivoli Bay the soundings have altered so much as to make a new survey requisite. A reef has lately almost closed this harbour. Other reefs have appeared at Cape Jaffa, &c. It would appear that a vast movement is taking place in the whole of the south of Australia. In Melbourne the observations of surveyors and engineers have all tended to confirm this remarkable fact. In Western Australia the same thing is observed at King George's Sound, the same," &c., &c., and so on, for many pages. (See Wood's Geological Observations in South Australia, 135-207, and *passim*.)

The facts I have enumerated, which might be almost indefinitely multiplied, are sufficient to prove the position that every large mass of land near the South Pole which we can examine shows signs of upheaval, and justifies the conclusion that the circumpolar land is rising at both poles, and that there is a general thrusting out of the earth's periphery in the direction of its shorter axis.

I must modify the opinion expressed in a previous paper that the 57th parallel is the southern limit of upheaval in the northern hemisphere. The limit of upheaval is an irregular line. I believe that the district intervening between the two projecting poles, with its focus along the equator, is an area of subsidence. This conclusion I believe to be of crucial importance in solving both geological and meteorological problems.

THE AGE OF THE BOLIVIAN ANDES

Anonymous; *Geographical Record,* 4:59, 1917.

In a paper of only three pages (E. W. Berry: The Age of the Bolivian Andes, Proc. Natl. Acad. of Sci., Vol. 3, pp. 283-285, April, 1917) there are announced some remarkable fossil evidences which confirm recent physiographic conclusions as to the late Tertiary and early Pleistocene uplift of the Central Andes. Fossil plants at Corocoro (13,000 feet) and Potosi (14,000 feet), which include a fern and tropical trees allied to those now living on the Amazon lowlands, denote a more humid climate and a far lower elevation, and, the author says, "the sea deposited a part of these strata [on the Bolivian highland] in late Tertiary or Pleistocene time, and since that time there have been differential vertical movements amounting to a minimum of 13,500 feet." The author concludes: "There is, then, definite evidence that parts of the high plateau and of the eastern Cordillera stood at sea level in the late Tertiary."

In various papers in past years Bowman has demonstrated the rapid and recent uplift of the Central Andes and more recently in "The Andes of Southern Peru" (1916) has elaborated a physiographic argument, based on detailed topographic surveys in southern Peru, which concludes that an uplift of at least 7,000 feet is demonstrable and that it may have been much more. The convergence of the physiographic and the fossil evidence is singularly conclusive, and the full report on the fossil evidence may be expected to form one of the major contributions to the physiographic history of the Andes within the decade.

Chapter 5
TERRESTRIAL MAGNETISM

INTRODUCTION

The earth's magnetic field is invisible but every child has discovered it with a toy compass. During the Nineteenth Century, scientists remarked that high quality compasses were set quivering by magnetic fluctuations stimulated by solar events. Unusual transitory magnetic excursions of this type are described in the companion work HANDBOOK OF UNUSUAL NATURAL PHENOMENA. The magnetic anomalies of this chapter are more permanent in nature, as exemplified by the gross deflections of ship compasses when sailing past and over certain spots on the globe. Such macroscopic anomalies doubtless indicate important buried geological features or, if the anomaly is regional in scope, idiosyncracies of the internal dynamo that supposedly generates the geomagnetic field.

On the microscopic level, magnetism has apparently been frozen into sediments during their formation by the prevailing geomagnetic field. Paleomagnetism was born of this revelation, for past changes in the direction of the earth's field could be correlated from stratum to stratum and continent to continent. As this new discipline matured, scientists discovered that magnetic excursions (particularly reversals) might be convenient time markers in geology, geophysics, and archeology. But after much analysis there seem to be some missing parts in the paleomagnetic clock, as well as some grains of sand in the gears.

ANOMALOUS MAGNETIC ANOMALIES

Strictly speaking, the great majority of magnetic anomalies are of little concern to paleomagnetism, for they are defined simply as local departures from the nominal magnetic field. Exploration geophysicists and ship captains encounter such magnetic eccentricities frequently. These "ordinary" magnetic anomalies rarely suggest any conflict with prevailing dogmas. Rather they reveal among other things buried minerals and, on a small scale, past lightning strikes.

To qualify for inclusion as an anomalous magnetic anomaly, the departure from the nominal magnetic field must be extremely large and/or suggestive of some geological mystery. An anomaly where north and south poles are exchanged over a small area certainly betrays something curious and unusual, such as a large buried meteorite. On a planetary scale, the asymmetry of the earth's field has been used to support the idea that the moon was torn out of the Pacific. Even more startling is evidence that the earth's field has been decaying with a short half-life. From this observation, one sails off into the Never Never Land of oscillating internal dynamos and the unthinkable possibility that the earth might be very young and that paleomagnetism is but a chimera.

• Severe Local Magnetic Anomalies

MAGNETIC ROCKS

Anonymous; *Scientific American,* 64:308, 1891.

In a letter to Nature the following instance of extraordinary local magnetic disturbance, due to the presence of magnetic rocks, is cited by Commander Creak:

In September, 1885, when her Majesty's surveying vessel Meda was passing Bezout Island, near Cossack, Northwest Australia, a steady deflection of her compass of 30 degrees was observed. This remarkable result has, however, since been exceeded by observations made in the Penguin on November 6, 1890. The Penguin being two miles north, 79 degrees east, from Bezout Island, a deflection of 22 degrees was observed. The ship was immediately anchored, and some hours of the next day were spent investigating the matter. On Bezout Island itself the absolute values of the variation and dip were normal, the dip being 50 degrees 1'.7 south. But at a position north 79-1/2 degrees east, distant 2.14 miles from that on Bezout Island, the observed dip on board was 83 degrees south, with a very small deflection of the compass. At 900 feet to the westward of this the dip was normal, and it decreased rapidly as the center was quitted in any direction. At about 100 feet south of the center of disturbance, the compass was deflected 55 degrees. This was the largest deflection observed, but the compass was disturbed over an area of about a square mile. The general depth of water in this area was nine fathoms, and the quality of the bottom quartz sand. The observations of the magnetic elements at Cossack and the neighborhood showed little or no disturbance from local magnetic effects. It is therefore evident that the disturbances were due to magnetic minerals at the bottom of the sea.

MAGNETIC DISTURBANCES

Johnson, L.; *Marine Observer*, 6:102, 1929.

The following is an extract from the Meteorological Log, December, 1927---May, 1928, of S. S. Gascoyne, Captain L. Johnson, Singapore to Fremantle. Observer, Mr. S. L. R. Simpson, 2nd Officer.

"The abnormal local magnetic attraction at these places is mentioned in the Australia Pilot (Vol. V), and Lecky's Wrinkles also makes cursory reference to it, but I thought that I should at least mention it in my log.

"On arriving from---and departing for---southerly ports at Cossack, we almost invariably pass Bezout Island at three miles distant, and on passing over a spot with the south end of the Island bearing about S. 60^{o} W. the compass card is suddenly deflected between 55 and 60 degrees in an anti-clockwise direction. The card remains at this position for at least five minutes as a rule and then gradually readjusts itself, showing that the patch of magnetic sand (presumably) on the sea floor is fairly extensive.

"We visit Cossack on our itinerary regularly every six weeks, and the phenomenon is observed unfailingly on every occasion.

"I have never heard of such a large deflection anywhere else in the world, though possibly there are spots with as large---or a large---disturbing influence. I should like to hear of them.

"Similarly, on leaving Port Hedland on the line of leads, the card is deflected, although not nearly as much as at Cossack (about 25 or 30 degrees) but the period is much longer.

ABNORMAL MAGNETIC VARIATION

Parkes, C. E.; *Marine Observer*, 12:96-97, 1935.

The following report was received from Captain C. E. Parkes, S. S. Querimba:

"Whilst in the vicinity of Escape Island, on August 22nd, 1934, between the hours of 10.00 a.m. and 11.30 a.m. and steering S. 8^{o}E. (T) I experienced a most abnormal magnetic disturbance. All my compasses were rendered useless during this period, and the vessel had to be steered approximately by the lay of the land. At 11.10 a.m. Escape Island was abeam 8 miles. At 11.30 a.m. when this Island was bearing N. 61^{o} E., 9 miles (T), the standard compass and bridge compass gradually became normal again, but my steering compass card still remained quite useless, and had to be changed for the time being.

"I am well aware that parts of the N.W. and West coast of Australia are subject to exercising local magnetic attraction on one's compasses if one passes close to the land at these places of influence; but have never before experienced such a very pronounced disturbance to the compasses; and never at all in this particular vicinity, although having passed off Escape Island many times at 9-1/2 to 12 miles distance. I am not definitely sure in my mind if this disturbance was caused by some magnetic influence on Escape Island itself, or if I happened to pass directly over a thin line on the sea-bed, composed of some magnetic substance running approximately North and South, between say Latitude 30° 11' S. and 30° 25' S. and Longitude 114° 49' E. and 114° 51' E. I am rather inclined to the latter view, as my compasses behaved much the same as I have experienced them do, if one passes over an iron wreck in shoal water; only in this instance I was in about 27 fathoms of water, and the influence lasted fully 1-1/2 hour."

MAGNETIC DISTURBANCE

Evens, E. H.; *Marine Observer*, 12:144, 1935.

The following is an extract from the Meteorological Record of S.S. Berwickshire. Captain E. H. Evens. Cape Town to Fremantle. Observer Mr. J. C. Robertson, 2nd Officer.

October 25th to 30th 1934. "Running the Easting Down" in Latitude 39° S. Steering 090° (E.S.E.'ly courses by Compass) Normal Deviation 2°W., the deviation of the Compass was found to increase westerly between the Longitudes of 50° and 70° E. reaching maximum 6° W. in Longitude 70° and decreasing from thereon, until normal in Longitude 85° E.

On successive voyages over a period of some years this identical change has taken place in varying Latitudes from 38° S. to 43° S. always commencing about Longitude 50° E. reaching maximum around 70° and returning to normal again from 85° to 90° E. Longitude.

The depth of water, in this vicinity, surely precludes any possibility of local magnetic attraction, and it is suggested that the variation curves may take a much sharper curve to the northward than is charted.

It would be interesting to note if other ships have experienced a similar change.

CENTRAL ANOMALIES: WHY SO STRONG?

Smith, Peter J.; *Nature*, 260:486, 1976.

When marine magnetic anomalies were first analysed in detail in the early 1960s, it immediately became clear that their amplitudes decrease with distance from the corresponding oceanic ridge. Possible explanations for this phenomenon were not long in coming. For example, the magnetic constituents of the oceanic lithosphere newly formed along ridge axes may change chemically with time, giving rise to a gradual decrease of magnetisation. Another suggestion was that older igneous crust would be overlain by a thicker deposit of sediment; so the anomalies as measured at the ocean surface would be attenuated with respect to those observed above younger crust with less accumulated sediment.

But although these and some other processes, acting either individually or together, could possibly explain a gradual decrease in anomaly amplitude, they were apparently insufficient (at least in the form originally envisaged) to account for the precise form of decrease actually observed. For there is usually a particularly large reduction in amplitude immediately beyond the central anomaly followed by a much more gradual decrease outwards towards the continental margins. In the case of slow-spreading ridges (<30 mm yr^{-1} half-rate), for example, the central anomaly amplitude can be at least twice as high as those of near neighbours, although for faster-spreading ridges the difference is less-marked.

SOURCE OF THE GREAT ARCTIC MAGNETIC ANOMALY

Alldredge, Leroy R., and Van Voorhis, Gerald; *Journal of Geophysical Research,* 67:1573-1578, 1962.

Introduction. The magnetic field of the earth exhibits two maxima of vertical intensity (Z) and very elongated horizontal intensity (H) contours in the arctic region. One of the dipoles is located in Siberia and the other in northern Canada. Those two Z poles are accompanied by very similar total intensity (F) maxima. Magnetic meridians draw very close together near the geographic pole and then proceed as a bundle of nearly straight lines toward the north magnetic pole. This unique pattern of magnetic elements has been described by Hope as the great arctic magnetic anomaly.

Hope has ascribed this anomaly to geologic sources lying deep within the earth's crust but above the Curie-point level. He suggests that the magnetic anomaly is associated with a Mesozoic folding which crosses the Arctic Ocean from the New Siberian Islands to Ellessere Island.

This paper demonstrates that all the known unique features of the great arctic anomaly can be accounted for by magnetic sources at the core-mantle interface. Such an explanation is not handicapped by serious questions raised by unusual crustal structures and thermal conditions, which are a part of geologic explanations. (p. 1573)

SCIENTIST PURSUES 'MYSTERY' IN ARCTIC

Quinter, David; Toronto *Star,* March 20, 1974.

An Ottawa scientist is getting ready today to leave for the far north in search of clues to Canada's "deepest mystery."

For a month or more he will camp each day on a drifting ice floe while he watches highly sensitive instruments flutter in rhythm to earth's magnetic aura.

For want of a better word, John De Laurier is searching for "an anomaly," an eccentric wave in our planet's magnetic field---"and as far as I am concerned, it's the biggest anomaly in the world."

For there's something mysterious down there---as much as 18 miles down---that causes a magnetometer to register a higher magnetic reading than it should. And it stretches about 43 miles wide along a 450-mile path beneath the isolated northern settlements of Alert and Eureka.

De Laurier, a physical scientist in the earth physics branch of the Department of Energy, Mines and Resources, says his trip to the settlement of Tuktoyaktuk will determine if it stretches all the way to Canada's western Arctic regions.

Recently, De Laurier's researches were written up in a book on Atlantis and other legendary civilizations of the distant past. Author Brad Steiger, in Atlantis Rising, mentioned De Laurier's work in connection with beliefs that an "elder race" existed beneath the earth who tinkered with machinery that causes dislocations in our lives on the surface of the planet today.

De Laurier hadn't heard of the book, when informed by the Star last night, but said he knew his findings were being used to "illustrate some pretty odd ideas."

The anomaly was discovered first at Alert in 1957, and each successive year its spreading size has been charted.

"There are other such anomaly features around the world---such as down the Rocky Mountains in the United States, in fact wherever there are recognized earthquake zones," he said.

"But ours is enormous and could be larger than any of them. In fact, there's another anomaly connected with the Canadian one. It's not on an earthquake zone---the Arctic doesn't have earthquakes. It's very stable."

He said one theory suggests that such a build-up in magnetic forces comes where the plates, upon which the continents are built, rub together, a cause of earthquakes.

"But that doesn't explain our anomaly, and so far we can't find an explanation for it. It's a total mystery."

THE EARTH'S MAGNETISM

Bauer, L. A.; *Smithsonian Institution Annual report, 1913*, Government Printing Office, 1914, pp. 195-212.

[From the caption of Figure 2 in the referenced report.]

A Local Magnetic North Pole at Treadwell Point, near Juneau, Alaska, as disclosed by L. A. Bauer's observations in 1900 and 1907. [In the center of the tent the dipping needle stood vertical, with the north end down, and the compass reversed its direction when carried from one side of the tent to the other. Ships' compasses, a mile away, in Gastineaux Channel, are deflected about 11^{o}.]

A LOCAL "MAGNETIC POLE"

Anonymous; *Geographical Journal*, 11:663, 1898.

At a meeting of the Academy of Sciences of Paris on May 9 (Comptes Rendus, cxxv. (1889), p. 1380), M. Mascart announced that Prof. Leist of Moscow had discovered a curious magnetic disturbance at Kochetovka, in the government of Kursk. At this place there was a point at which the horizontal magnetic needle pointed indifferently in any direction, and the dipping-needle was vertical. The phenomenon was so local that at a distance of 70 feet from the centre of vertical dip the declination decreases by 1^{o}.

• Anomalous Pole Positions and Movements

TWO MAGNETIC NORTH POLES?

Hoffleit, Dorrit; *Sky and Telescope*, 7:5, 1947.

In 1937, a Soviet scientist, B. Weinberg, advanced the hypothesis of two magnetic north poles, and in 1940 predicted that the second should be in the Sedov region of the arctic. Now a Russian geographer, M. Ostrekin, concludes that "the existence of two poles in the Arctic is no more a speculation, but a certainty," according to the Indian journal, Science and Culture.

In 1945, a British expedition flying over the Sverdrup Islands noted compass deviations as great as 89 degrees, and the magnetic pole was assumed to have a new location (Sky and Telescope, IV, 10, page 11). Science and Culture comments on the importance of the Soviet findings, but cautions against any final decision until an international expedition has studied the problem.

THE MAGNETIC POLES OF THE EARTH AND THE BIRTH OF THE MOON

Lee, Oliver J., and Longfellow, D. W.; *Science*, 72:89 and 72:424-425, 1930.

Geophysicists recognize many structural asymmetries of the earth, such as the existence of continents of land and an elliptical figure of an equatorial sea-level section. The inequality of the two axes of this ellipse is of the order of one kilometer, the major axis terminating in central Africa and in Hawaii, the minor axis in Sumatra and the Andes.

A remarkable asymmetry exists in the longitude of the earth's magnetic poles, which are at present in 96° west and 155° east longitudes. They are, therefore, only 109° apart, and their longitudes mark out roughly the average boundaries of the Pacific Ocean, the vast basin of which has many "deeps" and is enclosed by a giant circlet of extinct and active volcanoes. If this basin is the birthplace of the moon, it does not seem unreasonable to expect that enough of the heavier, deep-lying magnetic elements in the earth may have been torn along, placenta-wise, on that natal occasion to actually fix the magnetic poles of the earth in these regions. Perhaps it would be better to say that when the lunar material departed, a shift in the distrubution of magnetic materials within the remaining mass took place toward the Pacific basin.

While it seems difficult to believe that the readjustment of the earth to approximately spherical form after such an enormous loss could leave anything fixed, other asymmetric vestiges of diastrophic changes in the earth during its long history have survived so that the one discussed here may not be ruled out a priori.

Attention may have been called to this bit of circumstantial evidence that the moon was born of the earth, but I have not found any mention of it in a casual perusal of several recent books on geology and geophysics.

Dr. Oliver Justin Lee's article on "The Magnetic Poles of the Earth and the Birth of the Moon" in Science of July 25 interests me greatly.

A number of years ago I was impressed with the same fact, namely, that the magnetic poles are not on the axis of the earth, which would seem to be the logical place for them, nor are they even antipodal to each other. When I found that the shortest distance between them was across the center of the Pacific I immediately began to wonder if the removal of the moon mass from the area which is now the Pacific was responsible for this peculiar fact.

In 1926 I had a number of mimeographed copies made of a short article on "The Origin of the Moon" which consisted of about 14 ordinary letter size sheets of typewritten material.

By 1927 I became impressed more with the earthly effects and had a twenty-six page booklet printed giving a large number of facts which seemed to me to support the theory that the removal of a large mass of crustal material, from what is now part of the Pacific Ocean, caused the shifting of the axis of rotation of the earth, caused the magnetic poles to become closer to each other on the Pacific side of the globe and created the major outlines of the continents. The title of this booklet is "The Formation of the Continents and Oceans as We Know Them."

In the September, 1928, issue of the Pan-American Geologist an article of mine on "Symmetric Disposition of Tertic Mountain Systems" was published. This calls attention to a very remarkable symmetry which is created when, on a globe, the magnetic poles, together with underlying continents, are placed back in their assumed original positions.

In the March, 1929, issue of the same journal another article of mine on "Continental Drifting in Northwestern Europe" was published. This article was not confined to a statement of the one bit of contributory evidence which the title indicates, but covers briefly some of the major features of my theory and the evidence supporting it.

In the May, 1930, issue of the same journal an article which I contributed on "Bilateral Symmetry of Earth's Largest Continental Block," with an illustration, described a symmetry of Europe, Asia and Africa around a great circle passing through the south magnetic pole, which I attribute to the removal of a large mass from part of the Pacific, which mass may now be our moon.

Before the Geological Section of the American Association for the Advancement of Science, at their Des Moines meeting last winter, I read a paper, with lantern illustrations, setting forth my theory and the facts on which it was built as well as a small part of the supporting evidence.

I have seen no other mention of this peculiar relationship that seems to exist between the magnetic elements of the earth and the major features of the earth.

Some of the conclusions which the evidence in the case has forced me to are almost revolutionary.

My theory, in a very peculiar manner, seems to fit in, to a certain degree, with Wegener's theory of continental drift of the Americas, so I submitted my theory to W. A. J. M. van Waterschoot van der Gracht, who recently conducted a symposium on the theory of continental drift. Of my theory and the facts which I advance in support of it he recently wrote me as follows:

These curious magnetic facts must have some explanation, and they may be very important for further speculation as to the internal constitution of the earth, and also for the changes in its facial expression....I think that your work brings some very interesting new facts and arguments into the discussion of this most involved problem....Your discussion of the magnetic situation is very interesting and certainly deserves further work and thought.

RECENT ORIGIN AND DECAY OF THE EARTH'S MAGNETIC FIELD

Barnes, Thomas G.; *S.I.S. Review,* 2:42-46, 1977.

Abstract. The only dependable historical data on the strength and direction of the earth's main magnet are the evaluations which were first made by Gauss in the 1830's and the subsequent evaluations made through worldwide magnetic observatory collaboration every few decades thereafter. These data show an exponential decay in the earth's magnetic field with a half-life of only 1400 years. A solution to Maxwell's equations for the electric currents and associated magnetic field of the earth's magnet reveals that there is an electric current of 6.16 billion amperes flowing in the core of the earth and a power loss (going into heat) of 813 megawatts at the present time.

It is obvious that this magnetic decay phenomenon could not have been going on for more than a few thousand years, as the magnetic field would have been implausibly large for the earth. This is strong physical evidence that there must have been a relatively recent origin of this electromagnet or some unknown catastrophic "re-energising" event. The validity of this theoretical and observational result is confirmed by means of an independent check, namely an evaluation of the total magnetic energy in the earth's present field and checking it against a hypothetical reference magnet of the same strength and dimensions. The check is excellent, and leaves little doubt that this physical solution is the most meaningful interpretation of the earth's magnetic history.

• Magnetized Rocks and Strata

MAGNETISM OF ROCK PINNACLES

Hill, E.; *Nature,* 50:318-319, 1894.

It is well known that the Riffelhorn powerfully affects the compass, and the like has been observed on other peaks in Switzerland; but I have never seen any record of similar observations in this country.

Four years ago, on a visit to the Lizard, accident drew attention to a strong influence on the compass exhibited by a crag on the moors near Kynance. I have taken the opportunity of a visit this year to ascertain whether that were a solitary case. I find that such influence, though not general, is by no means uncommon. Most of the rocks in which it was observed were serpentine; it occurred also in hornblende schist; there were no sufficient opportunities of testing the other rocks of the district. The influence was exhibited only in rather prominent crags, but among them often in lower adjacent blocks, as well as in the absolute summits. At a few yards' distance it was always imperceptible.

I saw no traces in any case of the crag having been struck by lightning. This was the only point to which I gave attention; but it would be natural also to inquire if all kinds of rock can possess the property, if wet or weather affects it, and if it be temporary or permanent.

I used a common pocket compass, taking the bearings of some distant object, first a few feet off, then in four surrounding positions as near as the compass could be held to the stone I was testing. The effects varied from no deviation or slight, to cases where the needle swung completely round while still a foot or two away. Among the strongest noted were some crags north of Kynance Cove, and some on a headland about a quarter of a mile south of Coverack, both consisting of serpentine. Any one whose holidays take him to a rocky neighbourhood, may find interest in carrying out similar observations.

MAGNETIC RECORD OF LIGHTNING STRIKES IN SANDSTONE

Purucker, Michael; *EOS*, 55:1112, 1974.

Abstract. Anomalous remanent magnetization of sandstone attributed to lightning strikes is documented in detail for the first time in this paper. The effects of lightning strikes on the remanent magnetization of volcanic rocks have been documented previously in a basaltic lava flow by Cox (1961) and in a dike by Graham (1961).

Cells of anomalous magnetization in sandstone were discovered during an investigation of the magnetostratigraphy of the Moenkopi Formation of Triassic age in north-central Arizona. Close-spaced sampling of a cliff face near Gray Mountain, Arizona, revealed two elongate cells of relatively high intensity remanent magnetization within several feet of one another. Each cell is about three feet wide. The pattern of the magnetic vectors in these two cells is suggestive of concentric circles centered on a line through each high intensity region and is similar to the patterns described by Cox and Graham. The directions of magnetization in these two cells are consistent with upward flow of negative charge on the cliff. Alternating field demagnetization of 500 to 1000 oe removes most of the NRM, leaving a residual magnetization similar in intensity and direction to that found in stably magnetized specimens from other parts of the Moenkopi Formation. In some specimens up to 99 percent of the NRM was removed. Thermal demagnetization removes comparatively little of the NRM below 550°C; the anomalous component of magnetization resides in hematite.

Anomalous magnetization has been found at many localities in the Moenkopi Formation where sandstone beds form ledges or prominent cliffs. At most localities lightning probably has produced these anomalies.

SOURCE MODELS TO ACCOUNT FOR LAKE MUNGO PALEOMAGNETIC EXCURSION AND THEIR IMPLICATIONS

Coe, R. S.; *Nature,* 269:49-51, 1977.

[High remanent magnetization is found in several places on earth and also on the moon. Geophysicists are hard put to explain how such localized areas could be created without far-reaching consequences.]

Indications of large and rapid excursions in the direction of the ancient geomagnetic field continue to create considerable excitement and debate in palaeomagnetic circles. Barbetti and McElhinny have published detailed evidence of a remarkable excursion at Lake Mungo, Australia dated at about 30,000 yr ago, on which they had briefly reported previously. I consider here various simple sources, all in the Earth's outer core, that could account for that excursion---an eccentric radial dipole or current loop, an eccentric horizontal dipole, and a pair of eccentric radial current loops of opposite sign---and discuss the merits of each in light of the modern geomagnetic field and with regard to the magnitude and spatial extent of the anomalous field produced.

Because most of the excursions proposed so far have been found in sediments and have not been convincingly documented over a sizeable portion of the globe, several workers have suggested that some or most of them may reflect sedimentological rather than geomagnetic phenomena. The record of the Lake Mungo excursion, however, is contained in sedimentary material that was baked in prehistoric aboriginal fireplaces. Thus, sedimentological phenomena cannot be invoked to explain the anomalous directions because the natural remanent magnetisation is not detrital or diagenetic in origin but rather is thermoremanent. This type of magnetisation is not only the most reliable recorder of ancient field direction but is also the best suited for making estimates of ancient field intensity.

The Lake Mungo excursion is especially intriguing because of the very high field intensity that Barbetti and McElhinny have found accompanying the large swing in field direction. The intensity estimates are as high as 1.83 Oe, about twice as strong as anywhere on the surface of the Earth today and three times what would be produced at that latitude by the maximum geomagnetic dipole moment previously reported for the past 8,500 yr. While the field was abnormally intense its direction was shallowly inclined first roughly west and then roughly east, very far from the normal field direction of an approximately axial and centred dipole.

[The bulk of the paper is devoted to examining various sources of magnetic fields that might account for the Lake Mungo magnetized strata with the minimum global consequences.]

At present, one can only conclude that if the very high field intensities are approximately correct and if the excursion was caused by non-dipole features similar in configuration to the modern ones, then unusually strong non-dipole fields must have occurred simultaneously over a significant portion of the rest of the world.

[It is interesting to observe that extraterrestrial sources or actions are not considered.]

MAGNETIC BOREHOLES

Millar, Albert; *Nature,* 113:14, 1924.

In practical oilfield work many phenomena are met with and investigated from time to time, but one of these, namely, the magnetic state of some boreholes, does not appear to have received the attention it merits, and it would be interesting to learn the experiences and conclusions arrived at by practical oilfield men who have encountered this occurrence.

No doubt many oil men know of instances where tools and casing are found to be highly magnetised upon withdrawal from the borehole, as well as the lifting tackle and headgear in the derrick being affected in a similar manner to a lesser or greater degree.

Some little time ago an instance of this kind came under my notice. A pole became unscrewed while drilling, and the drilling bit with several poles attached remained in the borehold. As the casing was not moving freely, it was decided to move it before fishing for the lost tools; this was done, that is, the casing was raised and lowered several times from four to five feet. A fishing socket was then lowered in, which should have taken hold of the lost tools at about 115 feet off bottom, instead of which it was found that the top of the lost tools was at 70 feet from bottom, at which depth a hold was taken. At the time this difference in depth could not be accounted for, as it was known that the tools and rods had not run away, but had simply become detached, and their maximum possible fall of one foot could not have accounted for the loss of measurement. When the lost tools were brought to the surface the above-mentioned difference was explained, the rods which had been left behind having become bent more or less in the form of a helical spring. This coiling of the rods could be attributed to several ordinary causes as follows:

1. That the tools had fallen a long distance; this, however, was not the case.
2. That the fishing socket had been carelessly lowered in and the rods forced down. As every care was exercised when lowering in the socket, this could not have happened, and was proved by the fact that the rods above the socket were not in any way distorted.
3. That poles had got below the casing shoe when it was lifted and had been forced down when the casing was lowered into position. As the rods stood about 100 feet inside the casing, this was obviously not possible.
4. It might be argued that one of the casing joints had caught the top of the poles or one of the pole joints when the casing was being let down. This is out of the question, because the casing was of the inserted joint type, perfectly flush on the inside, and careful examination showed no trace of catching.

This extraordinary occurrence of loss of distance and coiled rods could not be traced to any ordinary cause; and as it was known that the well was extremely magnetic, which was proved time after time by the condition of the tools whenever they were withdrawn from the borehold, as well as the magnetised state of the lifting tackle and derrick headgear, it would appear that the magnetic influence of the casing was the cause of the occurrence mentioned above.

One can assume that after the rods had become unscrewed they fell over to one side and rested for some considerable distance in contact with the casing, probably 100 feet or more. The casing as a magnet had not sufficient power to lift the poles plus the drilling tools, but upon the casing being lowered into place each time after lifting it partly held and dragged the poles down with it owing to its magnetised condition, and at each subsequent lowering in the poles became more and more deformed.

It may be that highly magnetic boreholes may considerably affect drilling as well as fishing operations, whether with pole tools or with cable, therefore it would certainly be of interest to learn whether experiences of a similar nature have been met with and recorded.

SOME CURIOUS MAGNETIC RESULTS FROM A PRECAMBRIAN GRANITE

Spall, Henry, and Noltimier, Hal; *EOS*, 52:822, 1971.

Abstract. The 1250 m.y. Spavinaw granite from northeastern Oklahoma is very strongly magnetized, averaging about 10^{-2} emu/cc. The NRM directions are randomly oriented: steep and shallow, positive and negative inclinations are equally represented. Although titanomagnetite and very fine grained hematite are primary Fe-Ti oxides, demagnetization produces no change in the NRM directions whether up to 660°C or in 1400 oe peak A. F. This tends to rule out self-reversal, particularly as there are no compositional variations throughout the granite. We discount lightning because the same magnetic features are shown by all surface exposures, as well as by subsurface samples from deep wells. Among possible, but unsubstantiated, explanations are: (1) the NRM may be due to a viscous component which has built up at depth over a billion years; (2) the cooling granite may reflect multiple reversals of the Precambrian field polarity; (3) there was some form of random motion in the crystal mush below about 550°C.

PALEOMAGNETIC PROBLEMS

Time yardsticks are of the essence in geology. Index fossils and then radioactive dating have led to grand reconstructions of terrestrial history, especially as regards the evolution of life and man. More recently, paleomagnetic excursions have been used in time keeping. A basic assumption has been that the index magnetic excursions occur at the same time all over the world. In fact, the modern edifice of Global Plate Tectonics has been built largely upon foundation of paleomagnetic data. This foundation, however, may be seriously flawed due to: (1) self-reversal of rock magnetism; (2) self magnetism; (3) distortion of the magnetized sediments; and (4) external physical and chemical processes that may modify magnetic properties. Caution must be advised in accepting generalizations based on paleomagnetism.

COULD PALAEOMAGNETISM BE WRONG?

Anonymous; *Nature*, 227:776, 1970.

It is now clear that paleomagnetic data provide the crucial evidence in favour of continental drift, sea floor spreading and plate tectonics, and the other ingredients of what has been called the "new global tectonics" in which the oceans are not only the youngest part of the Earth but are still being formed. The idea of global mobility has become the central dogma of Earth science. Naturally enough, like most dogmas it has attracted uncritical adherents.

Palaeomagnetic data are not the only evidence for global mobility, but they have the advantage of being quantitative. Although palaeontological, geological and palaeoclimatological data are mostly consistent with continental movements defined by palaeomagnetic poles, they usually have the status of supporting evidence simply because they are more difficult to quantify. Thus the doctrine of continental drift is consistent with what is known of the Earth's climatic zone pattern, but the broadness of the climatic zones means that it has been difficult to make precise use of climatological criteria. It has therefore always been an open question as to what would happen if anyone were to compare the results of palaeomagnetism more quantitatively with evidence from other sources.

This crunch has now come, although in a small way. The story is this. Continental movements are determined palaeomagnetically on the assumption that throughout the period covered by the rock record, the Earth's magnetic field has been axially dipolar. Needless to say, this is a reasonable assumption not internally inconsistent, but equally not susceptible to direct proof. Yet without such proof, palaeomagnetism falls to the ground. But Stehli (J. Geophys. Res., 75, 3325; 1970) now claims, on the basis of an analysis of palaeontological data, that for the Permian the axial hypothesis is not valid. Taken in isolation, his evidence is convincing because it is quantitative. His analysis is based on the observation that certain brachiopods are temperature dependent. The lower the temperature at any given place, the fewer brachiopod families there will be, which means that the diversity of brachiopod families will be a maximum around the equator but will fall off as the latitude increases. That this is the case is shown by the behaviour of Recent clams whose family diversity falls off quadratically with increasing latitude. The problem with Permian brachiopods from the northern hemisphere is that family diversity does not vary quadratically with palaeomagnetic latitude but does so when plotted on the present latitude grid. When plotted on the Permian palaeomagnetic latitude grid the Permian diversity bears no particular relationship to latitude, just as when the Recent clam diversity is plotted on the Permian palaeolatitude grid there is, as would be expected, no simple relationship. In short, the Permian axial field is not consistent with the Permian brachiopod diversity whereas the present latitude grid is. And if this is true for the Permian it could be true for other geological periods. That is why palaeomagnetists cannot afford to ignore Stehli's conclusions.

The first and most obvious question to ask, of course is whether the palaeontological sampling was adequate for clearly the number of brachiopod families detected at a given latitude will be critically dependent on the intensity of sampling. Stehli, at least, is satisfied on this score. In the samples of Recent clams there were sixteen families of "cosmopolitan dominants" which, being more or less temperature independent, were found at more than 70 per cent of the sampling stations. These were used to test the sampling efficiency. On the assumption that perfect sampling would reveal all sixteen families, the number actually discovered at any given sampling station gives a crude indication of the total proportion of families sampled. The cosmopolitan dominants themselves were not included in the diversity calculations simply because they were not temperature dependent and thus of no use in testing latitude dependence.

The second question which can legitimately be asked is whether the palaeomagnetic data from North America and Eurasia are sufficient to define the true geomagnetic field for the Permian. The answer is that they are, as far as it is possible to tell, because the North American and Eurasian poles agree when the two continents are reconstructed in their pre-continental drift positions determined without reference to palaeomagnetism. This is in itself evidence---but not proof---in favour of the Permian axial dipole field because pole positions are calculated using the axial dipole assumption.

If Stehli's analysis is valid---and it is difficult at present to show that it is not---the only conclusion to be drawn in isolation is that the Permian field was not axial. Palaeomagnetic evidence, on the other hand, cannot prove that it was axial but does offer strong evidence to that effect. Palaeontological and palaeomagnetic evidence are thus in conflict, which means, unless some unifying principle is discovered that one or the other is wrong.

MAGNETOSTRATIGRAPHIC PITFALLS

Kukla, George, and Zijderveld, J. D. A.; *Nature,* 226:774-776, 1977.

[So much of current geological theory depends upon the correlation of geomagnetic events in rocks at various spots around the world that it is rather shocking to find the following paragraph.]

Controversy is growing over the existence of young excursions of the Earth's magnetic field such as the Gothenburg event. Are these features real? Are they true records of magnetic anomalies? Do they influence climate? Or are they merely a product of overlooked natural or artificial strata deformations? The recently reported detailed study of Koobi Fora formation in Kenya shows that the magnetic reversal stratigraphy of Pre-Brunhes formation is not without difficulties either. With all these problems, can palaeomagnetic 'magic' still be taken seriously?

[The authors warn that:]

there are complicating features to which increased attention should be paid. The most important of these are the presence of post-depositional magnetostratigraphic overprints, natural deformation of the strata under investigation, deformation caused by the coring and sampling devices and the continuity and sedimentation rates of the deposits.

[The remainder of the article describes the various errors that can creep into magnetostratigraphic analysis. The authors do conclude that with care this kind of analysis can be accurate. (Nevertheless, this paper is a warning that science may be building an unstable house of cards.)]

• Difficulties in Interpreting Magnetic Reversals

DOES THE EARTH'S MAGNETISM REVERSE ITS POLARITY?

Wilson, R. L.; *New Scientist,* 27:380-381, 1965.

The reader may by now be convinced that former reversals of the Earth's magnetic field are already demonstrated beyond fear of contradiction. If so, he must now face, as those working in this field have had to do, a very awkward discovery.

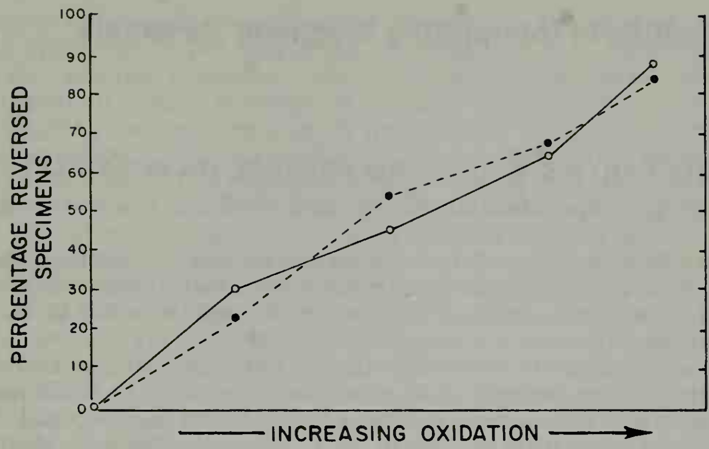
Last year, Dr. J. M. Ade-Hall, then at Imperial College, London, reported that, at high magnification under the microscope he could see very obvious chemical and structural differences between normally and reversely magnetized lavas from the Isle of Mull, Scotland. We were unable to find any definite corresponding differences in the magnetic properties of the same lavas. The geological setting of these lavas was very complex, and so the interpretation was doubtful. But subsequent work by Professor P. M. S. Blackett and by ourselves has brought to light several other cases of chemical differences between normally and reversely magnetized lavas sequences from various parts of the world.

With one exception, they have so far indicated the same statistical trend---that reversely magnetized lavas are more highly oxidized than normal ones. No differences in the distribution of other elements involved in the magnetic minerals, notably the relevant metals, iron and titanium, have been observed. I should add that the evidence suggests that this state of oxidation was achieved during the initial cooling of the lavas. It does not seem to have been a slow, subsequent phenomenon (due to weathering for example).

The most interesting lava sequences we have so far investigated are the Columbia Plateau Basalts from America, collected by Dr. N. D. Watkins. Sets of lavas from eleven different sites have shown a remarkably clear relation between natural magnetic polarity, the state of oxidation and the magnetic properties.

We have been able to divide these lava specimens into five petrological categories corresponding to stages of increasing oxidation. The diagram shows the percentage of reversed specimens in each oxidation state. The occurrence of reversed specimens is nil in the least oxidized state, and 80-90 per cent in the most oxidized state. There is a gradual change from one state to the other. By itself, this change strongly indicates a self-reversal mechanism operating in the reversed lavas.

Yet these same lavas also exhibit two of our classical tests for field reversal! There are five baked zones with reversed magnetization, each one agreeing in the polarity with the overlying lava; and one of the eleven sequences contains a set of "transition lavas" showing a gradual apparent turning over of the ancient magnetic field. The magnetic stability of these lavas has been checked, and the phenomenon seems genuine. Yet even within this transition one can see obvious chemical changes as one progresses from normal to reversed lavas (open circles in the diagram). A similar conflict has appeared in another lava sequence of Carboniferous age in Britain.



Basalts from the Columbia Plateau show a clear relationship between the proportion of reversely magnetized specimens and state of ionization.

The dilemma is this: if one accepts the evidences for field reversal, how can one explain the statistically different chemistries of normal and reversed lavas in some sequences? If, on the other hand, one accepts the hypothesis of self-reversal to explain the chemical differences, how can one explain away the variety of evidence for field reversal? Nor is the answer possibly sometimes field reversal and other times self-reversal, for the two conflicting kinds of evidence have occurred in the same lava sequence, in two instances of different age and geographical position.

Unless some of the evidence is entirely misinterpreted, or unless the chemical correlation with magnetic polarity is pure coincidence in several cases, one seems forced to conclude that the ancient magnetic field really has reversed its polarity, and that the state of oxidation of lavas can, for an unknown reason, be connected with the polarity of the magnetic field. This is difficult to believe, because one is hard pressed to imagine what physical connection can possibly exist between the polarity of the Earth's magnetic field, and the state of oxidation of lavas which became magnetized in that field. Whether or not we are forced to this conclusion depends on the weight of more, and different kinds. of evidence.

The reality of these polarity inversions of the field is important because their existence has a strong bearing on theories of the generation of the Earth's magnetic field; perhaps also of the magnetic fields of other planets; and of the stars, many of which are known to reverse their polarity continually on the time scale of hours to months. There is every reason to suppose that the presently accepted mechanism for the Earth's field ---a hydromagnetic self-exciting dynamo driven by convection currents in the fluid core---can indeed undergo spontaneous reversals of behaviour. If field reversals do occur, then any detailed theory must encompass the kind of instability which leads to the observed irregular polarity fluctuations in the past. (p. 381)

ON THE UNSTABLE NATURAL REMANENT MAGNETIZATION OF ROCKS AS A PALEOMAGNETIC "FOSSIL"

Domen, Haruo; *EOS*, 50:130, 1969.

Abstract. Seventeen years ago the coexistence of both normal and reversed natural remanent magnetizations (NRM) was found in the early Pleistocene or late Pliocene basaltic lava flow at Kawajiri-misaki, Yamuguchi Prefecture, Southwest Japan (Asami & Domen, 1954). It was once understood that the NRM was due to a reversed geomagnetic field at the time the lava flows erupted, and normal NRM was neglected because of its instability. However, the coexistence of both normal and reversed NRM, even in so small a portion of the lava flow, has remained a mystery. Was the earth's magnetic field reversed at that time, or did self-reversal take place? In this report, the author proposes a possible self-reversal mechanism as a solution to this mysterious phenomenon. He also considers that the unstable NRM might be usable in some cases as a paleomagnetic "fossil" rather than the stable NRM which usually seems to be a good indicator of the earth's magnetic field in the past.

SELF-REVERSING OCEANIC BASALTS

Anonymous; *Nature,* 217:1207-1208, 1968.

The fact that it has proved possible to construct, using continental igneous rocks, a world-wide geomagnetic polarity time scale for the past four million years implies predominance of field reversal over self-reversal in explanation of the majority of the world's reversely magnetized rocks. Furthermore, the recent discovery that the pattern of linear magnetic anomalies adjacent to mid-oceanic ridges correlates with the pattern of normal and reversed periods from the continental scale, not only gives strong support to the ocean floor spreading hypothesis, but also indirectly strengthens the evidence in favour of field reversal. The predominance of field reversal and the use of magnetic anomalies as evidence for ocean floor spreading are thus mutually consistent.

Despite this consistency, Ozima and Ozima (Earth and Planet. Sci. Letters, 3, 213; 1967) have now questioned the assumption that the linear ocean anomalies arise from repeated reversals of the Earth's field. They report that three out of eight submarine basalts obtained from Pacific Ocean deep sea mounts exhibit self-reversal properties under certain conditions. Saturation magnetization measurements show that each of the three specimens contains, in its virgin state, a single magnetic component with a Curie point of 250° C. On heating to 400° C, this component is partially converted to a new magnetic phase possessing a Curie point of 300° C. Heating to even higher temperatures produces a single phase having a Curie point of 560° C.

What is significant, however, is that if one of these specimens is heated to any temperature between 300° C and 330° C for a few minutes, and then re-cooled in the geomagnetic field, the resulting magnetization is antiparallel to the field. The reason is that the unconverted part of the primary magnetic phase, of Curie point 250° C, interacts magnetically with the newly produced component of higher Curie point to produce a net reversed moment. Below 300° C there is insufficient new material for this to occur, and above 330° C not enough virgin phase remains; but as long as the temperature of the specimen is not maintained at 300° C to 330° C for too long a time, the balance of old to new material is just correct for the interaction to occur. Nor is this merely a low magnetic field phenomenon, for fields of up to 2,600 oersteds are insufficient to suppress the self-reversal.

One may argue, of course, that the laboratory processes used by the Ozimas to produce self-reversal over a limited temperature range rarely occur in nature supported by the fact that virgin specimens still contained only the low Curie point magnetic phase), and thus that it is unlikely that self-reversal occurred during the production of the natural magnetization. Moreover, the correlations between the linear ocean anomalies and the continental polarity time scale, and between each of these and the reversals patterns in deep sea sediments, are too tight to allow the existence of widespread self-reversal in oceanic basalts. For these reasons the work of the Ozimas is likely to be of greater interest to those concerned with the phenomenon of self-reversal itself.

PALEOMAGNETIC EXCURSIONS AS MAGNETOSTRATIGRAPHIC HORIZONS: A CAUTIONARY NOTE

Verosub, Kenneth L.; *Science,* 190:48-50, 1975.

[Verosub begins by noting that paleomagnetic excursions are widely viewed as synchronous, worldwide phenomena that can be used as chronological markers in geology, geophysics, and archeology. There are, however, disturbing spatial and temporal inconsistencies that cast doubt upon this scheme.]

The geomagnetic field is generated by a dynamo within the earth's core. If paleomagnetic excursions represent geomagnetic phenomena, they must arise from instability in the fluid motions of the core. In this case magnetic potential theory requires that paleomagnetic excursions have a coherent variation on a scale of at least several hundred to a thousand kilometers. We expect therefore that evidence for a paleomagnetic excursion should be internally consistent within sedimentary basins the size of lakes or small seas. Most anomalous paleomagnetic directions represent the results of a study of a single piston core from a given sedimentary basin. When multiple cores have been taken, the results have not always been internally consistent. For example, of 15 cores taken from the Gulf of Mexico, only eight appeared to record the excursion. More importantly, the magnetic signature, that is, the precise variation of declination and inclination, varied markedly from core to core.

Difficulties are also encountered when paleomagnetic excursions are examined for spatial consistency on a global scale. A set of paleomagnetic anomalies from northern and central Europe, eastern Canada, the Gulf of Mexico, and New Zealand, with dates clustering around 12,500 years before the present (B.P.), has been interpreted as a global geomagnetic fluctuation and has been named the Gothenburg flip. However, the event is apparently not recorded in sedimentary sequences of the same age in southern Europe, the Mediterranean Sea, and western North America.

Finally, there is a lack of temporal consistency in the ages of paleomagnetic excursions. In addition to the cluster of dates around 12,500 B.P., other excursions have been reported in the intervals 15,000 to 20,000 years B.P., 24,000 to 25,000 years B.P., 28,000 to 30,000 years B.P., and 38,000 to 40,000 years B.P. If each of these represents a distinct excursion, then the geomagnetic field is much less stable than has been assumed in the past. Such a high degree of instability, extended back over geological time, would produce a paleomagnetic record far more complex than has been observed.

[To underscore his cautionary remarks, Verosub describes his own analysis of remanent magnetism in varves from a New England lake. Samples taken from a folded varve proved that remagnetization of the folded material did not occur after deformation and that the original remanence was "locked in."]

I have shown that, in some sedimentary environments, the sediments will not be remagnetized after deformation. The implication of this conclusion for paleomagnetic excursions is significant. If a deformation in the sediments is obscured because the sediment is not laminated or if the sediment is sampled by coring and the deformed structures are not recognized, then an anomalous remanent magnetic direction will be observed.

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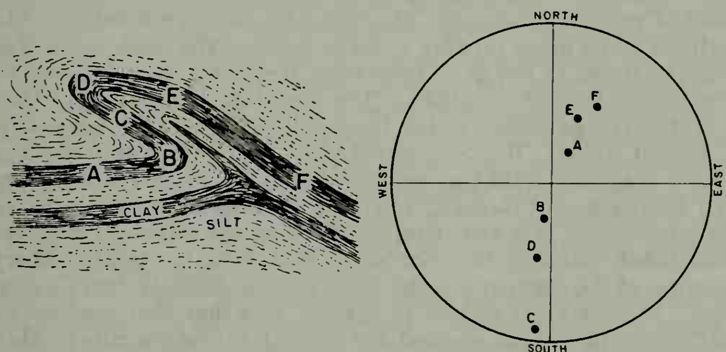


Samples from a folded varve demonstrate that the original magnetic remanence was locked in and that no remagnetization took place after folding.

REMANENT MAGNETIZATION OF THE UPPER-MIOCENE 'BLUE' SANDSTONES OF CALIFORNIA

Doell, Richard R.; *American Geophysical Union, Transactions,* 37:156-167, 1956.

Abstract. A study has been made of the magnetization of some upper-Miocene sediments of California. Field evidence and laboratory experiments indicate that the main component of magnetization of these sedi-

ments was not acquired by alignment of detrital magnetic grains at the time of deposition, nor is it due to a later isothermal magnetization of these grains. A strong and stable magnetization appears to have developed through post-depositional and, in some cases, post-deformational growth of crystalline magnetic minerals in situ.

MAGNETISM AND ARCHAEOLOGY

Ransom, C. J.; *Nature*, 242:518-519, 1973.

A recent discussion about reversed geomagnetic events in the Brunhes epoch contains the statement that no archaeological materials are known to be reversely magnetized. This may be true for the specific region that is considered in the article, but it is not true in general. G. Folgheraiter in "Rendi Conti dei Licei", 1896, 1899; Archives des sciences physiques et naturellas (Geneva), 1899; Journal de physique, 1899; and P. L. Mercanton, in "La methode de Folgheraiter et son role en geophysique", Archives des sciences physiques et naturellas, 1907, reported observations made on clay fired in kilns by the Etruscans and Greeks. Their results indicate that in the eighth century BC the Earth's magnetic field was reversed.

In 1896 Giuseppe Folgheraiter made studies of Attic (Greek) and Etruscan vases of various centuries, starting with the eighth century BC. The observations were made on clay fired in kilns. The position of the ancient vases during firing is known. They were fired in a standing position, as indicated by the flow of the glaze. The magnetic inclination or the magnetic dip of the iron particles in the fired clay indicates the nearest pole during time of firing. His conclusion was that in the eighth century BC the Earth's magnetic field was reversed at least in Italy and Greece.

P. L. Mercanton of Geneva, studying the pots of the Hallstatt age from Bavaria (about 1000 BC) and from the Bronze Age caves in the region of Lake Neuchatel, came to the conclusion that about the tenth century BC the direction of the magnetic field differed only slightly from its present direction. His material was of an earlier date than that used by Folgheraiter but, checking on the method and results of Folgheraiter, Mercanton found them correct.

This work has been brought to the attention of Elizabeth K. Ralph, Associate Director, the University of Pennsylvania Museum, who is presently investigating magnetic field reversals. She is considering investigation of material taken from kilns dating around the eighth century BC. These kilns were recently unearthed in Sarepta by James B. Pritchard who is also associated with the museum. This work could provide additional valuable data in the investigation of magnetic field reversals.

• Reversals Correlated with Climate Changes

GEOMAGNETIC POLARITY CHANGE, VOLCANIC MAXIMA AND FAUNAL EXTINCTION IN THE SOUTH PACIFIC

Kennett, J. P., and Watkins, N. D.; *Nature,* 227:930-934, 1970.

Geomagnetic field reversals occurred more than twenty times during the past 4 m.y. and probably more than one hundred times during the Tertiary. The most significant aspect of this discovery is the recognition of important features of the history of geomagnetic polarity in the linear magnetic anomalies of the oceanic crust, and their convincing interpretation in terms of sea-floor spreading.

The geomagnetic polarity history has also been recognized in deep-sea sedimentary cores. In such studies, several microfaunal extinctions and appearances have been recognized as synchronous, and virtually simultaneous with the period of transition between opposite geomagnetic polarities which lasts about 5,000 years. The reasons for these extinctions and appearances are unknown, but they may be the result of climatic change and polarity change being related, or of increased mutation rates during polarity changes, although several authors oppose this possibility.

Heirtzler has recently speculated on a relationship between earthquake activity (and by implication upper mantle activity) and geomagnetic polarity change. He reasons that because there is evidence to show that earthquakes of magnitude 7.5 or greater may cause wobble of the spin axis, it is therefore conceivable that an Earth wobble may be of a magnitude sufficient also to cause reversal of the geomagnetic field. Here we present data pertinent to Heirtzler's speculations, and we expand such speculations to include our preferred explanation of the synchronous geomagnetic polarity changes and faunal extinctions.

We know of no method to detect the time of occurrence and frequency of large earthquakes in the geological past. Stress release is often manifested in volcanic activity, however, so a search may be profitably made for evidence of relationships between volcanic maxima and geomagnetic polarity change. Volcanism certainly may have more than one cause, and on a global scale must be virtually continuous, so we therefore emphasize our use of the term "volcanic maxima". If relationships exist between polarity change and upper mantle activity they are more likely to be found in oceanic areas, for there the mantle is most mobile and accessible, and (in all probability) more commonly at "threshold", in terms of potential volcanism. Our search therefore examines the character of volcanic activity during polarity change in some deep-sea sedimentary cores.

[Analysis techniques are omitted here.]

We now briefly examine the relevance of our data to problems of climatic changes and microfaunal extinctions and appearances. If significant widespread increases in volcanism have occurred during restricted intervals of geological time, then climatic changes are very likely, particularly at high latitudes, because volcanic ash, which remains in the atmosphere for prolonged intervals of time and moves poleward at high altitudes, inhibits solar radiation at the surface. In this context it is therefore possibly significant that a distinct world-wide cooling occurred near the Brunhes-Matuyama boundary, and that other climatic coolings may be associated with the Gilsa event and Matuyama-Gauss boundary. Increases in volcanism within the Brunhes epoch as indicated by us in the Southern Oceans occur in New Zealand (personal communication from H. W. Wellman). This coincides with, and may be related to, the much greater climatic fluctuation of the past 0.7 m.y., compared with the preceding million years.

Of eight observed microfaunal extinctions and appearances in the Southern Ocean, six occur either during or very close to geomagnetic polarity changes. We suggest that the climatic changes which can result from volcanic maxima are much more plausibly the cause of such extinctions and appearances than increased radiation at the water surface during any dipole collapse accompanying a polarity change, although other explanations must be considered.

We conclude that our results provide sufficient evidence to justify serious consideration of Heirtzler's speculations of a connexion between geomagnetic polarity change and upper mantle activity, which was also proposed by Hide. Volcanic maxima during polarity changes may be expected to have an influence on climatic conditions, particularly at very high latitudes, and may therefore also be the indirect cause of those microfaunal extinctions which have occurred during geomagnetic polarity changes.

EARTH'S MAGNETISM DOES CORRELATE WITH CLIMATE

Anonymous; *New Scientist,* 77:848, 1978.

A new statistical study by a researcher at the British Antarctic Survey, Cambridge, reinforces evidence already presented for a connection between reversals of the Earth's magnetic field and climatic changes. Christopher Doake reports that, for the period between 1.5 and 4.3 million years ago climatic indicators show a "significant correlation" with geomagnetic field reversals recorded for New Zealand (Earth and Planetary Science Letters, vol 38, p 313). He looked at indicators, such as the changes in microfauna and oxygen isotopes, within an ocean core taken from west of North Island, New Zealand.

Doake used the results on core samples from site number 284 of the Deep Sea Drilling Project as the basis for his climatic changes. Sea surface temperatures can be deduced from the relative abundances of foraminifera, notably one called Neogloboquadrina pachyderma; and the past volume of ice across the globe is reflected in the oxygen-18/oxygen-16 ratios. He also used the results from carbon-13 analysis. Altogether the survey employed five separate climatic indicators and Doake selected the turning points in their respective curves for his correlations. Because the magnetic data, in general, do not occur within the same core as the climatic data, he took these from a separate study.

Although the ages for the geomagnetic reversals may have errors as large as 3 per cent, their dates relative to one another are much more accurate. Overall, Doake claims a time resolution of around 30,000 years.

With that resolution, he says, the results of the statistical analysis reveal a probability of about 0.4 that a climatic event will be associated with a magnetic reversal; whereas the chance that these coincidences are random "can be as low as 3×10^{-4}".

If the connection is real, how are we to explain it? Earlier suggestions included the idea that, in reversing, the Earth's magnetic field fell to near-zero intensity before increasing again in the opposite sense. During its weak phase, the belts of trapped radiation, and the ozone layer, which are controlled geomagnetically, would disappear---most probably with undefined climatic repercussions.

Doake, however, favours the alternative hypothesis that the climatic change was the cause of the field reversal. If the volume of global ice altered, he says, that would have affected the Earth's rotation. This, in turn, would have caused perturbations at the interface between the Earth's mantle and liquid core.

As the geomagnetic field is supposed to arise by dynamo action within the liquid, electrically conducting core, such perturbations might have caused the field to reverse. Alternatively, if the Earth's mantle behaves plastically, excess loading of the crust with ice could have upset the shape or temperature regime of the core boundary with similar results.

Chapter 6

GEOCHEMISTRY AND NUCLEAR GEOLOGY

INTRODUCTION

The layman conceives geology in terms of mountain ranges, coal strata, mineral specimens, and other palpable, macroscopic entities. The geochemical and nuclear reactions responsible for these obvious terrestrial features usually operate obscurely but on occasion produce microscopic data of interest to the anomalist. To detect such deviations from prevailing theories, the scientist must resort to the chemistry lab, nuclear particle counters, and high-power microscopes.

Following convention, this chapter is divided into data categories depending upon nuclear, isotopic, and chemical properties. Interweaving the established classifications is the thread of time. Geology allied with the hypothesis of evolution has given us a multi-billion-year tapestry on which to paint the earth's history. Has science's loom gone awry? This question is the focus of this chapter.

EXTRAORDINARY CHEMICAL PROCESSES

The segregation of ores, the conversion of plant material into coal, and the growth of deep-sea manganese nodules are all remarkable geochemical processes. Although all the chemical details have not been worked out, these and similar processes have been accepted into the scientific fold. A few other geochemical reactions, however, are more bizarre, and seem to contradict geochemical rules.

One category consists of chemical processes that appear to operate very rapidly. Abnormal petrifaction and the accelerated growth of dripstone are examples. A possible implication of such observations is that some petrifactions and cave structures are not as old as claimed.

A second category includes the effects of unusual exothermic reactions. Burning coal seams exist in many areas today. Natural ignition doubtless occurred in the past, and such fires should be considered remarkable only where they have wrought large geological changes in the past. Several strata at various places around the world display evidence of abnormal heating or "combustion metamorphism." Natural conflagrations seem to provide a likely explanation. More rare are those areas where there is anomalous heating that cannot be readily ascribed to underground geothermal sources or combustion of organic matter. Unidentified exothermic chemical reactions are possible explanations here.

• Rapid Petrifaction

REMARKABLE PETRIFYING SPRING

Anonymous; *Scientific American,* 2:335, 1847.

At Clermont, in the south of France, a place where mineral waters abound, there is a spring which possesses the power of petrifaction in a very extraordinary degree. Some years ago, when a learned professor by the name of Blanqui, visited that quarter, there was an ox undergoing the process of transformation; and although the animal had begun to sit, or stand, for his statue only twelve months before, one-half of him was already made into a stone monument! Several horses are said to be seen turned into monuments of themselves, and ornamenting, in the capacity of statues, the fields where they once pastured; while a collection of other quadrupeds, and of birds, fruits and flowers, bear ample testimony to the formidable powers of this truly magic spring. There are many petrifying springs in this country, but none whose powers at all approach that of Clermont. Even the renowned hot springs of Furnass must yield to it, although there also, the process is carried on to a great extent. It may be mentioned, that the district around Clermont is mountainous and volcanic, and that the tufa and ashes thrown out by the eruptions which occurred antecedent to the historical era contain an immense variety of the bones of animals of the quadruped class, as well as birds. Cuvier has described many of those remains as belonging to new or extinct species of the mastadon, elephant, hippopotamus and so on.

PETRIFYING SPRINGS

King, I. Charles; *Scientific American,* 60:181, 1889.

There is a well known petrifying stream of water at Knaresborough, Yorkshire, England, three miles from Harrowgate, the well known sanitarium. It is a cascade from the River Nidd, about 15 feet high and twice as broad, and forms an aqueous curtain to a cave known as Mother Shipton's Cave. The dripping waters are used for the purpose of petrifying anything sent to be hung up in the drip of the water ledge, which flows over, as it were, the eaves of the cave. This ledge of limestone rock is augmented unceasingly by the action of the waters which flow over it. This cascade has an endless variety of objects hung up by short lengths of wire to be petrified by the water trickling over them, as sponges, books, gloves, kerchiefs and veils, hunter's cap, fox, cat, dog, birds, boots, etc., just as fancy prompts people to seek petrifying results. A sponge is petrified in a few months, a book or cap in a year or two, cat or bird a little longer.

A museum of many interesting things is to be seen in the house of the custodian of the Mother Shipton Cave. The things petrified are mostly larger and somewhat misshapen by the gravitation of the silicate, making the mass larger on the under side of the suspension in the cascade. A cat, for instance, has the legs nearly joined and larger in proportion than the body. One cat shown in the museum had the head broken off at the neck, showing the whole was limestone throughout, with not a trace of the organic structure of the original cat. A glove became like a hand. A book of sermons, a block of stone, from which science may read its sermons through without printing or leaves. When looking at this cascade as an artist, I could not help thinking of the poor old woman who lived before her time, and who was spared from the fate of many thousands of human beings called witches, who have been burned by the ignorant mob or legally by the state officials, mostly at the instigation of the priesthood. It would be a fitting place for a statue of the historic personage---whose prophecies are one by one being verified---to be seated within the cave looking out through the veil of dripping waters on the visitors to the cave, and as fitting inscription in front, the words from a modern poet might be written:

"All things are sacred in their time and sphere!
Naught can escape the action of this fact,
Nor fail to yield an essence, growth, and share,
Through media with affinities to act."

The Epic of a Day.

I have a human head petrified, but by what action I do not know. It was found in digging a trench through gravel in the park at Bulstrode, in Buckinghamshire, England.

The subject of petrifaction is highly interesting, and deserves careful investigation. I believe many specimens of prehistoric tools, as well as organic remains, might be recovered from the earth if geologists were qualified to judge of tools by external formation. Geologists, unfortunately, are too often only book and stone students, and not capable of judging by appearance of a petrified tool as a bit of stone only or not.

PETRIFACTIONS

Bancroft, J. W., and Goodwin, Jas. M.; *Scientific American,* 10:211, 1855.

Messrs. Editors---In glancing over an old file of the Marshall (Mich.) Statesman, my eye caught a paragraph headed "Petrified Corpse in Wisconsin." I take the liberty of transcribing it for your benefit, inasmuch as it supports a remark of yours in an article upon that subject in No. 24. The cool and reckless positiveness with which some scientific men will assert periods of forty thousand, and a hundred thousand, or even a million of years to account for certain changes, is as amusing as it is alarming.

The paragraph in question appeared in the Statesman of May 7, 1851, credited to the Detroit Advertiser, whose authority was the Fond Du Lac Journal, and is as follows, viz: "On the 20th of August, 1847, Mrs. Phelps, wife of our informant, Abner P. Phelps, died, and was buried at Oak Grove, in Dodge Co. On the 11th of April inst., she was taken up to be removed to Strong's Landing. The coffin was found to be very heavy, and the body to retain its features and proportions. After its removal to Strong's Landing, a distance of some 45 miles, the body was examined, and found to be wholly petrified, converted to a substance resembling a light colored stone. Upon trial, edge tools made no more impression upon it than upon marble. In striking upon the body with metal, a hollow singing sound was produced. The disease by which she came to her death was chill fever and dropsy. When the body was buried it was very much swollen. The ground in which she had been buried was a yellowish loam, and the body lay about three feet above the lime rock."

The above particulars are so explicit that the facts could be easily verified if called in question. (J. W. Bancroft)

Messrs. Editors---In No. 25, Scientific American, there is an article on the subject of petrifaction, wherein is noticed the case of several petrified bodies, and you say "you have heard of such cases before;" let me give you a case of my own personal knowledge:

A few years ago a lady died in the neighborhood of Felicity, in this County, and was buried in the orchard on the farm. About four years, after she was disintered, for the purpose of removal to a public graveyard, and was found to be completely petrified, being as solid as stone and fully as heavy. Every feature was distinct and perfect. Facts like this are enough to disprove the false theory of Gliddon and Newton. The name of this lady was Carley. Her family are living in the same neighborhood yet, and can testify as to the truth of these statements. (Jas. M. Goodwin)

OBSERVATIONS OF A SO-CALLED PETRIFIED MAN

Stedman, J. M., and Anderson, J. T.; *American Naturalist,* 29:326–329, 1895.

On the 28th day of August, 1894, a human so-called petrified body was found by some workmen while repairing a public country road about one mile south of Tuskegee, Macon Co., Alabama. A few days later I heard of the find, and immediately proceeded to Tuskegee to make an investigation of the body and of the locality where it was found, and to obtain samples of the water, earth and body.

Through the kindness of Mr. J. S. Webb, who had the body in charge, I was enabled to make an examination on, and to procure portions of the body from the several places as samples. As Mr. Webb was trying to sell the body as a curiosity, he did not wish me to mutilate it any more than was necessary. I obtained, however, portions of the intestine, a section 75 x 25 mm. through the ventral abdominal wall, several pieces of muscle with tendon from the ankle, and a section 100 x 100 mm, was cut out from the dorsal region of the thigh and extending to the bone in thickness. Mr. Webb, by the way, offered me the body for the college museum for $75, but, as I hoped to be able to procure it later as a donation, I refused. He sold the body in a few days for $150, and it is now being exhibited in the villages and cities of the country, much to my regret.

The body is that of a Negro woman who was evidently rather fat. From two elderly gentlemen, who are now living in Tuskegee, and who remember the circumstances of the burial, I learned that the body was buried in 1837 in what was then a small neglected country or family burying-ground, situated a few rods from the road. They also remember the burial, at about the same time, of an Indian but a few feet from this Negro; and I am trying to have the Indian dug up to ascertain whether it is likewise preserved or not.

In company with several citizens of Tuskegee I drove to the scene of the find. The burial ground is near the top of a very large flat hill or plateau, and a few rods south of the grave is a small marshy or swampy bog, while some seven meters to the east there is a spring. Several years ago the public road was moved a few rods to the south in order to give it a better grade up the hill, and as the small, neglected burial ground had not been and was not worth keeping up, and was no longer used as such, the road was cut through a portion of it; and most people had now forgotten about its existence. The road was cut about one meter below the surface, and the ditch at the side was directly over the Negro woman's body, and served to carry off the water from the spring just above. The result was that the body lay but about one-third of a meter below the ditch, and the water from the spring kept it continually wet, even when no water appeared on the surface. While the workmen were repairing the road and picking in the ditch, they hit something that proved to be a pine board. On removing it they came upon others, which they removed, and thus exposed a plain pine coffin in a remarkable state of preservation.

The soil where the body was found is sandy, with enough fine, light-colored clay and moisture to give it the appearance of mortar. When a portion of the soil was dried, it held together with great tenacity, and the dirt left on one's hands became nearly white on drying, and felt smooth and slippery like powdered talc; in fact, I could detect no difference as regards looks or feeling. Portions of the soil had streaks of red color, probably due to iron. The hole left by the removal of the coffin soon filled with water, the soil being extremely wet, although very little moisture appeared on the surface on account of excessive dry weather. The water had a decided milky appearance. I obtained samples of the soil from the bottom of the hole, from the sides, and from the earth just above; and also samples of the water from the hole. These were placed in thoroughly clean jars brought for the purpose.

The first thing to be noted is the fact that the boards that covered the coffin, as well as the coffin itself, were in a perfect state of preservation ---not a sign of decay was to be found. They looked like newly-planed boards that had been exposed to weather for about six months; just long enough to partially color the wood gray. The nails in the coffin had all rusted away.

On opening the coffin, the body of the Negro woman was found to be in a remarkably good state of preservation. Of course it was saturated with water, but, nevertheless, it was firm like hard cheese, so that the workmen pronounced it petrified when they touched it, and found it would not give or bend. In general, the body at first glance has very much the appearance of sheet asbestos, being dirty-white in color, with a certain grain in places, due to the connective tissue in the fat where the skin is wanting. The abdomen and to a certain extent the thorax is swollen and bloated, so that part of the abdomen pressed tight against the top of the coffin, thus showing that decomposition had started when the body was first buried, and had continued for a short time. It is to be noted that no part of the body was decomposing when found, and it has shown no signs of doing so since; neither does it smell---all decomposition that had taken place was now checked. The head is not well preserved, part of the cranium having been decomposed, and other parts partially so, and more or less separated. All the hair, with part of the scalp is, however, well-preserved, while the face had been partially decomposed. One wrist and both ankles had been badly decomposed, and part of the feet and one hand slightly decayed. Some of the toe and finger-nails were perfect, others partially or wholly decayed. The rest of the body is practically intact and well-preserved, except that in places the skin is wanting; but this does not make itself apparent to the ordinary observer.

With a scalpel I cut through the ventral abdominal wall from right to left, and then cephalad at the two ends. The body at this place cuts very much like dense cheese. The cut portion was then lifted up and turned back, thus exposing the viscera beneath. The intestines, and in fact all the viscera, were only partially preserved. They had become more or less decomposed, and had then been checked in their decomposition and preserved in that state from further change. There was no particular smell from the abdominal cavity, and no decomposition was in progress. The intestines were moist, loose and pliable, and the foeces still preserved in them. All the viscera were light in color, due to the partial deposition in them of the finely-suspended, and perhaps more or less soluble, mineral matter in the water that filled and covered the body. The deposit of this mineral matter was not in sufficient quantity to give the tissue much firmness.

The abdominal wall which was cut through in order to examine the viscera, was 30 mm. thick, and owed its dense, cheese-like consistency and firmness to the deposition in it of the finely suspended mineral matter contained in the water that constantly saturated the body. The abdominal wall was practically completely charged with the mineral matter, while the process of filling the viscera had been nicely commenced. The mineral matter was extremely fine and of a light or almost white color, and thus it was that the body appeared light. So far as I was able to determine, this mineral matter in the tissues of the body is the same as that held in suspension in the water, and which gave it the milky appearance; and also that which in the soil or sand gave it the appearance of mortar, and that when dry, looked and felt exactly like powdered talc. With the exception of the fat, the tissues of the abdominal wall were practically intact, the mineral matter simply saturating them and filling up all the spaces; in the fatty tissue, however, which composed a large part of the abdominal wall at this point, there had been more or less substitution of the mineral matter for the fat. This substitution was, roughly speaking, about half and half. Hence it was that where the skin was wanting, there appeared a grain, due to the connective tissue remaining, while the fat was partially substituted. Wherever the skin was preserved, the black pigment could be distinctly seen in a cross-section.

• Combustion Metamorphism

NOTE ON BAKED CLAYS AND NATURAL SLAGS IN EASTERN WYOMING

Bastin, E. S.; *Journal of Geology,* 13:408-412, 1905.

A striking feature of the country just to the east of the Big Horn Mountains, and one which adds greatly to its picturesqueness, is the widespread development of red beds and slaglike materials in consequence of the burning-out of lignite beds in the Laramie division of the Cretaceous. The baking and accompanying reddening of the sandstones and clays have in some districts been so extensive that the landscape somewhat resembles that of the typical "Red Beds" of Jura-Trias age.

Explorers and geologists who have visited this region, from the times of Lewis and Clarke down to the present day, have noted the occurrence and characteristics of these beds, and have in most cases properly interpreted their origin. Mr. J. A. Allen, who accompanied the Northern Pacific Railroad Expedition, has given us an excellent account of these beds, and has summarized the previous literature. It is the intention here merely to add a few notes on the field occurrences and something as to the microscopic characters.

At the suggestion of Professor R. D. Salisbury, Mr. A. E. Taylor and the writer spent a few days in the study of these beds during the summer of 1903. These studies were confined to the district between Gillette and Buffalo, Wyo., but beds of a similar nature give color to the landscape and exert a notable influence upon the topography over a much more extensive region. Their occurrence has been reported over practically the whole northeastern quarter of the state of Wyoming, and over an area of about equal size in southeastern Montana and adjacent parts of the Dakotas ---a total extent of at least 100,000 miles. This vast region is characterized by horizontal or gently inclined strata, made up largely of clays and fine sands, with occasional seams of lignitic coal, the latter usually only a foot or two in thickness, but occasionally reaching a thickness of eight or ten feet. The beds have been sculptured by erosion into typical "Bad Lands" forms, giving the coal beds a large area of outcrop, and thus greatly facilitating their combustion.

The ignition of the coal has in certain cases taken place through human agencies, as in the case of a bed now burning (summer of 1903) six miles west of Gillette, Wyo., which was set on fire in 1902 by laborers at work on the railroad; in most cases, however, we must attribute their ignition to spontaneous combustion, or, at any rate, to agencies other than human.

At the locality above referred to, the coal outcrops along the sides of a deep gulch, and its burning is accompanied by the emission of much heat and of considerable volumes of sulphurous gases.

The unburned strata are typically of a gray or buff color, but upon the burning-out of an underlying coal seam they assume most gaudy hues of bright yellow, pink, or deep brick-red; the stratum beneath the coal is usually but little affected. Frequently a red layer may be traced from butte to butte, in each case underlain by the ash of the burned-out coal seam. With the change in color go incipient fusion and an increase in the coherence and resistance of the strata. This increased resistance has had a marked influence upon the topography, and it is common to find buttes capped with a layer of this baked material which has served to retard the progress of normal erosion.

Rocks resulting from the baking and fusion above described have been referred to by German geologists under the names Porzellanit and Porzellanjaspis and have been observed by them in a number of the European coal fields. Similar materials have been observed by the writer in the Coal Measures near La Salle, Ill. The principal varieties of altered material observed in the Wyoming region are described below.

1. By far the largest part of the metamorphosed beds consists of buff, brick-red, or indian-red argillaceous material. Much of this is fissile along bedding-planes, and incloses lamellibranch shells and shows impressions of leaves in great perfection; other portions are more massive and show a somewhat conchoidal fracture; still other portions, especially near the slaglike masses (No. 3, below), are extensively and very irregularly fractured. The metamorphism of these rocks finds a parallel in the artificial process of the burning of bricks, and consists simply in an oxidation of the iron from the ferrous to the ferric state, and in incipient fusion which greatly increases the coherence.

2. The coal itself leaves behind a typical ash upon burning; most of this is loose and incoherent, but some parts are clinker-like.

3. Slaglike masses make up only a small proportion of the beds, but are striking because of their close resemblance to lavas. They form very irregular, dark brown or mottled, vesicular masses, and usually inclose numerous fragments of shale and sandstone. Occasionally the slag occurs as an uneven layer just above the burned-out coal bed, but in most of the localities visited by the writer it formed isolated masses which in many instances seemed to be almost surrounded by the baked clays described above. Allen also describes "chimney-like" forms a few feet in diameter capping buttes because of their superior resistance. The forms of the slaglike masses, and the sharp transition to beds which have been but slightly metamorphosed, suggest that they represent channels of easy exit for the hot gases and vapors, along which the metamorphism was much more considerable than in any other portion, except immediately above the coal bed, where slags are also occasionally developed. The ropy surfaces exhibited by some of the slags show how fluid much of the material must have been.

4. The inclosing argillite near the slaglike masses has in most cases been much brecciated, and one of the characteristic types of rock is formed by the penetration of the crevices of such breccia by the slag. The process usually results in the induration of the breccia fragments to hard, flintlike masses, red, buff, or gray in color.

A microscopic examination of one of these slag veins in red argillite showed a central, relatively coarsely holocrystalline mass about one-tenth of an inch across. This was bordered on each side by a zone about one-fiftieth of an inch wide, fine-grained, prevailingly gray in color, and apparently representing the contact effect of the slag on the argillite. Outside this narrow zone the argillite shows a reddish tint. In passing from the reddish argillite towards the center of the vein, the contact zone shows a gradual decrease in the normal shale constituents and a development, in increasing amount and coarseness, of purplish-blue, pleochroic cordierite. Next the coarser part of the vein this mineral is present to the exclusion of all others. In this contact zone the red iron oxide of the argillite has been wholly reduced to magnetite. The central portion of the vein is a somewhat vesicular, holocrystalline mass, consisting of abundant magnetite in irregular masses, some hematite, usually lining the vesicles and following fractures, and abundant cordierite, feldspar, and pyroxene. The cordierite occurs in good-sized grains, some of which have a very irregular outline, while others show very definite crystalline forms, occurring in short prisms whose very perfect hexagonal cross-sections are the result of characteristic repeated twinning, as is shown by the optical properties. The feldspar occurs in narrow lath-shaped crystals with irregular terminations, and often with irregular lateral boundaries. No crystals were found which showed more than two twinning lamellae. The index of refraction is slightly above that of the balsam, and about equal to that of cordierite. This character, and the low extinction angles (less than 3°), fix its composition as oligoclase. Pyroxene occurs, sometimes in grains, but mainly in long, prismatic crystals, whose length ranges from ten to almost fifty times their width. The pleochroism is moderately strong; the colors for rays vibrating parallel to the prism length range from deep green to greenish-yellow, with occasional portions of the prism which are reddish-brown; for rays vibrating perpendicular to the prism, the color is usually greenish-yellow. Cross-sections show typical pyroxene cleavage, and the extinction angles range up to 32°.

5. A small proportion of the beds are fine-grained, porous sandstone which, upon baking, assumes the brilliant colors observed in the clayey members. Microscopically the slag is seen to penetrate this porous rock so thoroughly that it is impossible to draw a sharp line between the slag and the original sandstone. The sandstone, consisting of small angular quartz grains, fine argillaceous material, and hematite in scattered grains and as a fine coating on the other minerals, passes into a glassy mass inclosing scattered quartzes and abundant minute crystals of hematite, the latter frequently grouped in aggregates; this in turn passes into a vesicular, dark gray mass in which distinct quartz fragments are absent, the iron largely in the form of magnetite, and cordierite very extensively developed; some feldspar may perhaps be present, but could not be identified.

The complete crystallization of a vein of slag one-tenth of an inch across, and the perfect development of many of the crystals, are probably to be explained by high temperature of the rock walls when the slag flowed in, and a consequent slow cooling. In general, the physical conditions under which the metamorphism took place are similar to those in the slag furnace, and the resulting products are slaglike in appearance. The materials involved are, however, somewhat different from those of most slags. They are typical pelites, and it is not surprising that one of the minerals most abundantly developed, cordierite, should be a mineral developed in the contact metamorphism of pelitic sediments.

COMBUSTION METAMORPHISM IN SOUTHERN CALIFORNIA

Bentor, Y. K., and Kastner, M.; *Science*, 193:486-487, 1976.

Abstract. In several places in Southern California bituminous sediments of the Monterey Formation---siliceous shales, phosphatic rocks, dolomites, and arkoses---were affected during the Pleistocene and as late as the 19th century by spontaneous subsurface combustion of organic matter, during which temperatures up to 1600°C were reached. This oxidative heating (combustion metamorphism) affected rock complexes over areas of tens of square kilometers that tend to occur in clusters. As a result of these processes, the rocks recrystallized and partially melted to form pseudomagmas which intruded the country rocks. The chemical compositions of these melts differ from those of igneous magmas. Acid and intermediate siliceous melts as well as phosphatic melts have formed. These two types are generally immiscible. The following high-temperature minerals were determined: α and β-cristobalite, quartz, calcic plagioclase, diopsidic pyroxene, wollastonite, cordierite, graphite, fluorapatite, and fluorite; at lower temperature pyrite, gypsum, aragonite, calcite, jarosite, and hexahydrite crystallized.

During the last few years, several investigators have described the formation or mentioned the occurrence of rocks which burned spontaneously and were, in consequence, affected by what might be termed combustion metamorphism. These rocks were originally sediments rich in organic matter, mainly bituminous carbonates, shales, or siliceous rocks, for example, diatomites. Under suitable conditions, the uppermost few hundred meters of these rocks undergo spontaneous combustion. The very high temperatures developed during this process frequently lead to partial melting of the mother rocks and the formation of pseudomagmas; the latter behave in a way very similar to the behavior of ordinary magmas and form small-scale intrusions such as dikes, sills, and laccoliths. In contrast to most magmatic occurrences, stages in the formation of the melts produced by combustion metamorphism can actually be studied in outcrops in situ. Almost any form of naturally occurring organic substance---bituminous matter, coal, or oil---can serve as fuel, but the most effective of these seems to be bituminous matter because of its intimate association with the inorganic constituents of the rocks. Occurrences of combustion metamorphic rocks are now known from Israel, Jordan, the U.S.S.R., Iran, India, Australia, and Canada. The occurrence studied in most detail is that of the Hatrurim Basin in Israel, where not less than 130 minerals have been produced by this process. Combustion metamorphism in action was observed in the Kimmeridgean oil shales of Dorset by Cole in 1973, and Cretaceous oil shales along a 65-km stretch on the northern coast of Canada ("Smoking Hills") are known to have undergone burning for at least the last 150 years. In contrast, combustion metamorphic rocks in the United States have rarely been studied, with the exception of the Clinker beds of Montana.

Recently we have undertaken an investigation of combustion metamorphic rocks at several places in California: the Grimes Canyon and Virgines Canyon areas, Ventura County, and three separate localities near Santa Maria, Santa Barbara County. In all these localities, combustion metamorphism has affected rocks of the Miocene Monterey Formation, where it is particularly rich in organic matter. Some of these places are located within producing oil fields; the participation of oil in the combustion process can therefore not be excluded. The rocks of the Monterey Formation represent a broad lithological spectrum, and those affected by combustion metamorphism are correspondingly varied; they include diatomites, siliceous shales, dolomites, phosphatic rocks, and even arkoses.

The only locality we have thus far studied in some detail is Grimes Canyon, 5 km south of Fillmore. Here, the combustion metamorphic rocks form an almost uninterrupted belt 20 km long and 1 to 3 km wide. Within this belt, patches a few hundred meters long have occasionally escaped burning. Along some of the canyon walls, metamorphic rocks crop out over a vertical distance of about 400 m. Burning took place very recently, probably in the late 19th century, under the present topographical conditions; the depth below the surface affected by combustion is therefore not known. In the Hatrurim Basin, where burning occurred in the late Miocene, the metamorphic rock sequence is 260 m thick.

About 30 percent of the Grimes Canyon rocks are glasses, some vesicular and slaggy and others dense and closely resembling obsidian. The original melts were formed by selective melting of the parent rocks. Many Monterey rocks are finely laminated, phosphatic laminae alternating with others poor in P_2O_5. During the combustion process, the phosphatic laminae became molten, whereas the more refractory ones recrystallized only by sintering. The result is a strongly laminated rock in which stony layers alternate with glassy ones. Wherever only small amounts of melt were formed, the material solidified in situ, but, as the quantity of melt increased, it was mobilized and formed small intrusive bodies. Sills several hundred meters in length are abundant. Veins and dikes, small stocks, and occasionally a laccolith also occur, very similar to those formed by igneous magmas. The central part of the sills and dikes is frequently highly vesicular, the vesicles being strongly elongated in the direction of flow. Chilled zones, dense and darker in color, occur on both sides. Melts, forming stocks, frequently continued moving after initial solidification and broke up into a blocky breccia, reminiscent of an aa lava field (lava with a blocky structure). They contain numerous metamorphosed xenoliths of the country rock. The country rock frequently collapsed, owing to volume contraction because of the dissociation of carbonates, the oxidation of organic matter, and the loss of much volatiles. Therefore, both collapse breccias and intrusion breccias occur. The structure of the original rock sequence is generally preserved, however, and beds of the country rock can frequently be followed well into the metamorphic zone.

The boundary between metamorphosed and unaffected mother rocks is usually sharp but sometimes highly irregular. Two cases can be distinguished:

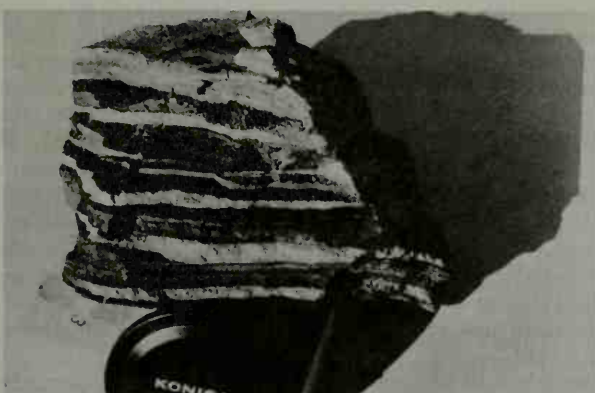
1) The contact follows a stratigraphic horizon, usually the formational boundary between the bituminous Monterey rocks and the overlying nonbituminous sandstones of the Pliocene Pico Formation. In this case, burning stopped for lack of fuel.

2) The contact is irregular, cutting steeply through the bituminous layers of the Monterey Formation. Outcrops of burnt rocks within the country rock and vice versa are common. In the Airox Mine area, near Santa Maria, pockets and veins of asphaltic residue accompanied by abundant jarosite are found on the metamorphic side near the contact. In this case, burning stopped for lack of oxygen.

The metamorphic rocks produced by combustion range from very soft to extremely hard and splintery; they are very colorful, red and yellow being most common. Texturally, three groups of rocks can be distinguished: (i) glasses, (ii) fine-grained stony rocks, and (iii) those rocks in which both stony and glassy parts are present, either as a breccia, in which stony pieces are cemented by glass or slag, or built of alternating stony and glassy laminae. All types of transitions from stony to sintered to fused rocks can be observed, and many rocks show textures very reminiscent of migmatites, in which the granitic portions of the rock are replaced by glass.

The minerals composing the stony rocks measure a few micrometers at most and can be determined only by x-ray diffraction and occasionally by microprobe analysis. Among the high-temperature minerals so far determined are α- and β-cristobalite, quartz, calcic plagioclase, diopsidic pyroxene, wollastonite, cordierite, graphite, gluorapatite, spinel, and fluorite. During cooling, pyrite, abundant fibrous gypsum, aragonite, and calcite were formed.

The glasses are highly variable. Some are holohyaline; their x-ray diffraction pattern is indistinguishable from that of obsidians. Some are structureless, and others show a pronounced fluidal texture. These melts were highly gas-charged but viscous, and were emplaced by turbulent flow. A widespread type of glass is composed entirely of tiny, sometimes welded shards in subparallel arrangement; the texture of these rocks is closely akin to that of welded tuffs. Glasses composed of shards frequently form



Laminated rock with stony and glassy layers created by natural combustion. (M. Kastner) sills or dikes. Gas pressure must have shattered the cooling glass and forcefully intruded it, a mechanism similar to that which leads to the formation of tuffisites.

Other melts crystallized partly or entirely during cooling into tiny, usually needlelike crystals. Their mineralogy is similar to that of the stony metamorphic rocks. These glasses are still undergoing reactions, and on their surface a caliche consisting mostly of gypsum, but locally of zinc-bearing hexahydrite, is at present being formed.

We determined the highly variable chemical composition of the glasses by microprobe analysis. Some are acid, and others are intermediate silicate melts. These glasses are chemically heterogeneous, confirming the evidence of the mineral assemblages that, because of the short duration of the thermal process, equilibrium was rarely reached. The siliceous glasses differ in composition from igneous magmas but some approach the composition of engadinitic granite. A third group consists of almost pure phosphatic melts with a P_2O_5 content of as much as 39.25 percent. Siliceous and phosphatic glasses frequently appear side by side with sharp boundaries between them, even on a microscopic scale. Moreover, droplike bodies of phosphatic glass occur within siliceous glass. Obviously, the two types of melts were immiscible.

FISSION TRACK AGE OF THE 'MOTTLED ZONE EVENT' IN ISRAEL

Kolodny, Yehoshua, et al; *Earth and Planetary Science Letters,* 11:269-272, 1971.

The Mottled Zone is a peculiar rock complex which appears in five separate basins in Israel, always in the same stratigraphic location, replacing a normal sequence of Maestrichtian to Paleocene sedimentary rocks. The normal sequence (the Ghareb and Takiye formations) consists of highly bituminous and phosphatic marls, chalks and limestones. The Mottled Zone complex is characterized by irregular and strong coloration, disappearance of bedding, and occurrence of schist-like structures. The most peculiar property of the Mottled Zone complex is its mineralogy. A rock composed of calcite and spurrite is very common; ettringite is abundant; garnets, hydrogarnets, larnite, brownmillerite, fluorapatite, portlandite, and many other rare minerals are also found. The mineral assemblage, especially the occurrence of anhydrous calcium silicates, is characteristic elsewhere of environments in which high temperatures were reached, such as contact-metamorphosed limestones and Portland cement clinkers. Some of the minerals encountered in the Mottled Zone have hitherto been known only in synthetic form. There is no indication of magnetic activity in the vicinity of these rocks. Thus, one is faced with a high temperature mineral assemblage with no apparent explanation of the heating event.

Previous workers have attempted three different approaches in seeking such explanations. Bentor and his co-workers suggested that the high temperature was reached by means of subsurface oxidation of the bituminous compounds and sulphide minerals in rocks of the Ghareb and Takiye formations. This oxidation which was termed "sedimentary hydrothermal activity" was envisioned "at some time after the burial of these strata by marine sediments of Eocene age". Avnimelech explained the formation of high temperature minerals by subaerial solar heating "on an old Danian land surface". Gross et al. speculated that in view of the confinement of metamorphism to sediments of Campanian-Palaeocene age only, the heating event must have been penecontemporaneous with the deposition of the sediments. (p. 209)

NATURALLY REDUCED IRON

Tyrrell, J. B.; *American Journal of Science,* 3:33:73, 1887.

On the North Saskatchewan River, about seventy miles above the town of Edmonton, in the district of Alberta, in rocks of Laramie age, an almost horizontal bed of lignite may be seen cropping out at intervals in the river-bank for several miles, overlaid by dark gray clay-shales and gray and yellow soft argillaceous sandstones containing nodules of clay ironstone. Although none of the nodules from this particular locality have been analyzed, similar ones from Edmonton, obtained from beds of the same formation, were found to be essentially carbonates of iron containing 34.98 per cent of the metallic iron.

The seam of lignite has been completely burned out over a considerable area, leaving the surface covered with a bed of debris of ashes, clinkers and burnt clay, in places to a thickness of twenty feet, supporting at present a thick growth of grass and underbrush. From this mass of burnt clay and cinders pieces of metallic iron can be readily picked out, weighing, in some cases, as much as fifteen or twenty pounds, doubtless derived from the nodules of ironstone mentioned above, which had been reduced to the metallic state by the heat caused by the burning of so large a body of lignite.

Most of the pieces of iron observed were very much rusted and fell to pieces readily on being struck with the hammer, though when scratched with a file they everywhere showed a bright surface.

HEATING OF LOCAL AREAS OF GROUND IN CULEBRA CUT, CANAL ZONE

MacDonald, Donald F.; *Science,* 35:701-703, 1912.

The marl shales, through which Culebra Cut extends, in the region opposite the Culebra railway station, have, from time to time, on exposure to the atmosphere, become hot. The intensity of this heat has varied from noticeably warm to a temperature sufficient to readily char wood, without, however, causing it to burst into a flame. The duration of this heating has been from a few days to several weeks. These shales are dark, thin bedded, soft and easily crumbled, and some of the layers are largely fine basic tuff, loosely cemented by lime. Other beds contain more carbonaceous material, with some local partings of lignite an inch to a foot or more thick. The relatively unweathered character of these basic sediments is evidence that they were derived from nearby volcanic mountains, and the carbonaceous and lignitic layers in them indicate shallow water and swamp conditions of deposition. The presence of fossil oysters, pelecypods, corals and foraminifera show that these shallow estuaries were marine, and that they existed in early Tertiary time. Dr. T. Wayland Vaughn, of the U.S. Geological Survey, examined some of the specimens on the ground and gave it as his opinion that they are Oligocene in age. The evidence so far points to a shallow water connection between the Atlantic and the Pacific during Oligocene time.

After exposure to the atmosphere by drilling, or blasting, certain local areas of this formation become, in the course of a few days, warmed up, and as the heating goes on the carbonaceous matter in the shales in gradually oxidized off and they tend to assume a gray to dull reddish color. The first working hypothesis entertained in looking toward a solution of this heating phenomenon was that possibly the heavy blasting had furnished heat enough to break down the calcium carbonate present to the oxide form, and that ground water and atmospheric moisture reacted on this to slake it and thus probably generate sufficient heat to start the oxidation of the carbonaceous material. This hypothesis was, however, rendered untenable by three lines of evidence:

1. The heating was much more local than the calcium carbonate, and the carbonaceous matter.

2. The heating bore no definite relation to the lime and carbon content of particular beds.

3. Colonel Gaillard, in charge of the Division, informs me that in some instances the heat began in the holes some time after they had been drilled, but before the ground had been blasted at all.

Another line of inquiry was suggested by finding a small amount of pyrite in some of the beds which were heating. It was suspected that this, through its oxidation, was a factor in furnishing the initial heat of the action. In April, 1911, samples of the beds then heating were sent to the chemical laboratory of the U.S. Geological Survey with instructions to make qualitative tests for sulphur and other products that might serve, through oxidation, as the mainspring of the action. These tests revealed the presence of sulphuric acid to the amount of 1.92 per cent., also minute crystals of gypsum. This confirmed the hypothesis that pointed to the pyrite present as the substance acted on by atmospheric oxygen to develop the initial heat.

The most aggravated case of heating so far noted is now going on in Culebra Cut, about 350 yards north of the foot of the stair at the observation tower near Culebra Station. The mass of heated ground here is about 500 feet long by 20 feet wide, and the action reaches a depth of perhaps 15 or 20 feet. Blue smoke, which contains a high percentage of sulphurdioxide, issues from vents in the mass, and fragments of wood inserted in these are readily charred and consumed. A small amount of steam may also be detected emanating from local moist spots, but this is mainly due to the vaporization of ground water. In the investigation of this heated mass samples were taken, and these were tested qualitatively for sulphuric acid and for sulphates of calcium, aluminum and magnesium. The tests were made by Mr. Jacobs, of the Hospital Laboratory Staff at Ancon, and they revealed the presence of all of the above substances, both in the shale and as the white coating on the moist spots and steam vents of the mass. The yellow deposit near the larger vents is sulphur. Sulphuric acid, especially, was shown to be present in considerable quantity. The origin of the sulphuric acid here was at first a puzzle, because the examination of many samples, with the naked eye and with the microscope, failed to reveal the presence of pyrite. Finally samples of eight to ten pounds were taken, ground with water in a large mortar for some minutes, and then concentrated to a few ounces by washing or "panning." This concentrate showed a high content of pyrite, much of which could scarcely be seen with the naked eye. Under the microscope very small crystals of pyrite were noted; also considerable magnetite, present as black sand, and some sub-angular to fairly rounded grains of quartz.

The mainspring of the action here then, as in the other instances observed, has undoubtedly been the oxidation of the pyrite. The reasons why this oxidation has been so rapid and effective, seems to be as follows:

(a) The finely divided, almost microscopic, character of the pyrite gives maximum surface exposure to atmospheric agencies and greatly promotes oxidation.

(b) The very warm, moist atmosphere. The tropical sun shining directly on dark rock surfaces produces a temperature sufficiently high to greatly promote oxidation, especially in the presence of slight moisture.

(c) Once oxidation of the pyrite has been started the heat thus generated tends to accelerate chemical action and thus the heating increases in geometric progression.

(d) When the heat of pyrite oxidation reaches the comparatively low temperature of oxidation of the hydrocarbons present in the lignitic shale, they, too, become oxidized and still further add to the temperature. Finally the fixed carbon content tends to become oxidized, at least in part, and gives maximum intensity to the action.

(e) Some heat is also generated by the action of the free sulphuric acid on the calcium carbonate for the formation of gypsum. Other minor chemical actions added their quota to the total heat.

As the temperature rises all chemical activity is vastly stimulated and the heating increases to a maximum. After the most readily oxidizable substances are consumed the heat gradually dies down toward normal temperatures, which may be reached in a few weeks or months. The intensity and duration of the heat depends largely upon the percentage of finely divided pyrite, volatile matter and fixed carbon in the rocks.

Some of the geological considerations suggested by a study of this phenomenon are:

(a) Chemico-thermal spring. Whenever jointing fissuring or change of groundwater level gives free access of oxygen-bearing surface waters to beds which contain the necessary finely divided pyrite, and carbonaceous matter, a heating up of such beds is likely to result. Groundwater flowing over such heated beds, and coming to the surface in the general vicinity of them, would constitute thermal springs.

(b) Should a rise of land surface bring pyrite-bearing beds from subaqueous to terrestrial conditions, oxidation of the pyrite might, in the course of a year, give local redbeds that would otherwise require centuries of atmospheric action to produce. Of course it is recognized that no very extensive redbeds could be produced in this way.

(c) The very fine pyrite sparingly disseminated through the carbonaceous shales, herein described, seems to have resulted from the action of sulphur, from decaying animal and vegetable life, on the ferro-megnesian silicate fragments which are abundant in these sediments.

THE HEATING IN THE CULEBRA CUT

Williams, Edward H., Jr.; *Science*, 35:892-893, 1912.

Mr. MacDonald's interesting article on the heatings in Culebra Cut, in your issue of May 3, No. 905, is paralleled by the spontaneous combustion of bituminous coals, and even of the anthracite culm banks, owing to the oxidization of pyrite. It is a common occurrence, and is the cause of endless trouble in preserving museum specimens of pyrite in fine dissemination during damp weather.

In the case at issue the iron content proceeded from the ferro-magnesian silicates, as Mr. MacDonald has stated; but from ordinary surface oxidation, as is always the case in regions containing the black bisilicates, and as shown by the rustiness of springs and streams. The sulphur content is also generally present in lagoons as more or less dilute sulphuric acid. The presence of carbonaceous material points to a lagoon formation at Culebra Cut.

The function of iron is to be a carrier of oxygen from the air to the precipitated organic debris, changing from hydrated sesquioxide to protoxide: picked up by the above acid: again breaking up as hydrated sesquioxide, and continuing its endless rounds unless it happens to be included and imprisoned under a mass of vegetation; when the round is stopped, the sesquioxide and the solution of sulphate in which all the ingredients are bathed are robbed of the oxygen and form pyrite.

The classic laboratory experiments show that organic animal matter acts with greater rapidity and sureness, and the resulting pseudomorphs of sphalerite, chalcopyrite, or pyrite, when a live clam is placed in a saturated solution of a sulphate of the above, are well known. We find them abundantly in nature, in the Trenton rocks as well as in the coal measures.

VOLCANIC SIGNS IN NEBRASKA

Anonymous; *Scientific American*, 38:8, 1878.

The seat of disturbance is on the banks of the Missouri, in Dixon county, about thirty-six miles from Sioux City. A bluff, about 1,000 feet long and 160 feet high, sloping at an angle of 60° to 80° toward the river, is at present the place where the phenomena are most exhibited, but other bluffs at a few miles' distance have been similarly affected. Two years ago a portion of this bluff, half as large as what is left, broke away and fell partly into the river. On the bluff sounds were heard proceeding from the interior, especially on placing the ear to the ground. Flames sometimes broke forth, occasionally at night. Steam escaped from crevices. On digging into the bluff, intense heat stopped the work after proceeding a few feet. Selenite, alum, and magnesia sulphate in crystals were abundant. Professor Aughey regards these features as not volcanic in the usual sense of the term, but simply the result of local chemical action. The formation is cretaceous. The bluff is capped by calcic carbonate. Beneath are shales containing ferric bisulphide in crystals or pyrites. Below the shale is a soft limestone, containing carbonates of magnesia and alumina. The chemical reactions consequent upon part of the soil being soaked with water after its fall toward the river, have been the decomposition of the pyrites, the production of sulphuric acid, and the attack of the acid on the alkaline carbonates. The heat evolved in the first of these reactions is, of course, very great; in the latter part the violence of the performance must be increased by the liberation of carbonic anhydride. All the authenticated disturbances are thus easily explained. Professor Aughey does not connect them with the earthquake. He thinks the bluff might furnish alum and other salts in quantities sufficient for profitable manufacture.

A HUGE CALDRON

Anonymous; *English Mechanic,* 48:77, 1888.

According to an account given by Dr. Ernst Weisenbauer, Professor of Geology at the University of Heidelberg, who has been recently visiting the natural gas districts of Ohio, the inhabitants of the town of Findlay, in that State, are actually living over a huge caldron, in which they may be engulfed sooner or later. Prof. Weisenbauer states that the extent of the region of the American natural gas wells is considerably under-estimated, and that at a great depth under the town of Findlay in particular there is a large cave which is filled with highly explosive gases, and that a frightful explosion, considering the great pressure at which these gases are bottled up, may take place at any time. The following are his reasons for arriving at such a conclusion. By means of a pyrometer the professor ascertained that under the town of Findlay, at a depth of a mile below the cave filled with gases, a fire is raging, developing a temperature of 3,500°. The same observations were made by Prof. Weisenbauer at various spots within a radius of five miles. He concludes that at a depth of only 1,200 ft. below Findlay there is an immense cave, compared with the size of which the well-known Mammoth Cave is insignificant. The cave extends for many miles, and has a depth in various places of over half a mile. Highly explosive gases fill this cave at a great pressure. There are several strata of rock about a mile thick below the cave. The flames of an interior fire are impinging against this wall of rock at the high temperature mentioned. From the continuous noises observed by means of the telephones it may be concluded, he says, that the consumption of the protecting rock by the fire is making uninterrupted progress. Prof. Weisenbauer expresses the opinion that the bursting of that portion of the earth's crust on which Findlay stands, should an explosion of gas take place, is not only possible but probable, and that an early catastrophe is impending. It should be added, however, that American geologists, and among them Prof. J. K. Gilbert, of Washington, do not share Prof. Weisenbauer's apprehensions, and have expressed doubts as to the correctness of the observations of and the validity of the conclusions arrived at by the German geologist.

ISOTOPIC ANOMALIES

The natural terrestrial abundances of most isotopes have been established by decades of exacting measurements. Whenever a geologist comes across rocks containing abnormal abundances or anomalous ratios of isotopes, he must search for an explanation. Either the rocks in question did not receive their fair share of isotopes when formed or subsequent geochemical processes have selectively concentrated or depleted the isotope inventories. Often isotopic discrepancies will reveal unusual historical conditions, such as hot and cold climates. Isotope analysis, therefore, is a valuable addition to the geologists' repertoire.

Some of the items below, especially those on primordial lead, are closely related to the following section on isotopic dating.

WHAT HAPPENED TO THE EARTH'S HELIUM?

Anonymous; *New Scientist*, 24:631-632, 1964.

Physicists studying the upper atmosphere have to explain how the Earth came to lose nearly all its helium. They have tried to argue that the gas escapes from the Earth's upper atmosphere, steadily and continuously, sufficiently fast to reduce its abundance to known levels. A recent laboratory experiment conducted at the Central Radio Propagation Laboratory of the US National Bureau of Standards has led to the suggestion by Dr. E. E. Ferguson, head of the atmospheric collision processes section there, that instead "some catastrophic event" may have made most of the helium boil off in geologically recent times.

At first sight there ought to be about a thousand times as much helium in the atmosphere as there is. This light, inert gas is produced by radioactive decay of the uranium and thorium in the Earth's crust. At present known rates, radioactivity would produce all the neutral helium gas now in the atmosphere in no more than a few million years. Current estimates make the Earth about 4500 million years old.

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EVIDENCE FOR PRIMORDIAL HE-3 IN THE EARTH

Clarke, W. B., et al; *EOS*, 50:222, 1969.

Abstract. We have found a large enrichment of He^3 in deep Pacific water, relative to atmospheric He^3/He^4 determined for air samples with the same helium content as the sea water samples. A sample from 1900m shows 21.8 ± 2.11 excess He^3, and deeper samples range from $7.8 \pm 1.9\%$ to $12.2 \pm 2.0\%$, whereas a surface sample and one from 1000m show identical He^3/He^4 as compared to air within experimental error. We have also

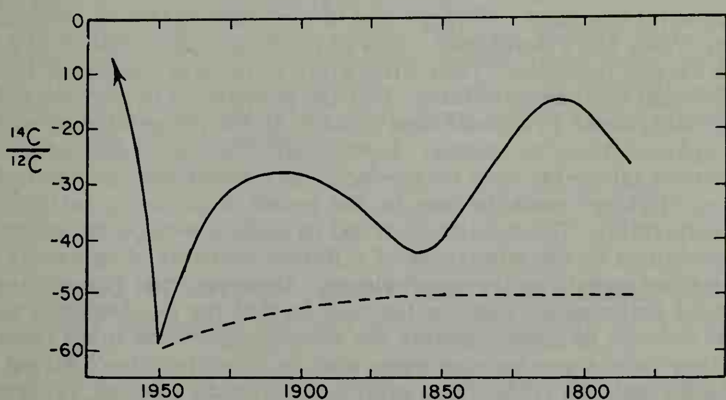
measured total helium contents and find excess amounts of 3 ± 3% to 8 ± 3%, relative to solubility data. The results for total helium are in agreement with recent work of Bieri, Koide, and Goldberg. There does appear to be a rough correlation between He^3 excess and He^4 excess indicating that there are two components in varying proportions, one with an atmospheric He^3/He^4 ratio, and another with a considerably higher ratio. We conclude for the moment that the excess He^3 is due to leakage into ocean water of a remnant of the earth's primordial He^3---there appears to be no other possible mechanism. The effects we see could be accounted for by a leak rate of about 5 atoms cm^{-2} sec^{-1}, approximately the amount required to balance the production rate of He^3 from various other sources and the escape rate by thermal and non thermal processes.

CARBON-14 VARIATIONS IN CORAL

Anonymous; *Open Earth*, no. 3, 30, 1979.

The relative amounts of the various carbon isotopes in the atmosphere are known to have been affected by several human activities---most notably fossil fuel burning and nuclear bomb testing---as well as by natural processes. To discover just how well these atmospheric changes are reflected in seawater, Nazaki et al. (Geophys. Res. Lett., 5, 825; 1978) have analysed a Bermuda reef brain coral that was 'born' in 1770 and collected in 1976. Using the annual growth bands of the coral, it proved possible to take dated samples from the entire growth period. The samples were then analysed for C14/C12 and C13/C12 ratios, and the results were interpreted on the assumption that the coral recorded the carbon isotopic composition of the surrounding water.

The sharp rise in C14/C12 from about 1955 onwards, the result of nuclear bomb testing, is clearly visible in the coral data. So is the al-



Carbon isotope ratios plotted versus calendar year for Bermuda corals (solid line) and the Florida Keys (dashed line).

most monotonic decrease in C14/C12 from about 1900 to 1955. This is the so-called Suess effect and arises from the fact that fossil fuel burning adds C12, but not C14, to the atmosphere. Fossil fuel burning does add C13 to the atmosphere but proportionately less than C12; so the C13/C12 ratio also decreases from 1900 to 1955. Moreover, it continues to decrease after 1955, for bomb testing produces no C13.

Throughout the whole period 1900–1976, the coral C14/C12 and C13/C12 ratios, though not the same in magnitude as the corresponding ratios from tree ring analysis, nevertheless match them in general trends. In other words, variations in the carbon isotopic composition of the atmosphere find expression in the coral, presumably because of an equilibrium between near-surface water and the atmosphere. But as far as carbon isotopes are concerned, the seawater surrounding the coral may also be influenced by the rise of deeper water isolated from the atmosphere for some considerable time. In other words, a coral will record not just atmosphere effects (influence A) but also the consequences of longer-term deep sea processes (influence B).

CAN ROCKS SEPARATE ISOTOPES?

Anonymous; *New Scientist,* 26:35-36, 1965.

There is currently a growing interest in isotope analysis among geochemists. Investigation of the relative amounts of carbon isotopes in natural compounds associated with petroleum may well illuminate the problems of its origin. An example is provided by some recent work on the gas fields of southern Italy and Sicily (Nature, Vol. 205, p. 1303).

The ratio of carbon-13 to carbon-14 has an exceptionally high range of values in natural methane (CH_4), being variable between about one per cent and nearly ten per cent. Associated ethane (C_2H_6) and propane (C_3H_8) have much more constant proportions of the two isotopes, U. Columbo and his colleagues at the "G. Donegani" Research Institute of the Montecatini Company, Novara, and of the Laboratorio di Geologia Nucleare, Pisa, have developed a new chromatographic method of assessing these carbon isotopes. They find, after examining the gases from nine Italian and Sicilian gas fields, that the proportion of carbon-13 to carbon-14 decreases in a consistent fashion as the proportion of methane to other hydrocarbons increases. Isotopically "heavier" methane, containing more carbon-14, may be produced as a breakdown product of petroleum; "lighter" methane may be the result of bacterial activity on organic materials. The consistent trend in carbon isotope ratios could thus be explained by the admixture of different amounts of bacterial methane to that resulting from petroleum. However, the researchers also suggest that another explanation may be that the two isotopes were originally present in approximately the same proportions in all instances, and that they have since become separated by "fractionation" during their migration through the rocks from their source to the present reservoirs. This would almost certainly alter the proportions of the respective gases in the final mixture and, if it also changed the isotope ratio, the two would show the kind of relationship observed. A rough laboratory experiment performed by the Italian workers shows this to be a possibility.

CARBON ISOTOPIC STUDIES OF ORGANIC MATTER IN PRECAMBRIAN ROCKS

Oehler, Dorothy Z., et al; *Science*, 175:1246-1248, 1972.

Abstract. Reduced carbon in early Precambrian cherts of the Fig Tree and upper and middle Onverwacht groups of South Africa is isotopically similar (the average value of $\delta^{13}C_{PDB}$ is -28.7 per mil) to photosynthetically produced organic matter of younger geological age. Reduced carbon in lower Onverwacht cherts (Theespruit formation) is anomalously heavy (the average value of $\delta^{13}C_{PDB}$ is -16.5 per mil). This discontinuity may reflect a major event in biological evolution.

UNDERGROUND SITES OF ANCIENT EARTH

Anonymous; *New Scientist*, 83:886, 1979.

Gerald Wesserburg at Caltech and Donald dePaolo of the University of California at Los Angeles say they have evidence that a thick rock layer, which has remained unaltered since the Earth formed, lies underneath the continents. They reject the concept of an homogeneous mantle and instead suggest that it has two distinct zones. The lower of these is a layer of ancient, unseparated rocks, which is tipped by residues of materials from which the continents above are derived.

The geologists' evidence comes from study of the ratio of two isotopes of neodymium---^{143}Nd and ^{144}Nd---in continental and sea-floor lavas. Neodymium-143 originates as a decay product of the radioactive material samarium-147. Scientists have already established the isotope ratio for neodymium, and its variation with time, in the "raw materials" of the Solar System. Materials in a homogeneous mantle, however, should be enriched in ^{143}Nd compared with the Solar System in general, as crustal materials floating to the Earth's surface during its molten phase would carry away more neodymium than samarium.

The mid-ocean lavas which extrude from the shallow part of the upper mantle do indeed show such an enrichment, but lavas from the continents do not. Instead the continental volcanoes which tap much deeper sources within the mantle extrude lavas sporting an isotope ratio that might be expected from ancient rocks.

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THE ATOMIC WEIGHT OF LEAD FROM THE BELGIAN CONGO

Anonymous; *American Journal of Science*, 208:81-82, 1924.

This determination has been made by Theodore W. Richards and Paul Putzeys. Within the past few years a new source of uranium and radium material has been developed in Central Africa, and the metal employed for the investigation was extracted from several secondary minerals containing lead and uranium which occur in this locality, accompanying the original uraninite. Consequently, it appears that the lead was probably chiefly derived from the radioactive disintegration of uranium and its subsequent products. A qualitative test of the lead showed appreciable radioactivity.

No details need be repeated here in regard to the purification of the materials used for the work, nor in connection with the carrying out of the analyses; for the very remarkable care and precautions, as well as the wonderful skill always employed in Professor Richards' laboratory are very familiar, so that it may be stated, simply, that two final determinations of the atomic weight of the radioactive lead were carried out, as well as two preliminary determinations on less carefully purified material, and that three determinations on ordinary lead were made for comparison. In all cases the method consisted in the comparison of lead chloride to the silver with which its chlorine combined. The results were as follows:

Ordinary lead: 207.21, 207.18, 207.15. Average, 207.18, accepted 207.20.

Congo lead (Prelim.) 206.10, 206.14.

Congo lead (Final) 206.20, 206.20.

The authors say that evidently the lead from the uranium deposits in the Congo region has an atomic weight exactly one unit less than ordinary lead, and perhaps 0.14 unit higher than that of pure uranium lead, and they draw the conclusion that about 88% of this lead consisted of uranium lead, while about 12% of it was ordinary lead. They say that this is a far lower percentage of ordinary lead than that existing in the similar metal from Australia and that it is clear that these minerals must have been formed long after the original deposit of uraninite crystallized in its bed.

ANOMALOUS LEADS FROM THE UPPER GREAT LAKES REGION OF CANADA

Farquhar, R. M., and Russell, R. D.; *American Geophysical Union, Transactions,* 38:552-556, 1957.

Abstract. We have previously reported on the presence of lead minerals of anomalous isotopic composition in the Sudbury, Ontario, mining area, and have used these anomalous isotope ratios in trying to determine the history and age of the Sudbury ores. We have since found a number of anomalous leads in the upper great lakes region of Ontario, some of which are more anomalous than the most anomalous Sudbury galenas.

As in the case of Sudbury, the anomalous leads vary enormously in isotopic composition even when closely related geographically. Leads found in the Thunder Bay region show extreme variation. There seems to be a correlation between isotopic composition and distance from the Lake Superior shore: those leads nearer the shore have generally large radiogenic components. Leads in the basement rocks some distance northwest of the lake are not apparently anomalous, having the isotopic constitution typical of the very old Keewatin leads.

It is calculated that the ratio Pb^{207}/Pb^{206} in the anomalous radiogenic component is 0.185 ± 0.005. From this it is deduced that the time of final mineralization of these leads is not greater than 1700 ± 30 m y ago and that the rocks from which the radiogenic lead was derived cannot be older than 2740 ± 40 m y.

NUCLEAR GEOLOGY AND ISOTOPIC DATING

The discovery of natural radioactivity by Becquerel in 1896 radically changed the earth sciences. The possibility of a long-lived heat source within the earth's crust cast doubt on Lord Kelvin's famous dictum that the earth could not be hundreds of millions of years old because it would have cooled off far more in that length of time. Also of fundamental importance, radioactivity allowed geologists to devise a new type of chronometer based on supposedly unalterable nuclear decay rates. Geology has not been the same since. But just how satisfactory is isotopic dating? Many "discordant" dates have been measured; that is, some nuclear dates do not agree among themselves and others fly in the face of dates established by conventional geological methods. These anomalies have not been resolved to everyone's satisfaction.

During the 1970s, several fossil fission reactors were discovered in Africa. Although the conditions for nuclear chain reactions are well-known, it was a great surprise to find that nature had preempted Fermi's 1942 experiment by millions of years. The many anomalous lead isotope ratios may be related in some way to ancient nuclear environments on earth.

More controversial are the pleochroic halos found in mica and a few other minerals. Some of these halos seem derived from short-lived polonium in the absence of long-lived parent isotopes; while other halos are larger than one can account for in terms of known, naturally occurring isotopes. The former phenomenon could imply that our geological time frame is seriously distorted; the latter suggests the existence of superheavy elements. Many schemes have been offered to explain these embarrassing situations. As always in science, hypotheses couched in traditional terms are to be preferred, but radical, almost unthinkable notions still persist about young earths and heavy primordial elements resisting dissolution on some island of stability far beyond uranium.

• Abnormal Natural Radioactivity

UNUSUALLY RADIOACTIVE FOSSIL BONES FROM MONGOLIA

Jaworowski, Zbigniew, and Pensko, Jerzy; *Nature,* 214:161-163, 1967.

Part of the fossil material excavated by Polish-Mongolian palaentological expeditions to the Gobi Desert in the years 1963-65 has been found to be highly radioactive. We have examined the following specimens: (1)

samples of bone from various dinosaurs and turtles from Upper Cretaceous beds corresponding to Campanian or Maestrichtian from the Nemegt Valley in southern Gobi Desert (at Altan Ula IV, Tsagan Hushu and Nemegt); (2) bone samples of turtles and mammals from the Palaeocene beds of Nemegt Valley (at Tsagan Hushu and Naran Bulak); (3) dinosaur bone samples from the Upper Cretaceous of Bain Dzak, corresponding probably to Turonian; (4) bone samples of mammals from the Oligocene beds of Hsanda Gol; (5) mammalian bones from the Miocene beds of Berger Nur; (6) bones of rhinoceroses from the Pliocene beds of Altan Teli; and (7) mammalian bones from Palaeocene beds of Hashyat (Gashato). Sandstone samples have also been collected from the majority of these localities and analysed.

Measurements of the gamma radioactivity in these materials compared with 0.12 per cent uranium ore have been made with the gamma scintillation counter using mechanically pulverized samples of volume 10 c.c. The results of these measurements show that only those specimens collected in the Nemegt Valley have high radioactivity. Specimens of similar age from other localities (400–1200 km from Nemegt Valley) have been found to be much less radioactive. It is, however, interesting that the radioactivity of the bones from Tsagan Hushu in Nemegt Valley is approximately seven times higher in Cretaceous specimens 75–80 million years old than in the younger Palaeocene bones 10–15 million years old collected in the same area. This indicates that not only the locality of deposition of the bones but also the age of fossils influences their levels of radioactivity.

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The radioactivity of the rock surrounding the bones from the Nemegt Valley was found to be similar to that from other localities, except that one sample from Tsagan Hushu was approximately four times more radioactive than the other sandstone samples. This indicates that the concentration of radioactivity material in the rock immediately surrounding the bone deposits has little influence on the level of radioactivity in the bones. Thus the parent uranium probably accumulated in the bones, presumably from the percolating ground waters which might have transported minute concentrations of uranium even from distant sources of the nuclide. The duration of accumulation, the amount of percolating water and the concentration of uranium in this water were probably the main factors influencing the levels of radioactivity in the fossil bones examined. Our results do not support the suggestion of Diggle and Saxon that excessive radioactivity can be found only in particular kinds of fossil animals, because we have found such radioactivity in the bones of different kinds of dinosaurs, turtles and mammals collected in the "hot" Nemegt Valley localities. We did, however, find that radioactivity was higher in bones containing greater amounts of organic matter.

• Natural Fission Reactors

NUCLEAR REACTOR IN THE JUNGLE

Durrani, S. A.; *Nature,* 256:264, 1975.

Nature, it would seem, had anticipated man by something like 1,800 million years in bringing about the first self-sustained nuclear chain reaction on the Earth. And, contrary to common belief, it was not in the squash court of the University of Chicago in December 1942, but in the wilds of what is today the Republic of Gabon at a place called Oklo that this fantastic phenomenon took place.

The history of the discovery of the phenomenon, as it unfolded during the symposium, is briefly as follows. In June 1972, a team working under the direction of Dr. H. F. Bouzigues at the CEA service laboratory at Pierrelatte in France noticed a marked anomaly in the abundance of the uranium-235 isotope (0.7171 ± 0.0010 in atomic per cent instead of the normal 0.7202 ± 0.0006) during the certification of a secondary standard of UF_6 by the gas diffusion method. Later, much larger depletions of this isotope were discovered (down to 0.621%, and eventually to 0.296% ^{235}U) in uranium samples from this source, which was traced back to the Oklo deposit. First positive proof of the hypothesis that a natural chain reaction was responsible for the depletion of the fissile component was furnished by Mme. M. Neuilly and co-workers of CEA through the measurement of the ratios of fission-product rare earths detected in the ore by the spark source mass spectrometry technique. Two simultaneous submissions by the above two groups on September 25, 1972, to the Proceedings of the Academy of Sciences, Paris, announced the discovery and the proposed explanation of this remarkable phenomenon. It was pointed out that at the time of the reaction the natural abundance of the relatively fast-decaying ^{235}U isotope was more than 3%. This natural 'enrichment', helped by the moderation of the fission neutrons by the water content of the soil which enhanced their fission efficiency, and possibly by the relative absence of neutron-absorbing elements in the surroundings, allowed a nuclear chain reaction to develop. It is perhaps worth mentioning that such a natural chain reaction had already been predicted, on theoretical grounds.

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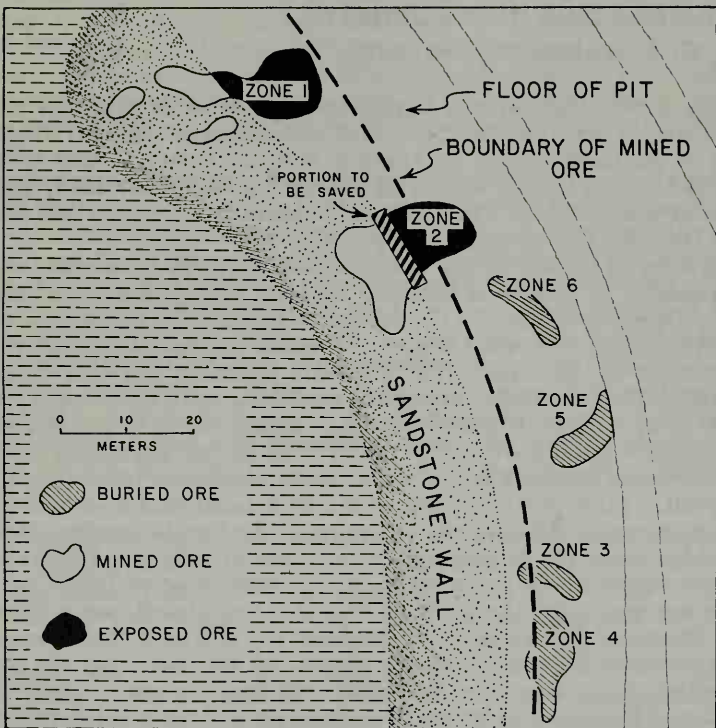
[The age of this natural nuclear reactor is estimated at 1.8 billion years. Some scientists speculate that the nuclear radiation emitted by Oklo-type nuclear reactions occurring at various spots around the world might well have accelerated evolutionary processes. Coincidentally, some paleontologists believe that mitotic, nucleated cells originated between 1.5 and 2.0 billion years ago.

The Oklo natural nuclear reactors were described widely in the scientific and semiscientific literature. An extensive article in Scientific American, 235:36-47, July 1976, adds the following facts: (1) one uranium sample from the reaction zone contained only 0.44% uranium-235 rather than the normal 0.7202%; (2) at the time of the reaction, the concentration or uranium-235 was about 3% (most of this subsequently decayed into lead); and (3) a total of six reaction zones have now been found at Oklo (see figure).]



The six natural nuclear reactor zones at Oklo were in lenses of exceptionally rich ore. (Adapted from Scientific American, *235:36-37, July 1976.)*

OKLO REACTOR RE-ANALYZED

Brookins, Douglas C.; *Geotimes,* 23:27-28, March 1978.

The geology of the mine has been carefully worked out by F. Gauthier-Lafaye, F. Weber (both at Strasbourg) and J. Pfiffelman (MOKTA Co.); and M. Bonhomme (Strasbourg) has continued his work on geochronologic aspects of Oklo. The geology is much more complex than first indicated 2 years ago, and the basic question common to virtually all very-high-grade uranium deposits, that of how the uranium was remobilized from relatively low grade ore (0.2 to 0.9% U_3O_8) to extremely rich concentrations (5 to 70% U_3O_8), remains unanswered. Certainly the location of the high-grade ore, which sustained the fission reactions, is tectonically controlled in folds and faults at the Oklo site, but the mechanisms for transport and precipitation are speculative at best. One of the unfortunate aspects of Oklo is that the zones that were first identified as having sustained fission reactions (dated at 1.85 to 1.9 x 10^9 years ago) have essentially all been removed by mining. Only part of zone 2 remains, preserved by an enclosed cover some 50 ft above the present mine floor, on the foot-wall side of the open pit. Gone are the zones previously identified as 3 through 6, although not before the French investigators demonstrated that zones 3 and 4 were connected as were zones 5 and 6.

Not unique to Oklo are the problems associated with the role of the organic carbonaceous matter and uranium, concentration of magnesium in uranium-rich zones (commonly in chlorites); however, apparently unique to the high-grade ore at Oklo is the near-absence of quartz in the highest-grade ore zones. Whether due to dilution or to dissolution concommitant with uranium mineralization remains uncertain.

On the positive side, careful search for more 235-uranium-depleted ore at deposits located along the same series of tectonic elements noted at Oklo has resulted in the discovery of additional ore that sustained fission reactions at the Okelobondo deposit, about 1 km south of Oklo. The Okelobondo deposit is still in an early development stage, and it is hoped that the hydrodynamics, geochemistry, geochronology, and detailed geology of this newly discovered reactor site can be studied with utmost care as mining proceeds.

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• Superheavy Elements in Nature

X-RAY EVIDENCE FOR SUPERHEAVY ELEMENTS

Robinson, Arthur L.; *Science,* 193:219-220, 1976. (Copyright 1976 by the American Association for the Advancement of Science)

[The announcement in 1976 by Gentry et al (Physical Review Letters, 37: 11, 1976) that they had discovered evidence for the existence of superheavy elements in monazite had several profound implications. Gentry's work emphasized first of all that the giant halos found in some minerals (see following text) had never been explained. If these giant halos are actually due to superheavy elements, their presence in rocks a billion years old (according to radioactive dating) infers that either: (1) the superheavy elements are much more stable theoretical physics permits; or (2) radioactive dating is wrong and the monazite deposits are really extremely young. Neither of these alternatives is attractive in terms of the current world-view of science and, as the following reports prove, extreme efforts have been made to find other explanations of the giant halos.]

Last month, a team of scientists announced that it had evidence for the existence of superheavy elements with atomic numbers of (in order of decreasing confidence) 126, 116, 124, and 127. The investigators from the Oak Ridge National Laboratory (ORNL), Florida State University (FSU), and the University of California at Davis (UCD) could not determine the masses of the heavy atoms, which were found in naturally occurring mica formations, from their data, however.

The superheavy elements in themselves are not surprising to physicists, who have long predicted their existence. Although elements with atomic numbers much greater than 100 are highly unstable, numerous calculations have indicated the possibility of long-lived nuclei with from 110 to 114 protons and 184 neutrons. These predictions have, in fact, stimulated intense searches for superheavy species in recent years, both in nature and in accelerators. Until now, no convincing evidence had been found.

If their findings are confirmed by subsequent experiments (one scientist said he would bet $10 but not $1000 they would be), a frantic race can be expected between nuclear physicists around the world to explore this so-called island of stability of superheavy nuclei. And because the new elements have atomic numbers larger than expected, nuclear physicists will have to revise existing theories of nuclear structure and nuclear synthesis.

The investigators detected the elements by bombarding small monazite inclusions in a mineral known as biotite, with a 30-micrometer-wide proton beam from the Florida State tandem Van de Graaff accelerator. Agreement between the energies of the x-rays emitted from the monazite with values of x-ray energies that were previously predicted for superheavy elements by Thomas Carlson and his associates, who are also researchers at Oak Ridge, led the ORNL-FSU-UCD team to conclude that the heavy atoms were present.

Inasmuch as the putative superheavy elements were present in very small amounts (less than 100 picograms), the x-ray signals were weak, resulting in less than optimum signal-to-noise ratios. This, combined with the observation of only one x-ray line for each of the species (or, in one case, two weak lines), led the group to emphasize that it is only claiming evidence for, not the discovery of, superheavy elements.

This attitude also characterizes those observers who have seen the data. Says Francis Perey, one of a group of several Oak Ridge scientists who reviewed the ORNL-FSU-UCD group's results before they were made public, "The peaks are there, but the statistics are not quite good enough to be completely convincing as to their identification."

Monazites are minerals containing the rare earths cerium and lanthanum and the actinides uranium and thorium. They occur widely throughout the world, in such places as Brazil, South Africa, and India. The particular specimens used in the x-ray investigation originated in the Malagasy Republic and were given to Robert Gentry of ORNL several years ago.

Gentry was interested in explaining the origin of giant halos that occur around some thorium-rich monazite inclusions in biotites. Halos are discolored regions caused by radiation damage to the material surrounding an inclusion when the radioactive elements therein decay by emitting alpha particles. Halos traced to uranium and thorium decay have been characterized by Gentry and others. The size of a halo increases with the energy of the alpha particle emitted, but the giant halos (with radii from 50 to 100 micrometers) were too large to be explained by alpha decay of any known element.

Mystery of the Giant Halos. After exhausting other explanations for the giant halos (some were shown to have a chemical origin), Gentry turned to investigating the possible existence of new sources of radioactivity, such as superheavy elements. The use of an ion microprobe mass analyzer (an instrument in which a narrow scanning beam of oxygen ions sputters ions from the surface of a sample into a mass spectrometer) provided evidence for high mass particles in the inclusions, but could not exclude the possibility that they were molecular ions, such as oxides. The use of a scanning electron microscope beam to excite x-rays from elements in the inclusion was also unsuccessful because a high background radiation obscured signals coming from anything present in very small concentrations.

Then, last fall, Gentry queried Thomas Cahill and Robert Flocchini of UCD about an x-ray technique that they and their associates at Davis had been using to monitor air pollutants. It is one of the ironies of life that these researchers were stimulated to develop the ion-induced x-ray method for analysis of such environmental contaminants when support for the Crocker Nuclear Laboratory accelerator at UCD was terminated 6 years ago, and the laboratory was left to pay its own way.

After conferring with Gentry, the UCD researchers decided that a hunt for superheavy elements would be feasible with the UCD technique. Exciting x-rays with ions from an accelerator reduces the background considerably at high x-ray energies. Moreover, there would be a window in the monazite for the L x-rays (those emitted when electrons fill vacancies in the L shell of an atom) expected from superheavy elements. The window occurs between 21 kev, the highest energy of the L x-rays emitted by uranium and thorium, and 30 kev, the lowest energy of the K x-rays emitted by lanthanum and cerium. The theory for L x-rays is also more accurate than that for the higher energy K x-rays because L shell electrons tend to avoid the nucleus.

In order to ensure that the x-rays came only from the monazite inclusion and that enough x-rays were counted to obtain a statistically significant result, the researchers had to focus the ion beam on the inclusions, which have diameters of 50 to 100 micrometers, for long periods of time (an hour), a never-before-achieved accomplishment in itself. The UCD accelerator was not up to this task. As it happened, however, Cahill was going to FSU on sabbatical, and the tandem Van de Graaff there was, if not ideal, the best machine available anywhere. Thus, Cahill joined with Neil Fletcher, Henry Kaufman, Larry Medsker, and William Nelson at FSU to perform the x-ray experiments.

If confirmed, the identification of superheavy elements will have a profound effect on nuclear physics. It may also serve to raise the sagging spirits of U.S. nuclear physicists, who have been suffering the indignities of funding cuts in recent years. And, if the x-ray evidence holds up, the two most successful laboratories in producing elements with high atomic numbers, the University of California's Lawrence Berkeley Laboratory (LBL) and the Joint Institute for Nuclear Research in Dubna, U.S.S.R., have been scooped. As soon as more material becomes available, according to Albert Ghiorso of LBL, these laboratories and others will engage in a race to explore the properties of these superheavy elements and to create new ones by bombarding the monazite in accelerators.

Finding superheavy elements in monazites, which were formed early in the earth's history, raises at least two questions for nuclear scientists. Calculations based on a synthesis of the liquid drop and shell models of the nucleus had indicated that element 126, for example, would decay by alpha emission with half-lives from a few nanoseconds to about a thousand years, depending on the number of neutrons, according to J. Rayford Nix of the Los Alamos Scientific Laboratory in New Mexico. But the geologic age of the earth is 4.5×10^9 years.

The short half-lives expected are due to the large electrostatic repulsion between protons which overcomes the attractive nuclear forces and makes spontaneous fission of nuclei more and more likely as their atomic numbers rise above 100. The probability of radioactive decay by emission of alpha particles also increases as coulomb forces become stronger. The shell model of the nucleus, whereby the protons and neutrons are arrayed in shells somewhat like atomic electrons, provides a way to circumvent these instabilities under certain circumstances.

When the proton and neutron shells are filled, a barrier to fission large enough to permit lengthy nuclear lifetimes occurs. The "magic number" for which this closed shell condition would hold was thought to be 114 protons and 184 neutrons. But all calculations of nuclear lifetimes are based on extrapolations of models known to fit much lower mass nuclei. Thus, calculating the stability of superheavies is a tricky business.

By making only small changes in the parameters used in a model such as Nix's, theoreticians can effect changes in nuclear lifetimes of several orders of magnitude, according to Fred Petrovich at FSU. Looked at from this point of view, the new superheavy elements provide a guidepost for assigning values to parameters which were heretofore selected on the basis of incomplete information.

A second problem for theoreticians has to do with whether the putative superheavy elements were created by the processes of nucleogenesis in stars. The most important of these for heavy elements is the r-process in supernovas, which involves a sequence of multiple capture of neutrons to increase the nuclear mass followed by emission of electrons to increase the atomic number. Calculations based on the liquid drop model of the nucleus had led theorists to believe that spontaneous fission would interrupt this process before superheavy elements could be formed, according to Nix. Moreover, the details of the giant halos are such that it is possible that they were caused by alpha decay of even heavier elements than those apparently now residing in the monazite inclusions, say the experimenters, and thus would be much harder to produce.

For now, the most important thing, all agree, is to verify the existence of superheavy elements. The ORNL-FSU-UCD team is now working to improve their data by correcting the tendency of the Van de Graaff beam to wander away from the inclusion. But, if further x-ray evidence proves inconclusive, a number of scientists who are waiting in the wings with other physical and chemical tests involving separation, concentration, or nuclear bombardment of superheavy elements would be only too happy to have a crack at the new elements.

SUPERHEAVY ELEMENTS: CONFIRMATION FAILS TO MATERIALIZE

Robinson, Arthur L.; *Science*, 195:473-474, 1977.

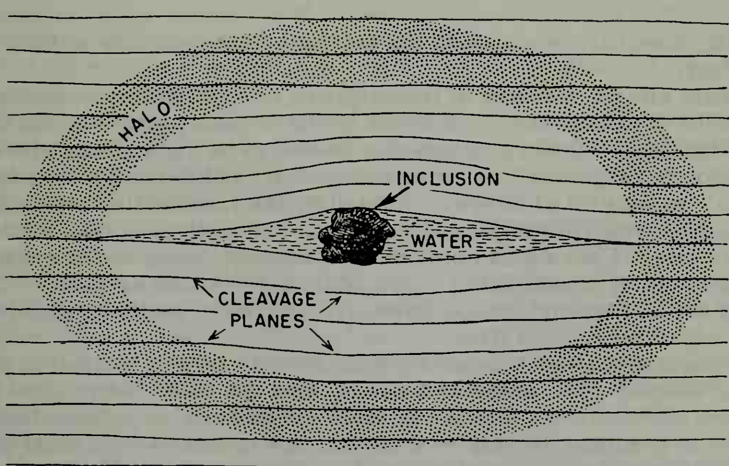
[Digest. After summarizing the problems posed by Gentry's findings, Robinson reported on two additional experiments that tended to undercut the evidence for the existence of superheavy elements. First, John Fox and his collaborators at Florida State University found that the gamma ray emitted when the praseodymium nucleus relaxes after creation from cerium (common in monazite) had the same energy as the x-ray peak of the supposed element 126. Secondly, more refined x-ray experiments by a group from Oak Ridge National Laboratory showed no obvious evidence of superheavy elements. As confirmatory data failed to materialize, most scientists decided that the monazite samples contained no superheavy elements, although they realized that the origin of the giant radiohalos had not been explained.

A similar article "Bleak Outlook for Superheavy Nuclei," appears in Nature, 265:496-497, 1977.]

GIANT HALOES IN MICA

Anonymous; *New Scientist*, 76:563, 1977.

Now P. H. Fowler and A. R. Lang of the University of Bristol have suggested another simple mechanism to account for the giant haloes (Nature, vol 270 p 163).



Water in a cleavage plane containing a radioactive impurity can increase the ranges of the particles and increase halo sizes.

They point out that the giant haloes are always associated with a rather large inclusion, or speck of radioactive material, and that this could well cause a crack in the mica along the cleavage plane. This crack could be formed by changes in temperature or pressure at some time in the past or it could be due to the swelling of the inclusion due to the high degree of radiation damage that it receives.

The crack could be filled with water and this would extend the area of radiation damage in two ways. Firstly, the alpha-particles from the inclusion would pass through the water for part of their range and thus travel farther, and secondly the radon in radioactive equilibrium with the isotope could diffuse through the water and decay at some distance away from it, again increasing their range from the centre of the inclusion.

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[Calculations showed that water in the cracks could easily explain the giant halos. The halos, of course, should be enlarged only along the cracks; and this had not yet been ascertained.]

• Pleochroic Halos

THE AGE OF THE EARTH

Joly, John; *Scientific Monthly,* 16:205-216, 1923.

I shall, however, now turn to the evidence of the pleochroic halo on this matter.

The halo affords a means of investigating certain facts respecting the break-up of the radio-active elements in the remote past. For the dimensions of the halo---minute though they be---can be determined with considerable accuracy, and these dimensions are conditioned by the added effects of the several alpha-rays emitted by the transmuting elements. Bragg and Kleeman observed and measured just such integral ionization effects in air. In the rocks the ionization curves, owing to the great stopping power of minerals, are on a scale 2,000 times as small. They are very faithful hieroglyphics, however, and carry back our knowledge over an appalling vista of time.

One single alpha-ray produces a well-known curve of ionization determined by Geiger. The range of the rays does not affect the general nature of the curve. If we imagine uranium or thorium as parent elements contained in a minute crystal---of zircon, for instance---we must picture the various alpha-rays affecting the surrounding substance---mica, we may suppose---in such a way as to build up concentric spherical shells more or less overlapping and corresponding to the radial distances at which the ionization of the several rays is at a maximum. As seen in section upon cleaved flakes of the mica, we find concentric colored rings representing the ionization due to the rays.

In order to arrive at the theoretical location of these rings we must add up the several ionization effects as observed in air. This involves assigning a Geiger curve to each ray according to its range and adding up the ordinates.

Let us consider first the case of the thorium halo. Fig. 1 [omitted] is a curve arrived at in the manner I have just described. Its ordinates are proportional to the integral ionization effects of those radioactive elements in the thorium series which emit alpha-rays. And above it I have marked, calculated into the range in air, the positions of the colored rings which in biotite we observe encircling a minute mineral particle containing thorium and all the successive products of its transmutation. This, of course, necessitates magnifying the halo enormously---rather more than 2,000 diameters. You perceive that the halo very faithfully conforms to the features of the air-curve. It may be of interest to mention that the finding of the third ring led to the discovery of the prominence on the curve which accounts for it. This part of the curve had originally been plotted from an insufficient number of ordinates. This close agreement really reveals a very important fact. The air-curve depends for its dimensions on the ranges of the several alpha-rays as we measure them to-day in the laboratory. The halo-measurements refer to radio-active effects which began their record in this mica in Carboniferous times---possibly long before. The halo reveals no sign of change in the several ranges concerned. As you are aware, the rate of break up, the transformation constant of the element, is related to the range. We are, therefore, in the case of the thorium family, entitled to read in these minute and ancient records a guarantee that the accumulation of the final product---the thorium isotopes of lead---was in the remote past affected at just such a rate as we have inferred from the splendid researches of our day. The thorium halo gives us this guarantee. It also tells us that it is improbable that the resulting lead is unstable. For if it were we must find room for rays additional to those we have used in deriving the ionization curve. True, a coincidence of range might enable a ray to lie concealed in the halo; but the fit of the halo is so absolutely faithful to every feature of the curve that this seems improbable.

It is also possible to observe the successive stages of development in thorium haloes. The first rings to appear are those corresponding to the two conspicuous crests of the curve, Fig. 1. If the central nucleus is small or feeble, nothing more may be developed.

We now turn to the uranium curve. The eight contributory ionization curves are placed according to the range of each ray, and Fig. 2 [omitted] shows the curve produced by adding up the ordinates. Above it are laid out the several rings observed in the uranium halo. Looking at these rings, we notice that the outer features of the halo seem in fair agreement with the present-day ranges. But the innermost ring has a larger radius than would be expected from the curve. Much care has been expended in varifying this point. In the Devonian mica of County Carlow these haloes are found in every stage of development according to the size or activity of the nucleus. The uranium halo begins as a single delicate ring surrounding the minute central nucleus. It can be measured from a stage bordering on invisibility to stage when its central area is beginning to darken up and the first shadowy signs of the outermost ring of all---that due solely to radium C---appear. A large number of readings on these embryonic haloes, made recently by various observers, confirm the mean value of its radius as cited in a paper communicated to the Royal Society in 1916. The discrepancy with the theoretic curve is small: 10 or 12 per cent. of the external radius. The allowance for, and measurement of, the nucleus is sufficiently difficult to introduce some uncertainty.

This misfit may be of considerable significance. I have already reminded you that the range of the alpha-ray emitted by a transforming element is related to its rate of break-up. The range is longer for the shorter-lived elements. Now, here the first ring of the uranium halo in mica shows a longer range than we would expect from the air-curve as observed to-day. The agreement between the two in other cases appears to show that this is not due to any unknown effect influencing the retardation in mica. The location of the first uranium ring is mainly referable to those short-range alpha-rays arising from the initial transformations of the uranium series. We infer that one or more of these rays must have had a longer range in past times, and, of course, that the corresponding transformation periods must have been shorter. A specially influential ray is that slowest of all the rays---that which is emitted in the break-up of uranium 1. The discrepancy might be due to this ray possessing a greater range in early geological times. But, whatever the cause, the nature of the misfit suggests evidently that formerly the rate of transformation of uranium to lead was faster than it is to-day.

It is with some reserve that I refer here to measurements made lately on haloes of comparatively recent and of very remote geological ages. I say "with reserve," for not only are the results of a nature calling for very adequate confirmation, but the measurements present considerable difficulty. The point at issue may be stated in a few words: Is the abnormality observed in the dimensions of the uranium halo dependent in amount upon the antiquity of the rock in which the halo is developed?

I had sought occasionally for uranium haloes in rocks younger than the Leinster granite---which is of early Devonian age. The granite of Mourne, which is of Eocene or early Tertiary age, for long refused to reveal any haloes suitable for measurement. However, recently I was so fortunate as to find a few of these early halo rings which I was able to measure. Further search has revealed a few more; but they are excessively scarce and rather difficult to detect. The nuclei of these haloes are only rarely zircon---they seem to be apatite; possibly allanite---and their average size is greater than the zircon nuclei of the Carlow mica. Both the mineral nature of the Mourne nuclei and their dimensions involve, therefore, a bigger subtractive correction on the observed radius than is required in the case of the Carlow haloes. But in addition to this, there appears to be a small difference in the external radius of the Eocene halo and that of the Devonian halo. According to a large number of readings by several observers, some of whom were not acquainted with the question at issue, the external radius of the Eocene halo-ring---no allowance being made for the nuclear radius---is 0.0135 mm. The same observers obtained for the Devonian halo 0.0146 mm.---without allowance for the nucleus. The nuclear correction, as I have said, would have increased the discrepancy, but the correction is a difficult one. There is no reason to believe that more than 1 per cent. of this difference can be ascribed to the chemical composition or density of the micas, both of which have been investigated.

Still more recently I have found these primary ring-haloes in the micas of Arendal and Ytterby, which are said to be of Archaean age, and which are certainly extremely ancient. These haloes appear to possess a radial dimension of 0.0160 mm., or a little less. Here, again, the nature of the mica does not appear to be responsible. According to these measurements it would appear that the radius of the Eocene halo-ring must be increased by about 7 per cent. to attain the size of the Devonian halo-ring, and that this is, in radial dimension about 10 per cent. smaller than the Archaean. It would seem as if we might determine a geological chronology on the dimension of these halo rings!

The foregoing results, if confirmed, would give strong support to the view that some factor, variable, over geological time, had affected the ranges and periods of certain elements concerned in building up the uranium halo. However, too much stress must not be placed on these measurements till they are confirmed by haloes in yet other micas. Pending further investigations, I return to the fact that the uranium halo of Devonian age does not conform to the ionization curve of the uranium family as determined on present-day measurements. Serious Discrepancy seems confined to the shorter ranges, more especially with that primary range which is most influential in determining the rate of production of uranium lead.

We do not appear to be in a position to deny the possibility that uranium 1 may have slowed down in its rate of decay over geological time. Such laboratory observations as can be extended to the case of short-lived elements would not, probably, shed any light on the matter. It is a possibility long ago suggested by Rutherford. But if this is the explanation we must admit that in the case of thorium any corresponding effect must have been much smaller. On the whole the former influence of one or more isotopes of uranium---which possibly may almost have disappeared---seems the more probable explanation. Hypothetical isotopes of uranium have been invoked by highly competent authorities to meet the difficulties affecting the ionization accounts of the uranium family of elements. Boltwood suggests as "not impossible" that what we now call uranium consists of three radio-elements: a parent element and two isotopic products all emitting alpha-rays. In 1917 A. Piccard put forward the view that the parent of actinium is a third isotope of uranium not belonging to the uranium family and having an atomic weight of 240. This view is regarded favorably by Soddy and Cranston. It clears up the difficulty respecting the atomic weight of uranium, and fits in with the atomic weights of radium and of uranium lead. Soddy and Cranston remark that in order to explain, in this case, the constant ratio of actinium to uranium observed in minerals we must suppose the period of uranium 1 and of the hypothetical isotope to be the same. This difficulty, however, is removed if we may assume that the ratio varied over geological time.

A somewhat similar theory to Piccard's may be invoked to explain the abnormality of the Devonian uranium halo. We have these facts to go on: The age indicated by uranium for Lower or Pre-Palaeozoic rocks is about four times too great as compared with the age indicated by thorium. We assume, therefore, that three fourths of the lead as measured in uranium minerals is derived from a certain isotope. This isotope, not having been detected in our time by its primary alpha-radiation, we must suppose to be now sensibly exhausted. We, therefore, have a known mass of this isotope transforming to lead in a known time---130×10^6 years. Assuming that only 1 per cent. of it is left we get its transformation constant (3.5×10^{-8}), and by Geiger and Nutall's relation we find the corresponding range as 2.6 cms. at $0^oC.$; or about 2.75 cms. at 15^o C. To-day the alpha-radiation of the hypothetical body would be only 1/1000 of that due to uranium 1, but during the period since the Devonian there will be about three alpha-rays from the short-lived isotope to one from the long-lived. The integral curve of ionization as modified by these hypothetical results would be in agreement with the Devonian halo. We have to assume that the ranges of the rays emitted by the successive disintegrating products of the supposed isotope were such as to leave the outer features of the halo sensibly undisturbed. This seems not improbable.

The salient features which appear in the study of radio-active haloes are: Firstly, that the agreement of our laboratory measurement of to-day with the features of the Palaeozoic thorium halo is such as to support the view that the periods of the several elements concerned in its genesis have remained unchanged over 130 millions of years. This fact, taken along with the stability of thorium lead, seems to render its reading of geological time authentic in a high degree. Its indications are confirmed by the consistent testimony of the denudative processes which have progressed on the earth's surface. Secondly, it appears that the uranium halo is not in conformity with the period we ascribe to-day to uranium--- a disagreement which is emphasized by the failure of uranium-time to conform with the united testimony of thorium-time and denudative-time; as well as by much that remains unexplained respecting the earlier changes in the uranium family elements.

The complete tale is not yet told, but I think the balance of probability is in favor of an age between 150 and 200 millions of years for the earliest advent of geological conditions upon the globe. (pp. 210-215)

RADIOHALOS IN COALIFIED WOOD.....

Gentry, Robert V., et al; *Science,* 194:316-318, 1976.

Abstract. The discovery of embryonic halos around uranium-rich sites that exhibit very high $^{238}U/^{206}Pb$ ratios suggests that uranium introduction may have occurred for more recently than previously supposed. The discovery of ^{210}Po halos derived from uranium daughters, some elliptical in shape, further suggests that uranium-daughter infiltration occurred prior to coalification when the radionuclide transport rate was relatively high and the matrix still plastically deformable.

[Gentry et al began by noting that while the biological fossil record has been documented extensively, the abundant record of fossil radiohalos is virtually undeciphered. Next, the various methods of analyzing the radiocenters are presented, with emphasis on the electron microprobe X-ray fluorescence (EMXRF) method. Much of the article is devoted to considering how wood might have been permeated by uranium-rich solution before coalification and how the process of coalification might have affected the formation of circular and elliptical halos. The authors' general conclusion is that the uranium-rich radiocenters were deposited before coalification and must be at least as old. The startling part of the evidence presented deals with EMXRF analysis of the $^{238}U/^{206}Pb$ ratios of the radiocenters. These turn out to be higher by at least two orders of magnitude than expected for coalified wood; that is, hardly any of the uranium has decayed to lead, and the coalified wood is seemingly much younger than the accepted geological age of the strata containing it, being perhaps thousands rather than millions of years old.]

Such extraordinary values admit the possibility that both the initial U infiltration and coalification could possibly have occurred within the past several thousand years. At the same time it may be argued that this view is quite improbable for there exists another explanation that could invalidate the association of the U/Pb ratios with the initial introduction of U. This explanation would admit that, although Po halos constitute evidence that U infiltration and hence U radiocenter formation occurred prior to coalification, some U may have been added or Pb may have been selectively removed, or both, by groundwater circulation after coalification. Hence variable U/Pb ratios would be expected, and the highest ratio would simply reflect the last time when U remobilization or Pb remobilization, or both, occurred. Although this hypothesis has been used to account for U disequilibrium in bulk specimens of U-impregnated Colorado Plateau material, there are some questions about its applicability here.

For example, if Pb was removed from the U sites, it must have been a very selective removal for both the EMXRF and IMMA results show that considerable quantities of Pb still remain in the nearby (within $\simeq 50\ \mu m$ of the U sites) Po halo Pb-Se inclusions. If Pb loss was minimal, then to explain the high $^{238}U/^{206}Pb$ ratios by remobilization requires that significant quantities of U were introduced into the U radiocenters quite recently. In any event, whether the hypothesis is U addition or Pb removal, the crucial point that seems quite difficult to explain under either assumption is the fact that, in general, the halos around U sites are embryonic. That is, since it seems clear that the U radiocenters formed during the initial introduction of U and if this were as long ago as the Triassic or Jurassic are generally thought to be, then there should be evident not only fully developed, but overexposed U halos as well.

Clearly, it was important to determine whether these phenomena were characteristic only of the U-rich Colorado Plateau coalified wood. We therefore initiated studies on coalified wood fragments which are occasionally found in the Chattanooga shale. Thus far only embryonic halos have been seen, and the $^{238}U/^{206}Pb$ ratios are much too high ($>10^3$) to correlate with the geological age of the formation (Devonian). The low U content of the Chattanooga shale (1 to 50 parts per million) makes it quite difficult to see how U remobilization could account for these very high isotope ratios. Thus the evidence does not appear to support the remobilization hypothesis as a general explanation of these unusual $^{238}U/^{206}Pb$ ratios in either the Colorado Plateau or Chattanooga shale specimens.

If remobilization is not the explanation, then these ratios raise some crucial questions about the validity of present concepts regarding the antiquity of these geological formations and about the time required for coalification.

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RADIOHALOS IN COALIFIED WOOD: NEW EVIDENCE FOR A YOUNG EARTH

Connor, Steven J.; *Creation Research Society Quarterly,* 14:101-102, 1977.

Since the turn of the century, radiohalos have intrigued geochemists and mineralogists. Lately, however, the halos have attracted the attention of nuclear researchers, geochronologists, and cosmologists throughout the world because of their important bearing on nuclear science and on the age of the earth. More specifically, the recent discovery of radiohalos in coalified wood has raised questions regarding the very foundations of geological science. Creationists should understand the radiohalo phenomenon and the implications pertinent to their unique scientific philosophy. Although a complete review of radiohalos will be reserved for a later article, some general background will be given here.

Radiohalos, occurring in over 40 types of minerals, are microscopic spheres of discoloration centered around a tiny radioactive inclusion. Viewed in thin section, they usually appear to be perfectly circular discs or concentric rings with a speck of rock in the center. The discoloration of the host rock is caused by alpha radioactivity emitted by the inclusion. The radii of the rings are related to the energies of the alpha radioactivity and are thus identifiers of the emitting radionuclides.

Radiohalos occur in many varieties, but the best known are those due to the uranium and thorium series. U^{235}, being in such low abundance, does not produce a corresponding actinide series halo. Several other unusual but important varieties have been discovered and are discussed quite thoroughly by Gentry.[1-4] Of special significance is the polonium halo which has been established as a distinct halo type apart from the uranium halo.[5-6] The polonium halo in rocks is considered by some to provide evidence for divine, fiat, creation.[7]

In coalified wood from the Colorado Plateau, both uranium and polonium halos are abundant. The halos are thought to have formed after uprooted trees, subsequently infiltrated by a uranium-rich solution, preferentially absorbed alpha radioactive nuclides into minute sites that were later to become the radiohalo inclusions (radiocenters).[8-10] This type of origin for radiohalos is, so far, unique to coalified wood, and in fact, has been ruled out for other types of minerals.[11]

Three Specific Facts Explained. There are three facts about radiohalos in coalified wood that are readily apparent upon optical examination. First, the uranium halos are generally embryonic;[10] that is, they are missing rings from the final stages of their development. Most of the U halos are missing the 7.69 meV Po^{214} ring. Second, the Po halos are all of the Po^{210} type (possible 2 or 3 questionable exceptions).[10] Third, the Po^{210} halos occur in three subvarieties: a. the normal circular disc, b. an unusual elliptical disc, c. a very unusual combination of the elliptical disc superimposed on a circular disc.[8-10]

The first fact can be understood by either of two possible explanations. Either the radiocenters contained little uranium to start with, and/or there has been insufficient time for the full uranium halo to develop. Electron microprobe X-ray fluorescence (EMXRF) analyses of the inclusions showed high concentrations of uranium with little or no lead,[10] the final daughter product of uranium decay. Ion microprobe mass spectrometer (IMMA) analyses showed U^{238}/Pb^{206} ratios to be variable but extremely high.[10] Since the U^{238}/Pb^{206} ratio is used as an age indicator, then quantitatively as well as qualitatively, it appears that there has been only a short time since introduction of uranium into the wood.

The second fact can be considered supportitive evidence for the preferential accumulation hypothesis for the halo origin. Both Po^{210}($t_{1/2}$ = 138 days) and its beta decaying precursor, Pb^{210} ($t_{1/2}$ = 22 years), are chemically suitable to be preferentially accumulated into the inclusions (composed mostly of Pb and Se), and their half lives are sufficiently long to be able to accumulate appreciable concentrations. However Po^{214} ($t_{1/2}$ = 164 microseconds) and Po^{218} ($t_{1/2}$ = 3 minutes) have half lives too short to accumulate in an inclusion before decaying. The same is true of Po^{214}'s beta precursors. Po^{218} has no beta precursor.

It can be concluded from the third fact that this U and Po infiltration occurred before complete coalification of the wood. The elliptical halos can be understood by assuming plastic deformation of the wood sometime after initial radioactive infiltration but before complete coalification. According to this model of origin,[10] development of a spherical halo could be predicted in 0.5 to 1 year from the accumulated Po^{210} atoms and a second concentric spherical halo in 22 to 50 years as the Pb^{210} atoms slowly beta decay to Po^{210} and then alpha decay to Pb^{206}. Obviously a properly timed tectonic event could deform the wood, producing the dual spherical-elliptical halos.

Radiohalos: Challenge to Geologists. The discovery of radiohalos in coalified wood has challenged the foundations of geological science. How is this so? First, it is interesting to note that the coalified wood was taken from Jurassic and Triassic formations in the Colorado Plateau. However the embryonic structure of the U halos combined with the EMXRF and IMMA analyses suggests that the halos may be only a few thousand years old.

If the infiltration of uranium occurred before complete coalification, then the coalified wood could not be any older. Also the time required for the coalification process must be considerably shorter than what is generally believed today.

Also, from the elliptical halos it follows that infiltration occurred before complete coalification. Thus here is a geologically "old" formation (by uniformitarian viewpoint) that apparently is only a few thousand years old. This is not just a local anomaly. Embryonic U halos have also been found in Devonian Chattanooga shale with U^{238}/Pb^{206} ratios too high for the accepted age of the formation.[10]

In conclusion, while exact ages are not here assigned to the formations in which the coalified wood[10] occurs, evidence has been presented which would chronologically place these formations at the time of the Flood several thousand years ago. The use of estimates of age from radioactivity can be justified in this particular case, since there seems to be no Scriptural evidence suggesting that the Creator has intervened on a global scale to produce perturbations in normal physical processes since the Flood.

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IMPLICATIONS ON UNKNOWN RADIOACTIVITY OF GIANT AND DWARF HALOES IN SCANDANAVIAN ROCKS

Gentry, R. V., et al; *Nature,* 274:457-459, 1978.

Giant haloes attracted little attention until it seemed that those from Madagascar might be associated with superheavy elements. Even though this association was not confirmed, this renewed interest has generated several additional suggestions for giant-halo origin which will be evaluated elsewhere (R. V.G. et al. in preparation). We report here some new data on the giant haloes found in certain Swedish biotites and the implications which these data furnish for a radioactive origin of the enigmatic dwarf haloes.

The majority of U and Th haloes in this Swedish biotite exhibit darkening which extends to the maximum halo radius ($\sim$38-40 μm for the Th halo). About 1% of haloes, however, have an inner bleached region which varies from $\sim$2 to 25 μm in radius surrounding a highly radioactive inclusion. Generally, when the bleached region is small ($\lesssim$ 6-8 μm), no change is evident in the dimensions of the halo. However, in those haloes in which the bleached region is more intense and of larger radius ($\sim$15 μm), a somewhat weakly coloured diffuse ring is generally observed outside the normal U-Th halo boundary.

These are the giant haloes which, because they were earlier reported to surround only dense Th haloes, were tentatively attributed to the low abundance, high energy αs from ^{212}Po in the ^{232}Th series. However, we now report that diffuse, abnormally large rings also surround dense

U haloes in this biotite, and as there are no high energy αs of any significant abundance in the ^{238}U chain, we therefore consider this hypothesis untenable. Instead, we are exploring the possibility that these bleached interior regions are somehow associated with the formation of the giant haloes.

Even though these giant haloes were found in Swedish granites obtained from the same location as the specimens Wiman used, the giant haloes described here are different from those he reported. Our giant haloes surround U and/or Th rich inclusions and have diffuse boundaries which may vary from ~42 to ~55 μm in radius. In contrast, Wiman reported giant haloes in biotite around zircon inclusions showing normal size inner rings and somewhat weak but rather sharply defined outer rings of 57 μm and more rarely of 67 μm. [Analysis omitted]

POLONIUM HALOS AND GEOCHRONOLOGY

York, Derek; *EOS*, 60:617-618, 1979.

[Derek York first describes the discovery of pleochroic halos by Joly in 1907 and proceeds to the work of G. H. Henderson in the 1930s. Henderson noted that halos apparently derived from polonium were not associated with uranium rings and required a special explanation.]

Since there are no uranium rings associated with Po halos, then the Po must have been separated from its supporting ancestors when it was being concentrated into the tiny volume which was to become the halo center. Since, as we have just seen, Po isotopes decay almost at the same moment as they are removed from their longer-lived ancestors, only a very limited number of separation and concentration processes may be envisaged. In fact, the second of Henderson's Royal Society papers was devoted to the elaboration of what seems to me to be the most probable explanation of these interesting halos.

In his discussion, Henderson emphasized one extremely important aspect about the mode of occurrence of Po halos. Henderson and Sparks observed that while many Po halos occur with their central nuclei randomly located within the cleavage planes of micas, many others are strung together along obvious channels of microconduits in the cleavage planes. Here was the clue. Evidently, said Henderson, at some unknown time after crystallization, uranium-bearing hydrothermal solutions had been moving slowly through the rocks, penetrating and flowing through the tiny conduits. In these solutions, the uranium was supposed to be in equilibrium with its daughter products. That is, in particular, Po isotopes would also be present in solution. Suppose that at various points along such channels the chemical conditions were such that Po would precipitate from solution but α-emitting earlier members of the uranium chain would not. Then pointlike accumulations of Po would start to build up at these nuclei. The precipitated Po would almost immediately decay and halo formation would have begun. Meanwhile, more Po would precipitate from solution at these Po centers and a halo would eventually be produced. Henderson discussed the details of this process in terms of order of magnitude of flow rates and concentrations. To explain the Po halos of random occurrence, one merely had to postulate that the solutions permeated the micas along whole cleavage planes, not solely along channels.

If these halos are in fact produced by Po isotopes, then Henderson's theory, or some version of it, seems to me to be very probably correct. Henderson, however, might have taken another tack. He could have said: Given the extremely short Po half-lives involved, I see no reasonable way of isolating Po from U and concentrating it into embryonic halo nuclei. Therefore, I call into serious question all of our concepts of time and our understanding of the laws of radioactivity. This, of course, would have meant a revolution in our understanding of physics perhaps more radical than that brought about by Einstein. Henderson, not surprisingly, did not propose such an absurd interpretation, based as it would have been on one isolated type of observation, when the accepted theories were based on a vast amount of information from a wealth of divergent fields.

Now Henderson's theory may not turn out to be correct. However, there is no doubt that he took the right philosophical step. From about 1950 onward, other radiometric dating procedures have been developed. For geology, the most important of these have been the K-Ar, Rb-Sr, and U-Pb methods. The widely differing radioactivities involved here are those of ^{40}K, ^{87}Rb, ^{238}U, and ^{235}U. These greatly differing systems, with distinct half-lives and varying responses to metamorphisms, have been brought to a remarkable state of development over the past 30 years. With them, it has proved possible to build up a coherent picture of the earth, the moon, and the meteorites as having been formed approximately 4-1/2 b.y. ago. A consistent time scale for the evolution of the moon and the earth has been developed. We now know that continental rocks were forming on earth at least 3.8 b.y. ago in Greenland and North America. We know that the biological evolution so well-documented by generations of paleontologists largely took place in the past 600 m.y. although extremely primitive life probably existed on earth over 3 b.y. ago. We now understand that the continents have been drifting slowly, at a few centimeters per year, over the surface of the globe for at least the past 200 m.y. We have a precise time scale for the reversals of polarity of the earth's magnetic field. Many more things have been established about the earth's history. And the time scale of it all has evolved in an internally consistent way principally from the study of these three radioactive systems. Within the past 15 years, the fossil-fission method of dating, based on the ever-so-slow spontaneous fission of ^{238}U, has been added to the geochronologist's armory. Results from it are consistent with the three major techniques. When we turn to the dating of very recent events, the ^{14}C, U disequilibrium, and thermoluminescence methods all fit in with our current conceptions of earth history. All of these results show that Henderson was correct in principle in accepting the current laws of radioactivity and looking for an explanation of the existence of Po halos within the context of what was then known of the time scale of earth history. Everything that has been discovered since, from the study of radioactivity in rocks, has served to justify Henderson's strategy. Because of its transparently obvious usefulness, geochronology based on radioactivity has now become a key part of general earth science. It is being practiced and developed in many countries by hundreds of scientists.

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• Discordant Isotopic Dates

DO RADIOLOGICAL "CLOCKS" NEED REPAIR?

Cook, Melvin A.; *Creation Research Society Quarterly*, 5:69-77, 1968.

Abstract. Radiocarbon dating is based on the incorrect assumption that C-14 is in equilibrium, the rate of formation equaling the rate of decay. But recent data show rate of formation is 18.4 and rate of decay 13.3 so that a non-equilibrium condition exists. This situation telescopes all radiocarbon ages to about 10,000 years or less. Consideration of uranium-thorium-lead age determinations show at least six basic difficulties involved in determining true age. Most serious is evidence for artificial aging by the so-called "neutron-gamma" reactions. A number of crucial examples are given. Thus the uranium ore at Shinkolobwe, Katanga contains no thorium or common lead, but .08% Pb-208! If it came from "neutron-gamma" reactions, the likely explanation of this ore, it is a modern ore, far younger than the assigned 640 million year old age of conventional dating!

Potassium-argon dating does not take into account the relatively great amount of argon-40, branching ratio data, and uncertain half-life of some isotopes. Pure guess work is required to establish the actual concentrations of the isotopes involved in the rubidium-strontium "time clock" at the beginning of a particular mineral.

An extensive discussion of radiocarbon dating in relation to a global sea level cycle is given. Also dates of various civilizations based on a equilibrium radiocarbon model are shown to be seriously older than reality.

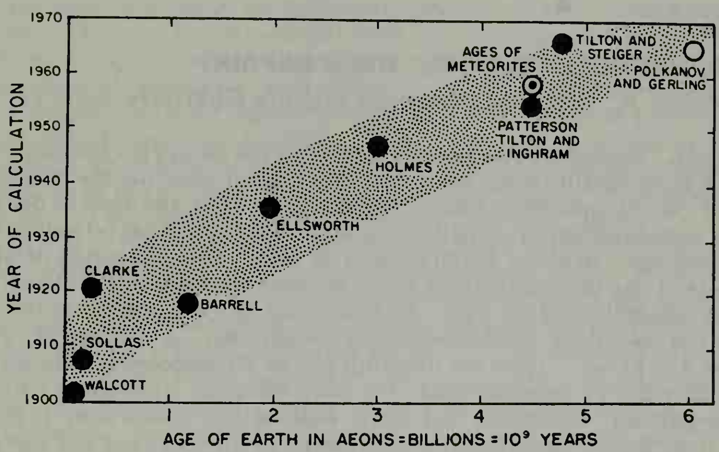
THE RAPIDLY AGING EARTH

Anonymous; *Sky and Telescope*, 39:223, 1970.

The calculated age of the earth has increased by a factor of about 100 since 1900, the accepted "age" being 50 million years then and at least 4.6 billion years now. A. E. J. Engel of Scripps Institution of Oceanography illustrates this point with the accompanying graph in his article "Time and the Earth," in American Scientist for Winter, 1969. He comments:

> Each of the earlier calculations, indicated by the cluster of points in the lower left, was remarkably precocious at the time it was made. Each was widely debated, and then accepted in the scientific community. All are almost surely wrong. The cluster of points of the upper right reflects the tumultuous but necessary wedding of classical geology and a chronology of the earth based on radioactivity. These are the so-called radiometric or 'absolute' ages of the earth that

have been determined by studies of the decay products, decay rates, and amounts of the radioactive nuclides, especially potassium, rubidium, uranium, and lead in crustal rocks and meteorites.



A. E. J. Engel's chart of estimates of the earth's age plotted by year of publication.

ANOMALOUS URANIUM-LEAD AGES

Kulp, J. L., and Eckelmann, W. R.; *Geological Society of America, Bulletin,* 66:767-768, 1955.

In principle, the time of formation of a uranium mineral can be determined from one of the following isotopic ratios: Pb^{206}/U^{238}, Pb^{207}/U^{235}, or Pb^{207}/Pb^{206}. Since these ratios are affected in differing degrees and direction by various errors in measurement or geological alteration, the concurrence of ages obtained from these three ratios suggests a true absolute age. Actually for a large fraction of the mineral samples on which these ratios have been measured, the three isotopic ages do not agree. Since the uranium-lead decay is the primary basis of the absolute geological time scale, and since it has been used to calibrate other methods, it is important to understand these anomalies.

In a recent paper, Kulp, Bate, and Broecker attempted to evaluate the factors that would produce the anomalous ages. It was concluded that uncertainties in the chemical and isotopic analyses and the physical constants were not a significant source of error. Except in the rare cases where the concentration of common lead in the total lead of a sample becomes large, the error in the correction for common lead is trivial. Radon leakage ranges from 0.01 per cent to 5 per cent in most minerals causing the 206/238 age to be low by this proportion for all minerals (i.e., <600 million years). For minerals older than 1000 million years the correction on the 207/206 age for radon leakage is generally unimportant. Five of about 50 samples for which uranium-lead ages have been published show the effect of recent oxidation and leaching. In these cases the 206/238 and 207/235 ages are higher than the 207/206 ages as expected for uranium removal. After a consideration of all these factors, many of the anomalous ages remain unexplained.

A single process that might produce the observed ages is that of the removal of lead from the uranium minerals at a time or times of recrystallization. Presumably this must occur at somewhat elevated temperatures and pressures in a neutral or reducing environment.

Table 1.---Representative Lake Athabasca Pitchblende Ages (Age in million years)*

Sample**	206/238	207/235	207/206
K-44	1315	1550	1860
K-45	1282	1490	1780
K-30	1005	1255	1650
K-53	220	395	1585
K-34	778	920	1300
K-48	254	321	820

* Probable errors caused by chemical and isotopic analysis are 1-2 per cent of the age increasing toward the younger samples.

** These samples are representative of the spread obtained in 24 samples.

Thermodynamically such removal is predicted since the lead ion does not fit in the uraninite lattice, but the rate of removal is apparently negligible at room temperature since specimens from some localities do not show this effect.

An unusual opportunity to study this hypothesis was presented by Dr. S. C. Robinson, Geological Survey of Canada, who submitted about 30 specimens of pitchblende and lead minerals from the Lake Athabasca cranium district. As can be seen from the representative samples of Table 1, a large spread in the apparent ages is obtained from the pitchblendes. The variation among samples from a single mine is as large as occurs in the entire district. These variations cannot be explained either by radon leakage or by the uncertainty of the isotopic composition of the lead in lead minerals which are intimately mixed with the pitchblende, since the leakage and the lead-mineral concentration are consistently small. The radiogenic-lead component of the lead minerals which are associated with the pitchblende appears to represent at least two distinct lead isotopic compositions (207/206 = 0.12 and 0.17) indicative of two periods of lead exsolution. If a single period of uranium deposition is involved, it must have occurred more than 1860 million years ago (Sample K-44), but less than 2000 million years ago. The upper limit is established by the 207/206 ratio of 0.12 for exsolved radiogenic lead. Also the last period of lead removal must have occurred less than 200 million years ago (Sample K-53).

Analysis of the data for all samples of the district indicates that the true age is 1900 ± 40 million years and that there must have been more than one period of lead exsolution. If there were only two periods of lead removal corresponding roughly to 150 ± 50 million years and 1200 ± 100 million years, all the apparent ages on all samples can be explained. This does not prove, however, that there were only two periods. Analyses of the Pb^{210} in these minerals show it to be in equilibrium with the U^{238}. Thus alteration is not occurring at present.

It is concluded that detailed study of the uranium and lead isotopic content of a district may make it possible to evaluate the time of deposition despite successive alterations. Further, some idea of the time or times of lead removal (thermal metamorphism?) may be obtained from the isotopic ratios. Except for young minerals, the 207/206 ratio gives a closer approximation to the true age than does the 206/238 and 207/235 ratios but remains a minimum. In extreme cases the 207/206 age may be less than half the true age. In general the 207/206 age can be assumed to be correct if accompanied by concurrent 206/238 and 207/235 ages.

The process of lead removal during the life of a radioactive mineral appears to be rather common particularly among the older samples. This concept is most useful in interpreting the earlier uranium-lead age determinations which have yielded anomalous results.

THE RELIABILITY OF HE/U DATES ON CORALS

Bender, Michael L.; *EOS*, 52:366, 1971.

Abstract. He/U ages were obtained on forty-five independently dated Cenozoic corals as an empirical test of the method. Three Eocene samples from Alabama give ambiguous results. Ten upper lower Miocene samples from the Chipola formation (Fla.) give concordant ages of 14-18 MYR. Eight Neogene samples from Florida give He/U ages which are internally consistent and in agreement with stratigraphic ages. Seven samples from the 82,000 and 124,000 year reefs of Barbados all have slightly more ($.5 \pm .3 \times 10^{-8}$scc) than the expected amounts of He^4; this excess probably comes from a small amount of detritus in the samples. On the other hand, samples from the Miocene of Eniwetok give internally inconsistent radiometric ages. The high values of Rn^{222} loss ($\leq 10\%$) observed for some Eniwetok samples suggest that the cause of these incorrect ages is anomalous disequilibrium of the U^{238} daughters. In summary, this work indicates that He/U ages on unrecrystallized corals are close to the true ages, provided that U^{234}/U^{238} and Th^{230}/U^{234} ratios are concordant, that the samples show low levels ($< 5\%$) of Rn^{222} leakage, that a correction is made for inherited He^4, and that a correction is made for alpha particles shot out of the coral.

ANCIENT SHELLS TEST OLDER THAN CHARCOAL

Anonymous; *Science News Letter*, 62:280, 1952.

Shells from ancient seashore places of human living give evidence of being a couple of thousand years older than charcoal of campfires analyzed by the same radiocarbon dating method.

Scientists are puzzling out this discrepancy because they believe that shells and charcoal are really the same age.

Because radioactive carbon 14 is being constantly formed in the high upper atmosphere by cosmic ray bombardment of nitrogen, a convenient method of dating organic or carbon-containing materials was discovered a few years ago. Materials up to 30,000 years old can have their ages determined with an accuracy of several hundred years.

The radiocarbon dating investigators of Columbia University's Lamont Geological Observatory at Palisades, N.Y., have run determinations on archaeological samples from Peru, California, Japan and the Aleutions and found that shells there have lower amounts of radiocarbon, which means that their carbon is more ancient.

About a year ago Dr. J. Laurence Kulp, leader of this group, found that deep ocean water is about 1,700 years old, thanks to extremely slow oceanic circulation from the arctic regions. His explanation of the seemingly older shells is that they were formed in coastal areas with abrupt, deep troughs offshore. They seem to be old because they were made with ancient water from the ocean depths.

In the Columbia group reporting in Science (Oct. 17) are, besides Dr. Kulp, Lansing E. Tryon, Walter R. Eckelman, and William A. Snell.

DISCORDANT RADIOMETRIC AGES FROM METAMORPHOSED BELT-SERIES SEDIMENTS, NORTHERN IDAHO

Hofman, A.; *EOS,* 53:543, 1972.

Abstract. Whole-rock Rb-Sr ages and mica K-Ar and Rb-Sr ages have been measured as part of a study on the effect of regional metamorphism on radiometric clocks in pelitic schists. The Beltian sediments north of the Idaho batholith were chosen because of the long time span ($\gtrsim$1000 m.y.) between deposition and final metamorphism and because of the wide range of metamorphic conditions. Six individual layers (1-6 cm wide) from a slab of a two mica gneiss (sillimanite zone) form a Rb-Sr isochron of 64 m.y. The initial Sr^{87}/Sr^{86} ratio of 0.816 is consistent with a nearly isochemical metamorphism. On a regional scale, the whole rock Rb-Sr data do not yield an isochron. K-Ar ages of micas are higher than the Rb-Sr ages in each metamorphic zone. The most highly discordant biotite has apparent ages of 43 m.y. (Rb-Sr) and 1750 m.y. (K-Ar). The excess radiogenic argon must have been introduced during final cooling 43 m.y. ago. The mica Rb-Sr ages range from 43 to 64 m.y. in the sillimanite, kyanite, and staurolite zones and increase to about 420 m.y. in the biotite zone. The lower age limit corresponds to the age of the last intrusive phase of the batholith. The high values in the low-grade zones may be partially reset ages of older metamorphic biotites or they may be excess ages due to direct transfer of radiogenic Sr from a parent phase such as glauconite into the crystallizing biotite.

ANCIENT LITHOSPHERE: ITS ROLE IN YOUNG CONTINENTAL VOLCANISM

Brooks, C., et al; *Science,* 193:1086-1094, 1976.

[In this rather lengthy article, we find first a description of an interesting anomaly encountered in the radioactive dating of obviously young volcanic material. The authors then explain how this anomaly may have been caused by magma rising through ancient rock and picking up some of it. The following excerpt summarizes it all nicely and makes one even more cautious about accepting radioactive dating as the final word in any geological (or archeological) situation.]

An important but commonly overlooked isotopic property of volcanic rock is that they often show Sr isotopic compositions that correlate with Rb/Sr ratios to form pseudoisochrons which give ages grossly in excess of the true age of volcanism. It is our contention that these pseudoisochrons are a key to the understanding of mantle processes both in continental and oceanic regions, and that for the former they furnish evidence for the participation of ancient lithosphere in continental magmatism. The high and variable $^{87}Sr/^{86}Sr$ ratios are, following this contention, the direct result of (i) large-scale "primary" heterogeneities frozen into the ancient lithosphere and (ii) small-scale "secondary" heterogeneities resulting from dis equilibrium accumulation of radiogenic daughter products in mineral phases guarded at subsolidus temperatures throughout their existence. We believe that the pseudoisochrons contain significant age information and are in reality mantle isochrons. It is the purpose of this article to elucidate this precept, and show that Sr isotopic study of young mafic volcanics provides windows through which the chronologic evolution of subcontinental mantle can be viewed, and regional variations mapped.

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DEEP-OCEAN BASALTS: INERT GAS CONTENT AND UNCERTAINTIES IN AGE DATING

Noble, C. S., and Naughton, J. J.; *Science*, 162:265-266, 1968.

Abstract. The radiogenic argon and helium contents of three basalts erupted into the deep ocean from an active volcano (Kilauea) have been measured. Ages calculated from these measurements increase with sample depth up to 22 million years for lavas deduced to be recent. Caution is urged in applying dates from deep-ocean basalts in studies on ocean-floor spreading.

Chapter 7

GEOLOGICAL MYTHS AND LEGENDS

INTRODUCTION

Scientists generally put little stock in legends and myths. Surely time and errors of retelling have distorted these ancient tales beyond any hope of scientific utility. The reader should therefore regard the following entries with great caution, expecting amusement on one hand and possibly a few geological clues on the other.

GEOLOGICAL MYTHS

Emerson, B. K.; *Science,* 4:328-344, 1896.

The Chimaera. In Lycia is a remarkable region, which the inhabitants call Ephestion. The ground is perforated in many places; a fire plays harmlessly without any injury to growing things. It is a pleasant region, therefore, and woody, nothing being injured by the flames.

Strabo says, simply: "The neighborhood of these mountains is the scene of the fable of the Chimaera, and at no great distance is Chimaera, a sort of ravine, which extends upward from the shore." And Pliny, with his accustomed mingling of truth and fiction, says: '---et ipsa (Chimaera saepe flagrantibus jugis' (and Chimaera itself with its flaming peaks). And again: "Flagrat in Phaselide Mons Chimaera et quidem immortali diebus ac noctibus flamma." (Mount Chimaera burns in Phasilis with a certain immortal flame shining by day and by night.) Also: "In the same country of Syria the mountains of Hephaestius, when touched with a flaming torch, burn so violently that even the stones in the river and the sand burn while actually in the water. This fire is also increased by rain. If a person make furrows in the ground with a stick which has been kindled at this fire, it is said that a stream of flame will follow it."

....

And thus the matter rested until, in the end of the last century, Admiral Beaufort, while anchored off Lycia on hydrographic work, saw each night a strong flame on the peak of a mountain a few miles back from the coast, and was told by the inhabitants that it had always burned there.

He visited the place, and found flames of natural gas issuing from a crevice on a mountain of serpentine and limestone.

In 1842 Spratt and Forbes report as follows on the locality: Near Ardrachan, not far from the ruins of Olympus, a number of serpentine hills rise among the limestones, and some of them bear up masses of that rock. At the junction of one of these masses of scaglia with the serpentine is the Yanar (or Yanardagh), famous as the Chimaera of the ancients, rediscovered in modern times by Captain Beaufort. It is nothing more than a stream of inflammable gas issuing from a crevice, such as is seen in several places among the Apennines. The serpentine immediately around the flame is burned and ashy, but this is only for a foot or two; the immediate neighborhood of the Yanar presenting the same aspect it wore in the days of Seneca, who writes "Laeta itaque regio est et herbida, nil flammis adurentibus."

Such is the Chimaera, 'flammisque armata Chimaera,' deprived of all its terrors. It is still, however, visited as a lion by both Greeks and Turks, who make use of its classic flames to cook kabobs for their dinner.

In 1854 it was visited by the Prussian painter, Berg, who has reproduced the scene in a fine painting now in Berlin. The flame which he says, gives the odor of iodine, is three or four feet high. Several extinct openings were found in a pool of sulphurous water.

The Austrian geologist, Tietze, found the flame two feet across, and a smaller one adjacent. The ruins of an ancient temple of Vulcan, near by and of a late Byzantine church, show how strongly it has impressed the inhabitants in all ages.

The natural phenomenon of a spring which is found by historic documents to have been burning for nearly three thousand years is sufficiently striking, although the slow escape of such gas from Tertiary limestones is not uncommon. The mention of sulphurous waters in the neighborhood may justify us in going back to the same antiquity and drawing from the remark of Theophrastus on the oxidation of pyrite in contact with bitumen, an explanation of the constant ignition of the gas.

Theophrastus says: "That, also, which is called Epinus (or Spelus) is found in mines. This stone cut in pieces and thrown together in a heap exposed to the sun, burns, and that the more if moistened or sprinkled with water."

We may of course assume the more prosaic spontaneous combustion of the volatile hydrocarbons to explain the constant rekindling of the sacred fires.

It remains to consider how the myth and its name arose. The mountain is still called Yanar-dagh, the burning mountain, and in a learned work on coins of Sicyon, which reproduces the Chimaera, M. Streber derives the name from the Phoenician word Chamirah, which means the burning mountain.

But the Greek word χίμαιρα means a goat, and has almost the same sound, and we can see clearly how, as the Greek settlements spread over Lycia, from the north, the meaningless Phoenician names were retained like the Indian names in America, and how the story slowly went back to the fatherland---et crescit eundo---of a strange mountain called Chamira, from which portentous flames escaped, and then of a monster Chimaera, of goat-like form, vomiting flames and ravaging in the mountains of woody Lycia. And so the story was finally fitted for the manipulation of the poets, who little thought they were making the stout Bellerophon run a quixotic tilt against a burning gas well.

The Niobe. Like the Chimaera, the Niobe is an episode in Greek mythology, easily separated from the rest without disturbing the Greek Pantheon. I do not need to describe the great group of the Niobe, the mother weeping over her children, who fall before the shafts of Apollo, which adorns the gallery of the Uffizi at Florence, and forms one of the masterpieces of Greek sculpture, the glory of Scopas or Praxiteles. I do not need to recall the story as told by Homer, how Niobe, the daughter of Tantalus, proud of her twelve children, despised Latona, who had but two; how, therefore, Phoebus and Artemis slew all the twelve with their arrows:

"They lay unburied on the plain for nine days, when Zeus changed them to stone, and on the tenth day the heavenly gods buried them. And now, upon arid Sipylus, upon the rocks of the desert mountain, where, they say, are the couches of the divine nymphs, who dance upon the banks of Achelous, Niobe, though turned to stone, still broods over the sorrow the gods have sent upon her."

And Ovid says:

> "She weeps still, and borne by the hurricane of a mighty wind,
> She is swept to her home, there fastened to the cliff of the mount,
> She weeps, and the marble sheds tears yet even now."

As one climbs from the Gulf of Smyrna, between Mount Tmolus and Sipylus, up the rich valley of the Nif, or Nymphio, there appears, high up in the vertical wall of limestone, the colossal bust of a woman standing on a high pedestal and in a deep alcove. It is cut out of the living rock, like the Swiss lion at Lucerne.

A recess twenty-five feet high and sixteen feet wide has been cut in the rock for the lower part, and a smaller alcove of much greater depth surrounds the bust itself. All the face of the rock around is smoothed, and a broad ledge is cut around the pedestal to receive the offerings of the ancient Phoenician worshippers of this almost prehistoric statue of the great Mother Cybele, or of Meter Sipylene; gods of the Phoenicians.

From the valley below it makes the impression of a full-length statue with flowing robes, but near at hand the robes are seen to be the very tears of Niobe, formed where the drip of the waters from the limestone roof of the alcove has first struck her cheeks, and running down across her breast has made rippling surfaces of bluish tufa, which has all the effect of tears.

The statue had been greatly corroded, and the stalagmite tears had formed already in the days of Pausanias, who says: "When standing close to it the rocks and precipice do not show to the beholder the form of a woman, weeping or otherwise, but if you stand farther back, you think you see a woman weeping and sad."

And even in the times of Homer the memory of the earlier and vanished worshippers was at best a dim tradition, and the facile imagination of the Greeks had built up the whole beautiful legend, every element of the surrounding scenery adding its portion of suggestion, and it is marvellous how all parts of the story still linger in the valley.

. . . .

Lot's Wife. Looking down on that most marvellous of all lakes---the Dead Sea, the Lacus Asphaltites of the Romans---the sea of Lot of the Arabs, still stands the great column of salt into which Lot's wife was changed.

"She was changed into a pillar of salt," says Josephus, "for I have seen it, and it remains to this day."

And Irenaeus explains how it came to last so long with all its members entire, because "when one was dissolved it was renewed by miracle." It was, in fact, the geological miracle of erosion.

The column looks down from the plain of Sodom, and on the great southern bay of the sea, ten miles square, and but one or two feet deep, where sulphur, deposited by many hot springs, is abundant in the clay, and where bitumen oozes from every crevice of the rock, and every earthquake dislodges great sheets of it from the bottom of the lake, where the Arabs still dig pits for the 'stone of Moses' to gather in, and sell it in Jerusalem, and where, in that most ancient fragment of the Pentateuch, four kings fought against five, and the kings of Sodom and Gomorrah slipped in the slime-pits and fell. One who has read of the burning of an oil well or Oil Creek, or in Apscheron will have a clear idea of the catastrophe which overtook the cities of the plain where the Lord rained upon Sodom and upon Gomorrah brimstone and fire out of Heaven.

Following the latest extremely interesting researches of Blankenkorn, we may picture the upper cretaceous plateau of Judea---an old land, cleft at the end of the Tertiary by many faults, between which a great block sank to form the bottom of this deep sea. It carried down in the fossiliferous and gypsum-bearing beds the source of the bitumen and the sulphur. We may picture the waters standing much higher than now during the pluvial period, which matched the northern glacial period, rising nearly to the level of the Red Sea, but never joining it. In the succeeding arid interglacial period, the time of the steppe fauna in Europe, the sea shrank to within a hundred meters of its present level, and deposited the great bed of rock salt which underlies the low plateaus around its southern end. The advent of the second glacial period was here the advent of a second pluvial period, which swelled the waters and carried the bitumen-cemented conglomerates over the salt beds to complete the low plateau. After the second arid period with some lava flows, and a third pluvial period with the formation of a lower and broader terrace, the waters shrank to the present saturated bitterns in the present arid period. In the earlier portion of this last or post-glacial stadium, a final sinking of a fraction of the bottom of the trough, near the south end of the lake, dissected the low salt plateau, sinking its central parts beneath the salt waters, while fragments remain buttressed against the great walls of the trench forming the plains of Djebel Usdum and the peninsula El Lisan, with the swampy Sebcha between. Imagine a central portion of one of the low plains which extend south from the 'Finger Lakes' to sink, submerging Ithaca or Havana in a shallow extension of the lake waters. It exposed the wonderful eastern wall of Dijebel Usdum, seven miles long, with 30–45 m. of clear blue salt at the base, capped by 125–140 m. of gypsum-bearing marls impregnated with sulphur, and conglomerates at times cemented by bitumen. It was this or some similar and later sinking of the ground, at the time when geology and history join, which, with its earthquakes, overthrew the cities of the plain and caused the outpour of petroleum from the many fault fissures and the escape of great volumes of sulphurous and gaseous emanations, which, ignited either spontaneously, by lightning or by chance, furnished the brimstone and fire from heaven, and the smoke of the land going up as the smoke of a furnace which Abraham saw from the plains of Judea.

But with Lot's wife the case is different. The bed of salt out of which she was carved, and has been many times carved, was exposed by the very catastrophe which destroyed the cities; and Lot fled to Zoar in a direction opposite to that in which the salt bed lies. As Oscar Fraas found his Arabs calling the salt pyramid 'Lot's column,' so, in early times, when the tradition of the burning cities was gradually growing into the myth of Sodom and of Lot, some old name of the salt column, grown meaningless, may have had such sound as to suggest the term, 'Lot's wife'---Bint Sheck Lut, or the woman's own name in the current language, as Chamirah, the burning mountain, suggested Chamaera, the goat, and the answer to the question why was the salt column called Lot's wife was quickly given and woven into the legend. In that dry climate successive erosions have reproduced it along the seven-mile ridge of salt, still called Kashum Usdum, or Sodom.

CALIFORNIA AS AN ISLAND

Carter, George F.; *The Masterkey*, 38:74-78, 1964.

It is a curious thing that California should have been considered an island, and that lengthy explorations were required to disprove the notion. Yet California was considered an island from the beginning, as Wagner illustrated by citing those who were on the Ulloa-Cortes expedition to California. Out of 56 entries there are 45 that use the word "island" in reference to California (Wagner 1925:9).

The causes undoubtedly were plural. There was a mythical island with the name California. Perhaps by some form of sympathetic magic the newly named land necessarily also became an island. That there was a northwest passage was a powerful notion, though exactly how this could be reduced to a mere connection between the Gulf of California and the Pacific is hard to see.

There is another possibility. That is that at the time of earliest exploration there really was a water body that led northwest from the head of the gulf and that would lead a navigator to think there was a strait leading to the Pacific. This notion is not as far fetched as it may at first seem.

We see the situation at the head of the gulf at a particular moment in geological history. Ten thousand years ago the sea stood about 100 feet lower than it now does, and the total situation was utterly different. The Colorado River must then have run in a deep channel and the delta must have lain some miles down the gulf. Under these conditions the channel of the river must have lain far below the threshold of the Imperial Valley, and the river could not enter. Now, and for the past 4000 years while the sea has stood at approximately its present elevation, the river could alternately spill into the Gulf of California and into the Imperial Valley, or at times send some of its waters both ways. To pursue the case, if the sea continues to rise at its present rate, a few thousand years will suffice to spill the salt water into the Imperial Valley, for the present divide is only 50 feet above sea level and the floor of the valley is nearly 250 below sea level. An arm of the gulf would then reach almost to the latitude of Los Angeles.

In the very recent past this condition was approximated when the Colorado River spilled into the Imperial Valley and filled it to about 30 feet above sea level. We long have known that this sea persisted into quite recent times. The Indian villages on its shores contain quantities of pottery and arrow points, both relatively late in the culture history of the area. In the beginning of the century the Cahuilla Indians still retained traditions of the prior existence of a vast body of water that once filled the valley and on whose shores their ancestors had lived. Their traditions retained the memory that as the lake dried up their ancestors had followed the receding shore line down until the water became too salt to drink.

Early conjectures as to the possible time of disappearance of the lake often lead to very recent dates. An estimate based on vegetation succession suggested a date of 500 years ago, or about 1400 A.D. Carbon-14 datings for the late stages of the lake, based on charcoal from the fires of the Indians who lived along its shores, now give dates about 220 years before the present for the last enduring lake. This means that the lake was seemingly in existence up until 1740, well within the time that the early Spanish explorations were underway in the area. For example, Ulloa was there in 1539 and Alarcon in 1541.

In the following discussion I will follow Wagner's reproduction of Ulloa's account of his voyage (Wagner 1925). It is always difficult to determine just where the early explorers were. Their latitudes are often wrong and their longitudes worse. Their descriptions seldom are detailed or specific enough to give much certainty as to the location they are trying to portray. In the Gulf of California we may accept Ulloa's description of the port of Guaymas as fixing his location toward the crucial upper part of the gulf. At this point he gave the latitude as 29.75 degrees, when it is actually 27.53' (Wagner 1925:19; footnote 26). The degree of error is important. Thereafter they went on northward until they found themselves in shallow, muddy, reddish water. Clearly they were entering the area dominated by the discharge of the Colorado River. He gave the latitude as 34 degrees, when it should actually be 32 degrees, if he was at the present delta.

Wagner here enters into a long discussion of the term ancon, used here to describe the inlet that Ulloa had entered. As he notes, in the 16th Century the usual meaning of this term "is a tidal channel connecting one body of water" (Wagner 1925: 22; footnote 37). Wagner comments on variants and rejects the notion that Ulloa could have used the word in the sense of a pass that connected with a body of water inland. Yet, if the Imperial Valley were full of water at that date, just such a term would have been appropriate for describing the connection from the gulf to that lake.

Wagner adds (loc. cit.): "Preciado, however, says, 'It seemed that there was an inlet of the mouthes of certaine lakes whereby the Sea went in and out. There were divers opinions amongst us, and some thought that that current entered into those lakes, and also that some great River there might be the cause thereof....'" These passages leave the question open. Perhaps they were only confused by the action of the water in some of the distributaries of the Colorado. It is a confusing region of shifting channels, strong tides, and a tidal bore that runs in strongly at some time of the year. Nevertheless they used a specific term whose ordinary usage would suggest a pass or strait connecting the sea with an inland waterbody. It is suggestive, if no more.

The next exploration was by Alarcon in 1541. Wagner, in discussing this, notes that upon reaching the head of the gulf Alarcon left on August 26 "to make an expedition up the river, which employed over two weeks. He was back again before September 14, when he named the country about the mouth of the river the Campana de la Cruz. From this point, according to the map, the gulf widens out and extends two degrees farther north, an obvious falsification." It would be no falsification if, in his two weeks of exploration, Alarcon had glimpsed the water-filled Imperial Valley, for it did indeed extend two degrees farther north than the head of the gulf, and according to the recent findings that body of water could well have been in existence at this date.

Alarcon made a second trip up the Colorado, according to Wagner, who tends to minimize the distance he might have gone. Had Alarcon gotten into the feeder stream of the Imperial Valley, and entered that great tideless lake, he could have rapidly sailed the length of it and reached latitude 34 degrees.

Wagner notes that while Alarcon was away one of the ships made a reconnaissance of the California coast. He says of this: "This expedition also discovered the channel which connects at high water the delta of the Colorado with the Laguna Salada, as appears from the 'Brazo de la Laguna.'" Again, if the fresh water lake in the Imperial Valley were in existence, this reference could well be taken otherwise, especially if Alarcon had on his first trip seen or heard of the lake and told his ship captains.

Perhaps the major evidence against the Spanish having gained any inkling of the existence of the water-filled Imperial Valley is to be found in their maps. None of those illustrated by Wagner show what would appear to be an arm of the sea reaching up to the northwest from the head of the gulf.

We are left, then, with uncertainties. The Imperial Valley may have been filled with water into the time of the first Spanish explorations. However, radiocarbon dating does not give absolute, but only approximate dates. Perhaps the very late date is off by just the amount necessary to make the lake just pre-contact, instead of lingering into the earliest contact time. Nevertheless the possibility exists that the lake was in existence and that Ulloa or Alarcon may have seen it. It is not impossible that Alarcon, during his two trips up to the delta, even entered the lake. Had he done so he would have had reason to add two degrees of latitude to the apparent northern limit of the gulf of California.

Historians might well consider the possibility of this water body's existence and look for allusions to it in the earliest accounts.

Reference.
Wagner, H. R.; California Voyages, 1539-1541. John Howell, San Francisco, 1925.

A CHOCTAW ACCOUNT OF THE FLOOD

Anonymous; *Nature*, 129:619, 1932.

The Smithsonian Institution has issued a summary of a report to be published in due course by Dr. J. R. Swanston on an investigation of the culture and legends of the Choctaw Indians, which includes an account of the Flood---a tradition which the Choctaw shared with other south-western

Indians. It gives an account of the destruction of mankind by the waters because of their wickedness. The form of the tradition as given here preceded the advent of the white missionaries. Later versions were modified to conform with the account in Genesis. A divinely pre-warned prophet went from village to village, proclaiming the coming of the flood; but no one heeded. Darkness, cold, and thunder came and the food of the Indians became mouldy and unfit to eat. Wild animals from the forest gathered around the camp-fires. Great waters rushed over the land from the north and destroyed everything. The prophet alone was saved. He made a raft of sassafras logs, upon which he floated for many weeks. A black bird circled over his raft, but when the prophet asked for help, it sailed away. Then a blue bird with red eyes guided him to an island in the direction of sunrise. The prophet landed and lay down in the mud to sleep. When he awoke, he found the island covered with all kinds of animals. Among them were the black bird and the blue bird. The black bird became the raven, a bird of ill-omen ever afterwards; but the blue bird became a beautiful woman, the mother of the new race of men. The Choctaw believe in a 'Great Spirit', which is closely associated with the sun, but can assume human form. Every man has two souls, of which one, identical with the shadow, is left behind after death and wanders about its former abode howling; while the other, "the inside shadow", goes to Paradise, an Elysium on earth of eternal springtime and perpetual youth, reached by crossing a yawning chasm by a slippery log.

TRADITIONS OF THE "DELUGE" AMONG THE TRIBES OF THE NORTHWEST

Eells, M.; *American Antiquarian,* 1:70-72, 1878.

Many of the Indians on this coast have a tradition of a Deluge. The Twanas on Puget's Sound speak of it, and that only good Indians were saved, though there were quite a number of them. It occurred because of a great rain, and all the country was overflowed. The Indians went in their canoes to the highest mountains near them, which is in the Olympic range; and as the waters rose above the top of it, they tied their canoes to the tops of the trees on it, so that they should not float away. Their ropes were made of the limbs of the cedar trees, just as they sometimes make them at the present time. The waters continued to rise, however, above the tops of the trees, until the whole length of their ropes was reached, and they supposed that they would be obliged to cut their ropes and drift away to some unknown place, when the waters began to recede. Some canoes, however, broke from their fastenings, and drifted away to the west, where they say their descendants now live, a tribe who speak a language similar to that of the Twanas. This they also say accounts for the present small number of the tribe. In their language, this mountain is called by a name which means "Fastener," from the fact that they fastened their canoes to it at that time. They also speak of a pigeon which went out to view the dead. I have been told by one Indian that while this highest mountain was submerged, another one, which was not far distant from it, and which was lower, was not wholly covered.

The Clallams, whose country adjoins that of the Twanas, also have a tradition of a flood, but some of them believe that it is not very long ago, perhaps not more than three or four generations since. One old man says that his grandfather saw the man who was saved from the flood, and that he was a Clallam. Their Ararat, too, is a different mountain from that of the Twanas.

The Lummi Indians, who live very near the northern line of Washington Territory, also speak of a flood, but I have not learned any particulars in regard to it.

The Puyallop Indians, near Tacoma, say that the flood overflowed all the country except one high mound near Steilacoom, and this mound is called by the Indians, "The Old Land," because it was not overflowed.

"Do you see that high mountain over there," said an old Indian to a mountaineer, as they were riding across the Cascade Mountains, about seventeen years ago. "I do," was the reply. "Do you see that grove to the right?" the Indian then said. "Yes," said the white man. "Well," said the Indian, "a long time ago there was a flood, and all the country was overflowed. There was an old man and his family on a boat or raft, and he floated about, and the wind blew him to that mountain, where he touched bottom. He stayed there some time, and then sent a crow to hunt for land, but it came back without finding any. After some time he sent the crow again, and this time it brought a leaf from that grove, and the old man was glad, for he knew that the water was going away."

The Yakima Indians also have their traditions, but at this time, writes Rev. J. H. Wilbur, their agent and missionary, it is impossible to tell what was their original traditions and what has been mixed with it from the early teachings of missionaries who were with them thirty or forty years ago.

When the earliest missionaries came among the Spokanes, Nez Perees and Cayuses, who with the Yakimas live in the eastern part of the Territory, they found that those Indians had their tradition of a flood, and that one man and wife were saved on a raft. Each of those three tribes also, together with the Flathead tribes, has their separate Ararat in connection with this event.

The Makah Indians, who live at Neah Bay, the north-west corner of the Territory, next to the Pacific Ocean, also the Chemakums and Kuilleyutes, whose original residence was near the same region, speak of a very high tide. According to their tradition, "A long time ago, but not at a very remote period, the waters of the Pacific flowed through what is now the swamp and prairie between Waatch village and Neah Bay, making an island of Cape Flattery. The water suddenly receded, leaving Neah Bay perfectly dry. It was four days reaching its lowest ebb, and then rose again without any waves or breakers till it had submerged the Cape, and in fact the whole country except the tops of the mountains at Clyoquot. The water on its rise became very warm, and as it came up to the houses, those who had canoes put their effects in them, and floated off with the current, which set very strongly to the north. Some drifted one way, some another; and when the waters assumed their accustomed level, a portion of the tribe found themselves beyond Nootka, where their descendants now reside, and are known by the same name as the Makahs in Classet, or Kwenaitchechat. Many canoes came down in the trees and were destroyed, and numerous lives were lost. The water was four days in gaining its accustomed level."

It is the opinion of Hon. J. G. Swan that this was simply a rising of the tides, and has no reference to the Deluge of Noah. I suggest, however, that if they had preserved any tradition of the flood in their migrations, when they settled at Neah Bay, where nearly all of their floods, though smaller, were caused by the rising of the tide, that they would naturally, in a few generations, refer it to the same cause. The natives of the Sandwich Islands, where floods are caused in the same way, have a tradition of a great flood, but refer it to the rising of the tide.

The Indians of the Warm Spring Reservation in Oregon, and of the Fort Hall reservation in Idaho, as far as I can learn, have no such tradition. It is possible, however, that they may have concealed it from their questioners, if they have one, as Indians do many of their traditions.

When these traditions are compared with those of other Indians in the eastern part of the United States, Mexico and South America, as well as the traditions and records of the Eastern Hemisphere, it forms in many minds a very strong argument in favor both of the truth of the Bible account, and also of the unity of the race.

Some have objected to these traditions that perhaps they were not handed down from former ancestors, but were received from early traders and teachers; but for four reasons I cannot accept the objection: (1) because the first travelers have often learned this tradition; (2) they will even now often distinguish between the traditions of their ancestors and the teachings of the first whites who came here; (3) they have names of their Ararat, the great monument of the flood, as "Fastener" and "Old Land;" (4) the Mexicans, when discovered, although they had no system of writing, yet had a way of representing events by pictures, and this event was recorded among others.

Hence we must either conclude that all the traditions had little or no foundation, which would be absurd, or that there were a large number of floods, which would be almost as absurd, for in that event the tradition of one flood in each tribe could not have been preserved so distinctly, especially when a bird of some kind, and a branch of some tree, is often mentioned in connection with it, or else that there was one great flood, so great that most of the descendants of those saved have preserved a tradition of it, and if so, all must have descended from the few who were saved.

THE DELUGE: ITS TRADITIONS IN ANCIENT NATIONS

Lenormant, Francois; *Contemporary Review*, 36:463-500, 1879.

American Stories of the Flood. "It is a very remarkable fact," says M. Alfred Maury, "that we find in America traditions of the Deluge coming infinitely nearer to that of the Bible and the Chaldean religion than among any people of the Old World. It is difficult to suppose that the emigration that certainly took place from Asia into North America by the Kourile and Aleutian islands, and still does so in our day, should have brought in these memories, since no trace is found of them among those Mongol or Siberian populations, which were fused with the natives of the New World.... No doubt certain American nations, the Mexicans and Peruvians, had reached a very advanced social condition at the time of the Spanish conquest, but this civilization had a special character, and seems to have been developed on the soil where it flourished. Many very simple inventions, such as the use of weights, were unknown to these people, and this shows that their knowledge was not derived from India or Japan. The attempts that have been made to trace the origin of Mexican civilization to Asia have not as yet led to any sufficiently conclusive facts. Besides, had Buddhism, which we doubt, made its way into America, it could not have introduced a myth not found in its own Scriptures. The cause of these similarities between the diluvian traditions of the nations of the New World and that of the Bible remains therefore unexplained.'"

I have particular pleasure in quoting these words by a man of immense erudition, because he does not belong to orthodox writers, and will not therefore be thought biassed by a preconceived opinion. Others also, no less rationalistic than he, have pointed out this likeness between American traditions of the Deluge and those of the Bible and the Chaldeans.

The most important among the former are the Mexican, for they appear to have been definitively fixed by symbolic and mnemonic paintings before any contact with Europeans. According to these documents, the Noah of the Mexican cataclysm was Coxcox, called by certain peoples Teocipactli or Tezpi. He had saved himself, together with his wife Xochiquetzal, in a bark, or, according to other traditions, on a raft, made of cypress wood Cupressus disticha). Paintings retracing the deluge of Coxcox have been discovered among the Aztecs, Miztecs, Zapotecs, Tlascaltecs, and Mechoacaneses. The tradition of the latter is still more strikingly in conformity with the story as we have it in Genesis and in Chaldean sources. It tells how Tezpi embarked in a spacious vessel with his wife, his children, and several animals, and grain, whose preservation was essential to the subsistence of the human race. When the great god Tezcatlipoca decreed that the waters should retire, Tezpi sent a vulture from the bark. The bird, feeding on the carcases with which the earth was laden, did not return. Tezpi sent out other birds, of which the humming-bird only came back with a leafy branch in its beak. Then Tezpi, seeing that the country began to vegetate, left his bark on the mountain of Colhuacan.

The document, however, that gives the most valuable information as to the cosmogony of the Mexicans is one known as "Codex Vaticanus," from the library where it is preserved. It consists of four symbolic pictures, representing the four ages of the world preceding the actual one. They were copied at Chobula from a manuscript anterior to the conquest, and accompanied by the explanatory commentary of Pedro de los Rios, a Dominican monk, who in 1566, less than fifty years after the arrival of Cortez, devoted himself to the research of indigenous traditions as being necessary to his missionary work.

The first age is marked with the cipher 13 x 400 + 6, or 5206, which Alexander von Humboldt understands as giving the number of years of the period, and Abbe Brasseur de Bourbourg as the date of its commencement, from a proleptic era going back from the period of the execution of the manuscript. This age is called Tlatonatiuh, "Sun of Earth." It is that of the giants, or Quinames, the earliest inhabitants of Anahuac, whose end was destruction by famine.

The number of the second age is 12 x 400 + 4, or 4804, and it is called Tlatonatiuh, "Sun of Fire." It closes with the descent on Earth of Xiuhteuchli, the god of fire. Mankind are all transformed into birds, and only thus escape the conflagration. Nevertheless, one human pair find refuge in a cave, and repeople the world.

As to the third age, Ehecatonatiuh, "Sun of Wind," its number is

10 x 400 + 10, or 4010. Its final catastrophe is a terrible hurricane raised by Quetzalcoatl, the "god of the air." With few exceptions, men are metamorphosed into monkeys.

Then comes the fourth age, Atonatiuh, "Sun of Water," whose number is 10 x 400 + 8, or 4008. It ends by a great inundation, a veritable deluge. All mankind are changed into fish, with the exception of one man and his wife, who save themselves in a bark made of the trunk of a cypress-tree. The picture represents Matlalcueye, goddess of waters, and consort of Tlaloc, god of rain, as darting down towards earth. Coxcox and Xochiquetzal, the two human beings preserved, are seen seated on a tree-trunk and floating in the midst of the waters. This flood is represented as the last cataclysm that devastates the earth.

All this is most important, as a mind of the order of Humboldt's did not hesitate to acknowledge. However, M. Girard de Realle wrote quite recently:

> "The myth of the deluge has been met with in several parts of America, and Christian writers have not failed to see in it a reminescence of the Biblical tradition, nay, in connection with the pyramid of Chobula, they have found traces of the Tower of Babel. We shall not waste time in pointing out how out of a fish-god, Coxcox, among the Chichimecs, Teocipactli among the Aztecs, and a goddess of flowers, Xochiquetzal, it was easy to concoct the Mexican figures of Noah and his wife by joining on to them the story of the ark and the dove. It is enough to observe that all these legends have only been collected and published at a relatively recent period. The first chroniclers so cautious already despite their honest simplicity, such as Sahagun, Mendieta, Olmos, and the Hispano-indigenous authors, such as the Tezcucan Ixthilxochitl and the Tlascaltec Camargo, never breathe a word of stories they could not have failed to bring to light, had they existed in their days. Lastly, we find in Mr. Bancroft's work a criticism of these legends, due to Don Jose Fernando Ramirez, keeper of the National Museum, which proves incontestably that all these stories spring from all too ready and tendency-fraught interpretations of old Mexican paintings, which according to him only represent episodes in the migration of Aztecs around the central lakes of the plateau of Anahuac."

I much fear that the tendency here is not on the side of writers who are looked on as ground to powder by the epithet Christian; which, indeed, be it said in passing, might well surprise a few among them. And this tendency, which resolved at any cost to attack the Bible, is as anti-scientific as when grasping at any uncritical argument in its defence. No doubt the identical character of Xochiquetzal or Maciulxochiquetzal, as goddess of the fertilizing rain and of vegetation, with that of Chalchihuitlicue or Mallalcueye, is a well-known fact, more certain even than the character of fish-god of Coxcox or Teocipactli. But the transformation of gods into heroes is a very common fact in all polytheisms, and most common in the kind of unconscious euhemerism from which infant peoples never free themselves. There is therefore nothing here to contradict the fact that these two divine personages, contemplated as heroes, may be taken as the two survivors of the Flood, and the ancestors of the new humanity. As to the theory of Don Jose Ramirez, about the symbolic pictures that have been interpreted as expressing the diluvian tradition, it is very ingenious and scientifically presented, but not so absolutely proved as M. Girard de Realle considers. But even granting its incontestability, it only removes part of the evidence which may have been unintentionally forced by those naturally disposed to see in it a parallel to Genesis; as for instance, with regard to the sending out the birds by Tezpi. Still the existence of the tradition among Mexican peoples would not be shaken, for it rests upon a whole of indubitable testimony, confirming in a striking manner the interpretation hitherto given of the "Codex Vaticanus." (pp. 488-491)

Polynesian Traditions. In Oceania even, and not among the Pelagian negroes or Papoos, but the Polynesian, racenatives of the archipelago of Australasia, the diluvian tradition has been traced, mingled with recollections of sudden rises of the sea, which are one of the most frequent scourges of those islands. The most noted is that of Tahiti, which has been specially referred to the primeval tradition. Here it is as given by M. Gaussin, who has published a translation of it, as well as the Tahitian text, written by a native named Mare:

> "Two men had gone out to sea to fish with the line, Roo and Teahoroa by name. They threw their hooks into the sea, which caught in the hair of the god Ruahatu. They exclaimed, 'A fish!' They drew up the line and saw that it was a man they had caught. At sight of the god they bounded to the other end of their bark, and were half dead with fear. Ruahatu asked them, 'What is this?' The two fishermen replied, 'We came to fish, and we did not know that our hooks would catch thee.' The god then said, 'Unfasten my hair;' and they did so. Then Ruahatu asked, 'What are your names?' They replied, 'Roo and Teahoroa.' Ruahatu next said, 'Return to the shore, and tell men that the earth will be covered with water, and all the world will perish. To-morrow morning repair to the islet called Toa-marama; it will be a place of safety for you and your children.'
>
> "Ruahatu caused the sea to cover the lands. All were covered, and all men perished except Roo, Teahoroa, and their families."

This story, like all in this part of the world currently referred to the memory of the Deluge, has assumed the childish character peculiar to Polynesian legends, and moreover, as M. Maury justly observes, it may be naturally explained by the recollection of one of those tidal waves so common in Polynesia. The most essential feature of all traditions properly called diluvian is wanting here. The island, observes M. Maury, has no resemblance to the Ark. It is true that one of the versions of the Tahitian legend states that the two fishermen repaired to Toa-marama, not only with their families, but with a pig, a dog, and couple of fowls, which recalls the entry of the animals into theArk. On the other hand, some details of a similar story among the Fijis, especially one in which, for many years after the event, canoes were kept ready in case of its repetition, far better fit a local phenomenon, a tidal wave, then a universal deluge.

However, if all these legends were exclusively related to local catastrophes, it would be strange that they should appear and be almost similar in a certain number of localities at a great distance from each other, and only where the Polynesian race has taken root, or left indubitable traces of its passage;---this race, indigenous in the Malay Archipelago, not having migrated thence till about the fourth century of the Christian era---

i.e., at a time when, in consequence of the communication between India and a portion of Malaysia, the Flood-tradition under its Indian form might well have entered in. Without, therefore, deciding the question one way or other, we do not think that that opinion can absolutely be condemned which finds in these Polynesian legends an echo of the tradition of the Deluge, much weakened, much changed, and more inextricably confused than anywhere else with local disasters of recent date.

The result, then, of this long review authorizes us to affirm the story of the Deluge to be a universal tradition among all branches of the human race, with the one exception, however, of the black. Now a recollection thus precise and concordant cannot be a myth voluntarily invented. No religious or consmogonic myth presents this character of universality. It must arise from the reminescence of a real and terrible event, so powerfully impressing the imagination of the first ancestors of our race, as never to have been forgotten by their descendants. This cataclysm must have occurred near the first cradle of mankind, and before the dispersion of the families from which the principal races were to spring; for it would be at once improbable and uncritical to admit that at as many different points of the globe as we should have to assume in order to explain the wide spread of these traditions---local phenomena so exactly alike should have occurred, their memory having assumed an identical form, and presenting circumstances that need not necessarily have occurred to the mind in such cases.

Let us observe, however, that probably the diluvian tradition is not primitive but imported in America; that it undoubtedly wears the aspect of an importation among the rare populations of the yellow race where it is found; and lastly, that it is doubtful among the Polynesians of Oceania. There will still remain three great races to which it is undoubtedly peculiar, who have not borrowed it from each other, but among whom the tradition is primitive, and goes back to the most ancient times; and these three races are precisely the only ones of which the Bible speaks as being descended from Noah, those of which it gives the ethnic filiation in the tenth chapter of Genesis. This observation, which I hold to be undeniable, attaches a singularly historic and exact value to the tradition as recorded by the Sacred Book, even if, on the other hand, it may lead to giving it a more limited geographical and ethnological significance. In another paper I propose to inquire whether, in the conception of the inspired writers, the Deluge really was universal, in the sense customarily supposed.

But as the case now stands, we do not hesitate to declare that, far from being a myth, the Biblical Deluge is a real and historical fact, having, to say the least, left its impress on the ancestors of three races---Aryan or Indo-European, Semitic or Syro-Arabian, Chamitic or Kushite---that is to say, on the three great civilized races of the ancient world, those which constitute the higher humanity---before the ancestors of those races had as yet separated, and in the part of Asia they together inhabited. (pp. 498-500)

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