ANOMALIES IN GEOLOGY:

PHYSICAL, CHEMICAL, BIOLOGICAL

Compiled by:

William R. Corliss

A CATALOG OF GEOLOGICAL ANOMALIES

ANOMALIES IN GEOLOGY:

PHYSICAL, CHEMICAL, BIOLOGICAL

A CATALOG OF GEOLOGICAL ANOMALIES

Compiled by:

William R. Corliss

Published and Distributed by

The Sourcebook Project P.O. Box 107 Glen Arm, MD 21057

Library of Congress Catalog Number: 89-90680

ISBN 0-915554-23-2

First printing: March 1989

Printed in the United States of America

TABLE OF CONTENTS

LIST OF PROJECT PUBLICATIONS

CATALOGS:	Anomalies in Geology (category ES, in part)
	Carolina Bays, Mima Mounds, Submarine Canyons (category ET)
	Stars, Galaxies, Cosmos (categories AO, AQ, AT, AW)
	The Sun and Solar System Debris (categories AA, AB, AC, AE, AS, AX, AY, AZ)
	The Moon and the Planets (categories AG, AH, AJ, AL, AM, AN, AP, AR, AU, AV)
	Lightning, Auroras, Nocturnal Lights (category GL)
	Tornados, Dark Days, Anomalous Precipitation (category GW)
	Earthquakes, Tides, Unidentified Sounds (categories GH, GQ, GS)
	Rare Halos, Mirages, Anomalous Rainbows (category GE)
HANDBOOKS:	The Unfathomed Mind: A Handbook of Unusual Mental Phenomena
	Incredible Life: A Handbook of Biological Mysteries
	Unknown Earth: A Handbook of Geological Enigmas
	Mysterious Universe: A Handbook of Astronomical Anomalies
	Ancient Man: A Handbook of Puzzling Artifacts
	Handbook of Unusual Natural Phenomena
SOURCEBOOKS:	Strange Phenomena, vols. G1 and G2
	Strange Artifacts, vols. M1 and M2
	Strange Universe, vol. A1 and A2
	Strange Planet, vols. E1 and E2
	Strange Life, vol. B1
	Strange Minds, vol. P1
NEWSLETTER:	Science Frontiers (current anomaly reports)

For information on the availability, prices, and ordering procedures, write:

SOURCEBOOK PROJECT
P.O. Box 107
Glen Arm, MD 21057

PREFACE

After more than sixteen years of scouring the scientific and semiscientific literature for anomalies, my major conclusion is that this is an amazingly fruitful activity. In fact, organized science should have been doing the same searching and compiling for the past 200 years. It is simply astounding that a Catalog of Anomalies does not already exist to guide scientific thinking and research. It is at least as important to realize what is not known as it is to recognize the well-explained. With this outlook, here is the ninth volume in such a Catalog. It is largely the product of one person's library research, carried forward entirely through the sale of my Catalogs, Handbooks, Sourcebooks, and related books.

Under the aegis of the Sourcebook Project, I have already published 25 volumes, totalling well over 8,000 pages of source material on scientific anomalies. (See page iv for a list of titles.) As of this moment, these 25 volumes represent only about 30% of my data base. New material is being added at the rate of about 1,200 new items per year, about 500 of which are from the current literature. These rates could easily be multiplied several-fold simply by spending more time in libraries. Even after sixteen years, only the scientific journals of the United States and England have received my serious attention. There remain the English-language journals of the rest of the world, those journals in other languages, university theses, government reports, the publications of scientific research facilities, conference papers, untold thousands of books, and an absolutely immense reservoir of newspapers. The cataloging task has just begun. The anomalies residing in the world's literature seem infinite in number. Every library foray uncovers new anomalies.

Given this rough assessment of the magnitude of the anomaly literature, one can understand why the planned Catalog of Anomalies will require at least 25 volumes, many larger than the one you now hold. I visualize a shelf of 25 volumes, with master indexes, to be only the initial step in providing scientists with ready access to what is not, in my opinion, well-explained. The underlining of "my" is important because anomalousness is often in the eye of the beholder. It depends upon how well one is satisfied with the explanatory capabilities of current theories. In the Catalog of Anomalies, the data rule; all theories and hypotheses are held to be tentative. The history of science proves that this is a wise policy.

Will the Catalog of Anomalies revolutionize science? Probably not---at least not immediately. Quite often the initial reaction to the volumes already published has been disbelief and even disdain. The data must be in error; the data are mainly testimonial; the data are too old; the supposed anomaly was explained long ago. Germs of truth reside in all of these complaints. The baseline of well-established theories, against which anomalousness is measured, is always shifting; and some data, indeed, are bad. But for every anomaly or example that can be legitimately demolished, ten more take its place. Nature is very anomalous or, equivalently, Nature is not yet well-understood by science. Much remains to be done.

William R. Corliss

P.O. Box 107
Glen Arm, MD 21057
March 1, 1989

"ROUND ABOUT THE ACCREOITED AND OROERLY FACTS OF EVERY SCIENCE THERE EVER FLOATS A SORT OF OUST-CLOUO OF EXCEPTIONAL OBSERVATIONS, OF OCCURRENCES MINUTE AND IRREGULAR AND SELOOM MET WITH, WHICH IT ALWAYS PROVES MORE EASY TO IGNORE THAN TO ATTEND TO . . . . ANYONE WILL RENOVATE HIS SCIENCE WHO WILL STEADILY LOOK AFTER THE IRREGULAR PHENOMENA. ANO WHEN THE SCIENCE IS RENEWEO, ITS NEW FORMULAS OFTEN HAVE MORE OF THE VOICE OF THE EXCEPTIONS IN THEM THAN OF WHAT WERE SUPPOSED TO BE THE RULES." **William James.**

HOW THE CATALOG IS ORGANIZED

Purpose of the Catalog

The Catalog of Anomalies is designed to collect and categorize all phenomena that cannot be explained readily by prevailing scientific theories. Following its definition, each recognized anomaly is rated in terms of: (1) its substantiating data; and (2) the challenge the anomaly poses to science. Next, all examples of the anomaly discovered so far are noted, some of more interesting ones in more detail. Finally, all examined references are listed. Thus, the Catalog is a descriptive guide as well as a compendium of examples and references. Scientific researchers have a substantial foundation for beginning further studies of these intriguing phenomena. This is the basic purpose of the Catalog: the collection and consolidation of the unknown and poorly explained to facilitate future research and explanation.

General Plan of the Catalog

It was tempting to organize this Catalog alphabetically, making it an "encyclopedia" of anomalies." But many of the phenomena have obscure names or, even worse, no names at all. Under these circumstances, access to the data base would be difficult. Therefore, a system of classification was designed based upon readily recognized classes of phenomena and the means by which the observer detects them. Subject matter is first divided into nine general classes of scientific endeavor, as illustrated in the diagram on the following page. Few would have difficulty classifying a phenomenon as biological, astronomical, etc. The second, third, and fourth levels of classification are also based on generally recognized attributes. The similarity of this kind of categorization to those employed in natural history field guides is quite intentional. Like bird identification, phenomenon classification soon becomes second nature. In fact, many of the phenomena described in the Catalog are accessible to anyone with normal senses and, especially in astronomy, a little optical help.

Most catalogs boast numbering systems, and this one is no exception. Rather than employ a purely numerical system, the first three classification levels are designated by letters. The triplets of letters selected have some mnemonic value. Thus, an ESC anomaly is easily recognized as being in the geology class (E), involving stratigraphy (S), and concerning chemical anomalies (C). The number added to the triplet of letters marks the fourth classification level, so that ESC1 signifies chemical spikes in the stratigraphic record, the first in the list of chemical anomalies. Every anomaly type has such a unique alphanumeric code. All indexes and cross references are based on this system. Catalog additions and revisions are also made easier with this scheme.

The Catalog codes may seem cumbersome at first, but their mnemonic value to the compiler has been considerable. The codes are simple, yet flexible enough to encompass the several thousand anomalies identified so far in many diverse scientific disciplines.

A glance through this volume will reveal that each example of a specific anomaly bears an X-number, and each reference an R-number. ESC1-X2 therefore specifies the second example of chemical spikes; and ESC1-R4, the fourth reference to this phenomenon. Indexes and cross references can consequently be made very precise.

How Data and Anomalies Are Evaluated

Each anomaly type is rated twice on four-level scales for data "validity" and "anomalousness," as defined below. These evaluations represent only the opinion of the compiler and are really only rough guides.

Data Evaluation Scale

1 Many high-quality observations. Almost certainly a real phenomenon.

2 Several good observations or one or two high-quality observations. Probably real.

3 Only a few observations, some of doubtful quality. Phenomenon reality questionable.

4 Unacceptable, poor-quality data. Such phenomena are included only for the purposes of comparison and amplification.

Anomaly Evaluation Scale

1. Anomaly cannot be explained by modifications of present laws. Revolutionary.
2. Can probably be explained through relatively minor modifications of present laws.
3. Can probably be explained using current theories. Primarily of curiosity value.
4. Well-explained. Included only for purposes of comparison and amplification.

Anomalies that rate "1" on both scales are very rare. Such anomalies, however, are the most important because of their potential for forcing scientific revolutions. As additional Catalog volumes are published, the relative proportion of "double-1s" will increase. especially in the fields of biology and psychology.

Catalog Coding Scheme

First-order classification	Second-order classification	Third-order classification	Fourth-order classification
A Astronomy	C Geochemistry	A Accretion structures	1 Chemical spikes
B Biology	G Gravimetry	*B Biological anomalies	2 Anomalies in igneous rocks
C Chemistry & physics	Q Seismology	*C Chemical anomalies	3 Surface films
E Earth sciences	S Stratigraphy	D Deposits of unusual size	4 Rapid exothermic reactions
G Geophysics	T Topography	G Geographical anomalies	
L Logic & math	Z Magnetism	I Inclusions	
M Archeology		M Disposition anomalies	
P Psychology		*P Physical anomalies	
X Unclassified		R Interrelations between strata	16 Origin of methane
		X Intrusive structures	

*Included in this volume

Anomaly Examples

Examples of anomaly types are designated by the letter X in the body of the Catalog. All examples discovered so far are listed. If the example is of the event type, time and place are specified where available. Such data are the foundations of the Time-of-Event Index, which could in principle lead to the discovery of obscure cause-and-effect relationships. Where library research has unearthed many examples of a specific type of anomaly, only the most interesting and instructive are quoted in detail. Direct quotations from eye-witnesses and scientific experts are employed frequently to convey accurately the characteristics of the phenomena.

The References and Sources

Each anomaly type and the examples of it are buttressed by all references that have been collected and examined. Since some references describe several examples, each reference includes the X-numbers of the examples mentioned. When a reference covers more than one type of anomaly, it is repeated in the bibliography following each anomaly type. Actually, there is little repetition of this sort in the Catalog.

Perusal of the Source Index will demonstrate that the great majority of the references comes from the scientific literature. Heavily represented in this volume of the Catalog are such journals as: Nature, Science, Geographical Journal, Bulletin of the Geological Society of America, and Journal of Geology. Some less technical publications are also mentioned frequently: Science News and Geographical Magazine. New Scientist, an important English technical magazine, also contains many geological items. All of the serials mentioned above are generally very reliable, though one must always be wary when unusual phenomena are reported. In addition to these often-referenced publications, there is a wide spectrum of other journals and magazines carrying geological information. Since the earth's topography is an easily observed phenomenon, useful observations may be found almost anywhere.

The time span covered by the sources ranges over almost 200 years; but the great bulk of the reports comes from the past 80 years. In particular, the data of marine geology is of very recent vintage, because sophisticated sonar equipment and deep-diving research submersibles are recent developments. The exploration of submarine canyons and guyots has obviously been the exclusive province of professional scientists with access to such apparatus. Subaerial geology, on the other hand, has been aided for centuries by amateur geologists, geographers, polar explorers, and mountain climbers. Almost everyone who writes about topographical phenomena also provides a theory of origin. Important though they are to the progress of science, little attention is paid to theories in the Catalog; the emphasis is on the data. One final remark, some areas of geology, especially marine geology, are moving ahead so rapidly that some things in this volume will be outdated before the books leave the bindery.

The Indexes

Most Catalog volumes conclude with five separate indexes. At first glance this may seem to be too much of a good thing. But in the context of a science-wide Catalog of anomalous phenomena, each index has its special utility.

The subject index is of course essential in any work of this type. It is placed last for easy access. The time and place indexes are analytical tools for the anomalist. They help connect diverse phenomena that are reported separately (often in widely different journals) but which are really different aspects of the same event. To illustrate, the subject of the earth's bombardment by large meteors or comets arises in this volume and also in those covering geophysics and astronomy. And, of course, when the volumes on biology are prepared, meteor bombardment will be linked to the problem of mass extinctions. It is the intent of the Catalog effort to generate a composite set of indexes that will link geology, astronomy, biology, and all other scientific fields.

The source index shows immediately the dependence of this Catalog upon scientific literature such-and-such an article by so-and-so back in 1950 in Nature. The exhaustive and rather ponderous source and first-author indexes can help pin down many references lacking specifics.

All five indexes use the catalog codes described above rather than page numbers. The codes are permanent whereas the page numbers will change as addenda and revised volumes are produced. The mnenonic value of the catalog codes is useful here, too, because the approximate nature of each index entry is readily apparent, while page numbers give only location.

Supporting Publications of the Sourcebook Project

The Catalog volumes currently being published are actually distillations of huge quantities of source material. The Sourcebook Project has already published 24 volumes of this source material, as detailed on p. iv. Phase I of the Sourcebook Project resulted in 10 looseleaf notebooks called "sourcebooks." To meet the objections of librarians, Phase II supplanted the sourcebooks with a series of 6 "handbooks," which are hardcover and much larger and more comprehensive than the sourcebooks. Phase III, now in progress, is the cataloging phase, which involves the systematization of a data base comprising some 30,000 articles. The Sourcebook Project also publishes a bimonthly newsletter, SCIENCE FRONTIERS, which informs customers about scientific anomalies appearing in the current literature.

Catalog Addenda and Revisions

Over 1,200 new reports of anomalies are collected from current and older scientific journals each year. New anomaly types and additional examples of types already cataloged are accumulating rapidly. When sufficient new material has been assembled, Catalog volumes will be revised and expanded.

Request for Additions and Corrections

The Sourcebook Project welcomes reports of new anomalies and examples of recognized anomalies not yet registered in extant Catalog volumes. Reports from scientific journals are preferred, but everything is grist for the mill! Credit will be given to submitters in revised volumes of the Catalog of Anomalies. Send data to the Sourcebook Project, P.O. Box 107, Glen Arm, MD 21057.

INTRODUCTION TO PHYSICAL, CHEMICAL, AND BIOLOGICAL ANOMALIES IN GEOLOGY

Key to Categories

ESB ANOMALOUS BIOLOGICAL PHENOMENA IN GEOLOGY

ESC ANOMALOUS CHEMICAL PHENOMENA IN GEOLOGY

ESP ANOMALOUS PHYSICAL PHENOMENA IN GEOLOGY

This volume of the Catalog of Anomalies was assembled by reviewing our hoard of thousands of papers and articles on geological anomalies and selecting those in which the predominant characteristic was either biological, chemical, or physical in nature. A few typical phenomena in these three categories will illuminate the selection process:

Predominant Characteristic	Sample Representative Phenomena
Biological	Paleontological signatures at biological extinction events; buried, undecayed organic debris (viz., frozen mammoths); periodic growth structures on marine fossils (astronomical cycles seen in shell ridges)
Chemical	Chemical spikes in the stratigraphic record; violent turnovers of lakes; anomalies associated with the origins of oil, coal, and natural gas
Physical	Anomalous radiohalos; musical sands and ringing rocks; jointing and crack patterns in rocks; glacières or natural refrigerators.

Left for other volumes in the geology series are topographical phenomena and phenomena concerned with individual strata and other sedimentary deposits and the often-anomalous interrelations among them

Although mentioned on page 1, it should have become more obvious from the preceding paragraphs that the hypothesis-free criteria used in classifying anomalies leads to subject matter organization quite different from that in the usual geology books. Topics are not organized to support Ice Age theory, Continental Drift, or the conventional evolution scenario. In the Catalog of Anomalies, theories are subservient to scientific observables, such as, in this volume, radioactivity, spontaneous chemical reactions, living bacteria at great depths in the crust, and so on.

ESB ANOMALOUS BIOLOGICAL PHENOMENA IN GEOLOGY

Key to Phenomena

ESB0 Introduction

The geological record is full of "biological" phenomena which cannot be explained easily using prevailing theories. These challenges to mainstream geological thinking are what make these phenomena anomalous, according to the definition employed in this Catalog of Anomalies.

The adjective "biological" is taken here to include fossils (mineralized bones, diatom skeletons, etc.), unfossilized biological materials (frozen mammoths, undecayed stumps, etc.), and even living animals (subterranean bacteria). We catalog here only those phenomena which have geological import; that is, they seem to tell us something about the earth's history and how the stratigraphic record was formed. Many other biological data found in the geological record have something to say about the development of life throughout our planet's history, especially the theory of evolution. These phenomena are covered in the next series of Catalogs on biology.

Biological evidence in the stratigraphic record reveals much about a current concern of science: possible catastrophism at major geological boundaries. Were there asteroid/cometary impacts, or did widespread volcanism cause the biological extinctions observed near several geological boundaries, notably the Cretaceous-Tertiary boundary? Or were these traumas the consequence of something entirely different? The fossils found in the rocks below and above geological boundaries can help answer such questions, and tell us as well something about how life recovered from these seemingly catastrophic events.

The earth's polar regions figure heavily in this chapter. There are the famous Siberian frozen mammoths and the heavy organic content of the muck surrounding the Arctic Ocean. Here, too, are found undecayed stumps millions of years old. There are dinosaur bones signifying great climate changes and, possibly, dinosaurs that learned how to cope with months of darkness near the pole. In the south polar region, scientists have also found undecayed wood, and the Antarctic ice shelves are full of biological surprises. Can simple climate changes account for these polar anomalies?

Scientific creationists and catastrophists of the Velikovsky school rely heavily on some of the anomalies recorded in this chapter. There is no intent here to advance their theories or, for that matter, the theories of any "movement." However, the publications of groups outside of science's mainstream often highlight anomalies that are disregarded or denied outright by the usual scientific journals. We occasionally draw on such "fringe" literature, with care and without apology.

ESB1 Paleontological Signatures during Biological Extinction Events

Description. The sharp, substantial reduction of biological diversity and/or population levels at verious positions in the fossil record. Zones of particularly severe reductions are termed "extinctions," although the term is not well-defined. Major extinctions usually mark the transition from one geological era or period to another. Extinctions are generally thought to indicate the occurrence of some sort of physical, chemical, or biogenic catastrophe on earth.

Extinctions may be correlated stratigraphically with various geological phenomena (viz., unconformities), other paleontological phenomena (biological "explosions"), chemical spikes, climate changes, the presence of microtektites, shocked quartz, and other possible indicators of catastrophism.

Background. Biological extinction events have long been recognized by paleontologists. Indeed, they customarily mark the terminations of major geological periods as well as "crises" in the history of life. The study of extinctions accelerated in the late 1970s, when a worldwide iridium spike was discovered at the Cretaceous-Tertiary (K-T) boundary. Such scrutiny has greatly increased our knowledge of the detailed nature of biological extinction events---their duration, biological selectivity, and geographical selectivity, etc.

Data Evaluation. Paleontology is a well-developed field. Many biological extinction events have been recorded in great detail. The fossil record, however, is incomplete in some regions, not clear-cut in others, and confusing in still others. Time and the elements have made the record difficult to read. Rating: 2.

Anomaly Evaluation. The fact that massive biological extinction events occurred in the past is not anomalous in itself, for geologic upheavals and even astronomical catastrophism are generally accepted today by mainstream science. But consensus as to the specific causes of specific biological extinctions remains elusive. For example, the cause of the Cretaceous-Tertiary extinction led to one of the most vigorous scientific debates of the early 1980s. The cause is still not pinpointed to everyone's satisfaction. And the question of the periodicity of biological extinction events is still unsettled. Rating: 1.

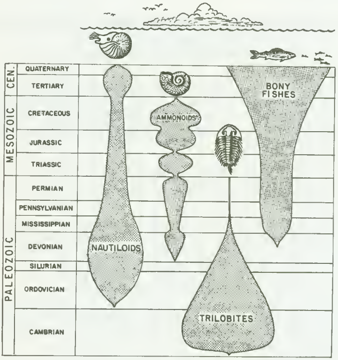
Possible Explanations. A lengthy list of possible causes of biological extinctions is given in X13 below.

Similar and Related Phenomena. Chemical anomalies in the stratigraphic record (ESC1); magnetic particles in sediments (ESI); crushed and shocked material (ESP11); biological explosion events (ESB2); evidence of catastrophic climatic changes (ESB4).

Examples

X0. Introduction to biological extinction events. The definition of biological extinction events is far from precise. Generally, when the fossil record reveals the extermination or catastrophic reduction in population of many species, in a geologically short period of time, over a wide portion of the globe, the word "extinction" is introduced. But there must be dividing lines somewhere! What proportion of existing species must be wiped out to make an extinction? During what time frame? Over how much of the planet? Fortunately, the anomalist can leave these details to the paleontologists and focus on the widely recognized extinctions---those "crises in the history of life" and their geological implications.

A survey of the massive literature on biological extinction events reveals the existence of four well accepted biological extinction events, another that is highly probable, and two more that are likely and which will frequently come to the fore in this Catalog:



Marine life forms have waxed and waned during geological time, as illustrated by the widths of the bands. (X0)

Widely recognized

The late Ordovician event
The late Permian (or Permian-Triassic) event
The late Triassic event
The late Cretaceous (or Cretaceous-Tertiary or K-T) event

Highly probable

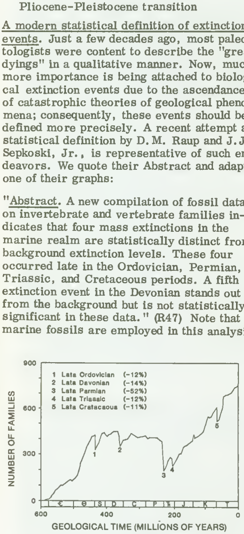
The upper Devonian (or Frasnian-Famennian) event

Potential and likely

Cambrian-Ordovician transition
Pliocene-Pleistocene transition

A modern statistical definition of extinction events. Just a few decades ago, most paleontologists were content to describe the "great dyings" in a qualitative manner. Now, much more importance is being attached to biological extinction events due to the ascendance of catastrophic theories of geological phenomena; consequently, these events should be defined more precisely. A recent attempt at statistical definition by D. M. Raup and J. J. Sepkoski, Jr., is representative of such endeavors. We quote their Abstract and adapt one of their graphs:

"Abstract. A new compilation of fossil data on invertebrate and vertebrate families indicates that four mass extinctions in the marine realm are statistically distinct from background extinction levels. These four occurred late in the Ordovician, Permian, Triassic, and Cretaceous periods. A fifth extinction event in the Devonian stands out from the background but is not statistically significant in these data." (R47) Note that marine fossils are employed in this analysis.



The five major biological extinction events in the fossil record, as measured by the number of families effected. (X0)

Marine organisms are more likely to be fossilized than land animals. Further, this study recognizes a background level of extinctions, which are difficult to attribute to any specific cause. Indeed, as we shall see, major extinction events do not have universially recognized causes either. (WRC)

Nature of the late Ordovician biological extinction event. G. G. Simpson notes simply that 50% of the fish families and 60% of the contemporary trilobite families perished. (R10)

That this extinction event was rather more complex is evident from a summary by D. J. McLaren: "There appears to have been a considerable change in the shelf benthos in North America, particularly in brachiopods at about the end of the Ashgill Stage. Changes in other forms appear to be less drastic, although corals were considerably reduced. Sheehan and others have emphasized the importance of regression induced by a glacial pulse as the cause for faunal changes at the boundary horizon. The African continental glaciation, however, developed earlier in the Ordovician and continued well into the Silurian. There were many advances, and there are many tills, separated by erosion surfaces or interglacial deposits. There does, however, appear to have been a major regression toward the end of the Ashgill Stage both in North America and Europe. Coupled with the fact that the faunal changes for the most part seem to have been rather gradual rather than sudden, there would not appear to be clear grounds for suspecting a shorter range catastrophic event to explain this horizon, although it represents a massive biomass extinction and drastic change in many community groups. The possibility of a short-term event contributing to the extinction cannot be entirely eliminated." (R51) The "short-term event" means an "impact event".

Nature of the late Permian biological extinction event. "The mass extinction at the end of the Permian, some 225 million years ago, has been called 'the great dying' by Harvard paleontologist Stephen Jay Gould. It was the most severe and widespread scouring in the history of life on earth. More than half the families of marine animals, including all the surviving trilobites and all the ancient corals, were obliterated. Some 75 percent of the amphibian families disappeared, by some accounts, and more than 80 percent of the reptilian. Raup estimates that by the end of the Permian 52 percent of all families of life forms had been extinguished. And from that he extrapolates: 'As many as 96 percent of the animal species then living were killed off at one swipe. That's a real holocaust.'" (R27)

Nature of the late Triassic biological extinction event. Again we rely on a paleontological overview from G. G. Simpson: "The next evolutionary acceleration occurred at the end of the Triassic Period when many of the remaining amphibians (Order Labyrinthodontia) and primitive reptiles (Orders Therapsida and Theocodontia) were abruptly replaced by more advanced types. Also at this time 24 out of 25 existing ammonite families became extinct." (R10)

For a geological perspective, we return to D. J. McLaren: "The Trias-Jurassic boundary extinction again corresponds to one of Boucot's unit boundaries, and affected virtually every marine fauna and community. The Trias was a time of high continentality, although Pangea had begun to divide into Laurasia and Gondwanaland with a developing Tethys in between. Although Hallam has claimed that it was a time of climatic equability, Tozer cites evidence of considerable latitudinal differentiation. The consensus of various taxa plots against time seems to be that this extinction is not as great as some of the others in the Phanerozoic, but may represent a relatively sudden event.... Sea level was relatively low, and there are few, if any, places in the world with a continuous marine succession across the boundary." (R51)

Nature of the late Cretaceous biological extinction event. This event, only 65 million years ago, has been the subject of extensive study due to the claim that it was caused by the impact of asteroid(s) and/or comet(s). "Both land and sea creatures perished at the end of the Cretaceous. Making an exit along with the dinosaurs were the flying reptiles, the giant marine reptiles, and numerous marine invertebrates, including the ammonoids---shelled animals which resemble the nautilus and which had twice before come to the verge of extinction, once at the end of the Permian and again at the end of the Triassic. Only a few species survived along the microscopic calcareous marine plankton whose skeletons of calcium carbonate sink to the ocean floor eventually to form limestone. Significantly for the present, mammals survived.

"The number of families going extinct at the end of the Cretaceous is probably somewhat lower than those wiped out at the end of the Permian, but the results are devastating enough. One estimate has 50 to 75 percent of all animal species dying out, and the evidence shows that the event was very abrupt in geological terms. Plankton disappeared from the seas within 200 years, according to Dutch geologist Jan Smit." (R37)

Nature of the upper Devonian biological extinction event. This event took place in the middle of the late Devonian, some 375 million years ago. Unlike the four major events described above, it does not mark the boundary between major geological periods. Instead it transpired at a lesser geological division---the Frasnian-Famennian boundary. According to G. G. Simpson, "90 per cent of the fish families, 95 per cent of the ammonoid families, and 60 per cent of the trilobite and coral families vanished, along with many others. Concurrent with the disappearance of these families primitive reptiles emerged and amphibians appeared and increased in number and diversity." (R10)

Nature of the Cambrian-Ordovician boundary event. "At this time about 65 per cent of the approximately 60 trilobite families became extinct. Inasmuch as the trilobites were the dominant fauna of the time, the significance of such decimation is apparent. Following this crisis, an abundance of new life forms, including ostracoderm fishes, tetracorals, and ostracodes, appeared in the Ordovician." (R10) On the Raup-Sepkoski graph (above) this event appears only as a minor dip.

Nature of the Pliocene-Pleistocene boundary event. "Again, between the Pliocene and Pleistocene epochs another worldwide occurrence of mass extinction caused the disappearance of the conodonts, the dominant mammals of the early Tertiary Period. Likewise, a decrease in the number of mammal families of fissipeds and ruminant artiodactyls occurred at this time." (R10)

Difficulties in the analysis of biological extinction events. In this section, we have adopted the term "biological extinction events". The word "event" is perhaps misleading, because paleontological events are not necessarily sharp and short-lived, like a solar eclipse or earthquake. A paleontological event, in the context of geological time, may be short---10,000 years---but long in human terms. Then, too, paleontological events may be sharp or broad, uniform or stepped, with species waxing or waning in and out of phase, and with many life forms not participating at all. Paleontology is obviously not physics!

Other measurement problems also intrude in the temporal analysis of a biological extinction event: (1) The fossil record is often incomplete; (2) Fossils may be "reworked" or displaced from their proper locations in sediments; (3) Paleontological boundaries and time scales may be defined differently in different parts of the world; and (4) We have no precise, uniformly agreed upon, quantitative definition of exactly what a biological extinction event is.

X1. Temporal structure of biological extinction events. A disproportionate amount of attention has been accorded the late Cretaceous (K-T) event. This has happened because of the asteroid/comet hypothesis. If such extraterrestrial catastrophism really caused the K-T event, the paleontological record should show a sharp, species-simultaneous, global transient in the biosphere. Indeed, mass extinctions have historically been considered "events"; but the studies focussed on the K-T boundary have shown that this boundary, at least, is a rather complex paleontological structure. Before and after the K-T biological extinction event, we have only a few temporal analyses; one at the late Triassic event, and another at the Eocene-Oligocene event, which was not even accorded major status in X0.

The late Triassic biological extinction event. First, illustrating the tenuous nature of biological extinction events, we quote the Abstract of a paper by P. E. Olsen and P. M. Galton:

> "Terrestrial vertebrate fossils show that part of the Newark supergroup of the eastern United States, all of the Glen Canyon group of the southwestern United States, and the Upper Stormberg group of southern Africa are Early Jurassic. This new correlation demonstrates that the supposed widespread tetrapod extinction at the Triassic-Jurassic boundary is an artifact of spurious correlation." (R25)

The message here is that extinctions may weaken or even disappear upon detailed analysis and changing ground rules. (WRC)

Further problems in the definition of the Triassic-Jurassic boundary and the possible stepped nature of the paleontological event are implicit in a paper by M. J. Benton: "These results indicate that the record of mass extinctions is not as straightforward as has been assumed by some authors: the choice of timescale may be crucial, and closer analysis of the fossil data may reveal quite different patterns from those presented so far. For example, in a recent study of the two mass extinctions in the Jurassic required by the 26-Myr cyclicity theory (end-Pliensbachian, end-Tithonian), Hallam found that the extinctions were regional, not global, in extent, being restricted largely to Europe.

"The record of mass extinctions is not yet well known. It should be possible to obtain more precise data on the stratigraphic and geographical ranges of different taxa, to refine geological time-scales, and to revise the systematics of various groups. Many authors have hitherto identified a single late Triassic mass extinction but more detailed studies of particular groups (for example, ammonoids and non-marine tetrapods) and of the whole marine and non-marine fossil record have indicated that there were two quite separate mass extinction events. This conclusion suggests that recent models of bolide-mediated cyclicity of mass extinctions may be incorrect." (R99)

The late Cretaceous (K-T) biological extinction event. It is at this geological boundary that the paleontologists and proponents of asteroid/cometary catastrophism have clashed. Is this event sharp or broad timewise? Here, too, questions about the demise of the dinosaurs have come to the fore. Had they already mostly faded away before the K-T event? Finally, was the K-T biological extinction event single or multiple in character?

Paleontologists, responding to the asteroid hypothesis of W. Alvarez et al, have generally maintained that the paleontological signature at the K-T boundary is broad and complex. C. B. Officer and C. L. Drake comment: "If there has been an extraterrestrial event, then the faunal transitions did not occur instantaneously in response to it; there is a range of transition times and transition time intervals depending on the fossil descriptor and site location." (R50)

To which, proponents of extraterrestrial catastrophism (and non-paleontologists) reply: "Evidence indicates that the Cretaceous-Tertiary boundary is very sharp, and, within the limits of resolution, it is apparently synchronous at the various boundary localities. Arguments to the contrary, particularly those of Officer and Drake, are shown to be invalid." (R74)

Paleontologists, however, have continued to demur. In 1987, A. Hallam wrote: "To summarize, the biotic record suggests a compound scenario, with a more or less gradual increase in extinction rate for many groups of organisms followed by a culminating catastrophe lasting no more than a few tens of thousands of years and maybe less." Hallam goes on to say that even if the extinction event were sharp, this would not establish an extraterrestrial cause. (R116)

Looking at the fossil record of the dinosaurs in particular, we find considerable dissension regarding their history just prior to the K-T event. D. A. Russell objects to the prevailing view that the dinosaurs were already in decline, and had been for about 10 million years, when the K-T event occurred: "The postulated decline is usually supported by comparing diversity levels in 76 Myr-old and 64 Myr-old dinosaurian assemblages from North America. The resulting differences in diversity have never been compared, however, with those observed between older dinosaurian assemblages, when their extinction was not imminent. I show here that, taken as a whole, the known fossil record of North American dinosaurs shows no evidence of a decline in taxonomic diversity lasting several million years or more before their extinction." (R64)

Disagreement prevails regarding dinosaur decline, as demonstrated by the opinion of W. A. Clemens, a paleontologist who doubts that an extraterrestrial impact is needed to explain the K-T boundary. "...there is still very good reason to question whether extraterrestrial objects had anything at all to do with terrestrial extinctions. In his own studies, for instance, he has found the last fossil traces of dinosaurs as far as three meters below the K-T boundary, suggesting that they became extinct well before the presumptive impact that produced the iridium spike. Moreover, Clemens has traced dinosaur diversity patterns through late Cretaceous rock formations and observed a significant reduction in the number of species and overall population size during the 10 million years leading up to the K-T boundary. To Clemens, this clearly suggests that dinosaurs were not in full flower but were, in fact, already well on their way out long before the putative asteroid event 65 million years ago." (R96)

The situation with plant fossils, on the other hand, is clear-cut; it is sharp and synchronous with the Cretaceous-Tertiary boundary. R. H. Tschudy et al summarize the situation in western North America: "Abstract. The palynologically defined Cretaceous-Tertiary boundary in the western interior of North America occurs at the top of an iridium-rich clay layer. The boundary is characterized by the abrupt disappearance of certain pollen species, immediately followed by a pronounced, geologically brief change in the ratio of fern spores to angiosperm pollen. The occurrence of these changes at two widely separated sites implies continentwide disruption of the terrestrial ecosystem, probably caused by a major catastrophic event at the end of the period." (R76) Similar results have been reported in Japan. (R100)

....

A most curious development in the study of biological extinction events has been the discovery of the stepped nature of the diversity and populations of the affected species. Are these quantum steps in the temporal structure of the event the consequence of stepwise catastrophism, either terrestrial or astronomical, or are unrecognized biological variables involved? Only more research will tell. (WRC)

"Perhaps the first scientist to take notice of stepping as a characteristic of K-T extinction and other mass extinctions was Erle G. Kauffman of the University of Colorado at Boulder. A marine paleontologist, Kauffman has for more than two decades concentrated largely on studies of the K-T boundary of molluscan macrofossils. His particular interest is mollusks, including Cretaceous, reef-forming rudists. These bivalves underwent a tremendous, global expansion in mid-Cretaceous times, displacing corals, by way of competitive superiority, as the major reef-building organisms. Kauffman investigated extinction among bivalves at various sites in the Western Interior, on the Atlantic Coast of North America, on continental sections of Western Europe, and in the Caribbean Sea and Central America.

"Through an extensive analysis of all available evidence for extinction patterns of marine macrofossils across the K-T boundary, Kauffman concluded in a report published in 1984 that the mass extinction was a protracted event spanning a period of about three million to four million years. In his reading of the data base, Kauffman sees the disappearances beginning about two million years before the K-T boundary and proceeding in a series of five discrete steps across the boundary into the early Tertiary period. He finds that the most dramatic extinction event occurred at the boundary itself. Each step, he explains, represents a short episode of highly accelerated extinctions. Those first affected were the most ecologically sensitive organisms (e.g., tropical creatures presumably able to withstand only the narrowest swings in temperature or oceanic chemistry), with progressively more tolerant groups succumbing in the later stages." (R96)

"Evidence garnered by marine paleontologists has also served to undermine the original Alvarez hypothesis. Here, too, the fossil record tends to refute a primary assumption of the collision thesis: that all late Cretaceous organisms that went extinct did so at the K-T boundary. Working in Zumaya, Spain, on an outcrop that had lain beneath the sea 65 million years ago---a section bearing perhaps the most complete, continuous, land-based marine fossil record of the Cretaceous and Tertiary periods---Peter Ward of the University of Washington in Seattle scrupulously tracked, layer by layer, the history of the ammonites, the once-populous marine invertebrates.

"He found that the ammonites---which bore a strong resemblance to today's chambered mollusk, the sea nautilus---had begun to go into serious decline six million to seven million years before the end of the Cretaceous period, and had all but disappeared 300,000 years before the K-T boundary.

......

"Closer analysis of the ammonite data brought yet another critical observation to light. It seems that these species died out not one by one in a series of gradual, continuous disappearances but rather in what amounted to three or four rather abrupt steps. First, a few species went out at one level, then a few more disappeared perhaps hundreds of thousands or a million years later, and so on. Still-viable species remained stable during the intervening sequences, though no new species of ammonites sprang to life." G. Keller observed similar stepwise extinctions near the K-T boundary in the fossils of planktonic foraminifera. (R96)

P. Hut et al has provided much more detail of the K-T stepped extinctions. He attributes the stepwise nature to cometary showers, thus modifying the original Alvarez single impactor theory. (R114)

The Eocene-Oligocene biological extinction event. This event, dated at about 36.5 million years ago, is marked by an iridium spike and the presence of microtektites. (See ESC1.) Alvarez and his camp suggested that these features and the accompanying biological extinctions are the consequence of the impact of a single astronomical projectile.

B.H. Corliss, et al, in 1984, reported that their analysis of calcareous and siliceous microfossils across this boundary revealed no massive extinction event, only gradual biotic changes. (R78)

Another researcher, however, did find extinction phenomena at this boundary---once again these were stepped in nature. The researcher was G. Keller, from Princeton, who had been analyzing deep-sea cores from the Eocene-Oligocene boundary for several years. " The cores were continuous (i.e., without geological gaps), enabling her to observe changes with resolution of just a few thousand years. The story the fossils told was that of stepped extinctions over a period of 3.4 million years, between 40 million and 36.6 million years ago. Close examination indicated that each of the four successive and rather sharply defined steps was marked by the extinction of three to five species. The steps were separated by relatively stable or quiescent periods and included the accelerated origination of new species. The species that became extinct at each step represented fewer that 15 percent of the number present, but the sum total of the late Eocene stepwise extinctions resulted in a near complete faunal turnover. Collectively, it was a mass wipeout." (R96) In contrast, the stepwise structure of the K-T "event" did not seem to involve the creation of new species. (WRC)

X2. Biological selectivity of biological extinction events. Although widely traumatic for the earth's biosphere, biological extinction events seem to leave some families of organisms largely unscathed. This biological selectivity is important because it may provide clues as to the nature of the geological, astronomical, and biological events that precipitate extinctions.

Only at the Cretaceous-Tertiary (K-T) boundary have we found any analysis in depth of biological selectivity. First, we present two overviews; one rather popular in style, the second more technical.

"The only taxa that did not make it across the K-T boundary at all, says (W.A.) Clemens, were the dinosaurs, the pterosaurs (flying reptiles), and one family of freshwater fish. Two orders of animals showed a high rate of extinction: marsupials (which lost 75 percent of late Cretaceous genera and 65 percent of families) and freshwater sharks and rays (which lost three of five Cretaceous genera). Turtles, by contrast, sailed through the boundary almost unscathed, according to recent studies by William Clemens' Berkeley colleague, J. Howard Hutchinson, and former student David Archibald, now at the University of California at San Diego. They detected a loss of only three of nineteen turtle genera---representing an extinction rate of merely 16 percent. Unlike marsupials, the other orders of mammals, multituberculates (rodent-like animals) and placentals, fared pretty well. Among the former, four of eleven genera and two of eight families became extinct during the transition from the Cretaceous period to the Tertiary period. Among placental animals, only one of nine genera and one of four families died out at the end of the period." (R96)

In Nature, in 1987, C. B. Officer et al descibe the K-T biological selectivity in the following terms: "The end of the Cretaceous is marked by the extinction of the marine reptiles, the flying reptiles, dinosaurs and ammonites together with numerous families of scleractinian corals, bivalves such as the inoceramids and rudists, gastropods and echinoids. In addition the coccolithophorids, planktonic foraminifera and belemnites suffered almost complete, though not geologically instantaneous, extinction with only a few species surviving the crisis; many genera of the larger benthic foraminifera and radiolaria also disappeared. On the other hand, and making due allowance for the poorer quality of the fossil record, a number of groups were little affected including many types of land plants, freshwater invertebrates, snakes, mammals and many marine invertebrates including deep sea benthic organisms." (R112)

Many writers have comments on various details of the selectivity manifest at the K-T biological extinction event. A few examples follow which may have special geological and biological significance:

Only 14% of freshwater genera and 20% of terrestrial genera became extinct, compared, say, with 48% of swimming marine organisms. (R39)

"Marsupials but not placentals nearly eliminated; most arboreal multituberculates and birds survived." (R70)

The ammonites were wiped out, but the quite similar nautiloids survived. (R52)

Although the dinosaurs met their demise, the crocodilians, which are very sensitive to temperature, survived. (R69)

"Tropical plants, the ones least equipped to resist prolonged darkness and the resulting cold, came through in the best shape." (R41)

These tidbits hardly lead to any profound conclusions. One might say, though, that darkness and cold may not have been important aspects of the K-T event. One might venture, too, that the disasters suffered by the marsupials and ammonites might have had biological origins, say, diseases or parasites or even disadvantageous mutations. (WRC)

X3. Geographical selectivity of biological extinction events. The study of the stratigraphic record has so far produced only generalities about geographical selectivity of extinction events. It would be extremely valuable to theorists to know of any geographical biases of extinction phenomena. To illustrate, the geographical concentration of mortality could help locate impact craters or volcanos responsible for the extinctions. Much of the problem in obtaining such data stems from the nature of the stratigraphic record itself. Paleontologists have good, uninterrupted exposures in some places, but elsewhere the rocks of the same period may be lacking altogether. Bearing these factors in mind, we commence with two general observations and then become as specific as possible.

First, N. D. Newell has commented on the tendency of some species to persist in some locales long after becoming extinct elsewhere: "A clue to the meaning of some of the systematic deficiencies of the fossil record is provided by the recent discovery of living coelacanth fishes and monoplacophoran molluscs long known from the fossil record and supposed to be extinct since the Cretaceous and Devonian periods, respectively. There are many such illustrations in the fossil record of stragglers from once widespread and abundant groups that have become greatly restricted geographically, living on in some isolated area for millions of years after their disappearance on other areas. For example, blastoids died out in early Pennsylvanian times over most of the world, but they survived well into the Permian period in Indonesia, a time span of forty or fifty million years." (R5)

Next, D. Ager reminds us how geographically spotty the stratigraphic record can be, even without extinction events: "A distant relation of Halorella, called Peregrinella, is even more remarkable in Early Cretaceous rocks. It is best known from the presbytery garden at Chatillon-en-Diois, in the French Alps, but has also been found in a single block in Poland, as a single specimen in Czechoslovakia, at a single locality in California and at not more than two or three other places in the world. Yet it is one of the most distinctive brachiopods in the whole record and it has internal structures that make it clear that none of the abundant brachiopods in the strata above or below could possibly be classified as even distant relations. Its name means, in fact, 'little stranger', though it is by no means small for a brachiopod.

"In other words, we have fossils that just suddenly appear around the world at one moment in geological history and 'whence, and whither flown again, who knows'?" (R20)

The biological extinctions near the K-T boundary were far from uniform geographically, as noted by J. D. Archibald and W. A. Clemens: "First and foremost is the already noted difficulty in correlating events in the terrestrial and marine realms. Second, the patterns of extinction of marine organisms and plants differ geographically. While the data of Kauffman indicate that among marine organisms, those in tropical to subtropical regions were hardest hit, the data of Hickey show that among land plants, those in more temperate regions suffered the greatest losses. Moreover, Hickey has pointed out that this pattern of land plant extinction is the opposite of what one would expect from a catastrophic event, namely, that plants in lower latitudes would suffer most, since they tend to lack the relatively better developed dormancy and carry-over mechanisms of more temperate plants." (R45)

This difference in the response of plants is sometimes ignored: "One very consistent pattern of mass extinctions, however, is that although each event typically affects different suites of organisms, tropical biotas are nearly always hardest hit, for which there might be several explanations. For one thing, there is always a species diversity gradient from high in the tropics to low in temperate regions, and so there could be a statistical element in the bias toward tropical extinctions. But there are real biological properties that might bear on this too." One of these biological properties is "geographic provincialism"; that is, the species that tend to survive extinctions tend to be generalized organisms that are geographically widespread. (R57)

X4. Possible periodicity of biological extinction events. Humans are entranced by cycles and sometimes see them where they do not exist. Even so, nature does display many periodicities, from the sunspot cycle to swings in animal populations. Occasionally a geologist has wondered if the earth, too, did not undergo cycles of orogeny and volcanism, which originated in some internal resonant phenomenon---perhaps like Old Faithful geyser at Yellowstone---but with a period of many millions of years. Cyclic astronomical catastrophism was hardly even considered as a modulator of biological extinctions. But geological fashions change too.

C. B. Hatfield and M. J. Camp were thinking about the astronomical modulation of biological extinction events a full decade before the great debate on this subject in the 1980s:

"We are impressed by the lack of emphasis placed on the periodicity of mass extinctions. As mentioned by (N. D.) Newell and (G. G.) Simpson, the seven most intense mass extinctions, based on percentages of the total known fossil assemblage affected, were in the late 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 biological 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 preceeded 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."

The authors continued by remarking that only astronomical cycles seemed to be long enough to compare with extinction cycles. Specifically, they mentioned the rotation of our galaxy in the sun's vicinity (200 million years) and oscillations perpendicular to the galactic plane (80-90 million years). (R12)

The debate of the 1980s involving the question of periodicity in biological extinctions was mainly the consequence of a study by J. Sepkoski and D. Raup. First, a popular appraisal of their work and then their own Abstract.

"For six years John Sepkoski of the University of Chicago has been engaged in the tedious job of compiling records of when families of marine organisms vanished from the fossil record. Recently, with David Raup, also at Chicago, he drew up graphs presenting the data. A curious pattern emerged, one that scientists could neither explain nor ignore. Roughly every 26 million years for the last 250 million years, the numbers of extinctions jumped above the background of extinctions that occur in the normal course of life. Mass extinctions, they conclude, are not random events, as has been widely believed. Instead, it appears, at regular intervals something perturbs the biological system, not destroying it but resetting it so powerfully that the ensuing changes forever twist the course of evolution." (R54)

And now, the Abstract of Sepkoski and Raup:

"Abstract. The temporal distribution of the major extinctions over the past 250 million years has been investigated statistically using various forms of time series analysis. The analyzed record is based on variation in extinction intensity for fossil families of marine vertebrates, invertebrates, and protozoans and contains 12 extinction events. The 12 events show a statistically significant periodicity ($P < 0.01$) with a mean interval between events of 26 million years. Two of the events coincide with extinctions that have been previously linked to meteorite impacts (terminal Cretaceous and Late Eocene). Although the causes of the periodicity are unknown, it is possible that they are related to extraterrestrial forces (solar, solar system, or galactic)." (R59) Referring back to X0, far fewer than 12 extinction events are generally recognized.

J.N. Wilford, in the New York Times, provided an interesting philosophical comment: "More immediate is the impact of the unexpected discovery on the thinking of those scientists who ponder the history of life, including paleontologists, geologists and evolutionary biologists. The idea of a cyclical pattern to mass extinctions calls into question some assumptions about the slow, steady workings of nature and elevates the importance of rare, catastrophic events in setting the course of life." (R53) In essence, Wilford sees periodicity as a denial of uniformitarianism.

Partisans of extinction cyclicity have found some support in the apparent periodicity of large terrestrial craters. In 1984, Alvarez and Muller found a 28.4-million-year cycle based on the radiometric dating of 13 large craters. (R66)

M.R. Rampino and R.B. Stothers published their results in the same year: "Abstract. Time-series analysis reveals two dominant, stable long-term periodicities approximately equal to 33 ± 3 and 260 ± 25 million years in the known series of geological and biological upheavals during the Phanerozoic Eon. Because the cycles of these episodes agree in period and phase with the cycles of impact cratering on Earth, these results suggest that periodic comet impacts strongly influence global tectonism and biological evolution. These two periodicities could arise from interactions of the solar system with interstellar clouds as the solar system moves cyclically through the galaxy." (R79)

For much more detail on the subject of crater periodicity, consult ETC4 in another volume of this series.

With all the uncertainties present in the fossil record, it is not surprising that the results of Raup and Sepkoski were quickly challenged. R.A. Kerr summarized this in Science: "Recent considerations of the original statistical analyses have tended to weaken the significance of the claimed periodicities. Tremaine believes that 'the extinction data simply don't have any reliable evidence for periodicity.' Carrying out their own Monte Carlo tests to determine how often an apparent periodicity might appear due to random events, (S.) Tremaine and Julie Heisler found a confidence level of less than 90 percent compared to Raup and Sepkoski's original confidence level of 99.74 percent. Raup and Sepkoski have recently reduced their number of reliably identified mass extinctions of the past 250 million years from 12 to 8, which reduces the confidence level to only 50 percent, according to Tremaine and Heisler's calculation. (E.) Shoemaker can find no evidence of extinction periodicity either. He pares the number of mass extinctions from 12 to 4 because he believes that the rest are either not certain to exist or are not dated precisely enough." (R91)

Raup and Sepkoski responded to these criticisms with an article in Science in 1986. By analyzing eight biological extinction events involving marine families, they confirmed their original periodicity of 26 million years. (R102)

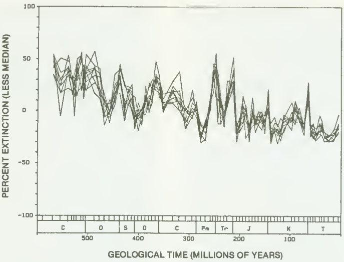
In an overview written for the National Science Foundation publication Mosaic, B. Patrusky noted that: "...many paleontologists are not at all convinced that the periodicty Raup and Sepkoski see in the marine record is, in fact, real. Among the counterarguments for cyclicity is the observation that not all the peaks in the Raup-Sepkoski analysis represent true extinction events. 'Several are actually nonexistent or barely above noise level,' says Donald Prothero of Occidental College in Los Angeles. 'And once peaks are missing, you no longer have cyclicity.' He notes too that even among the real peaks, where there is incontestable evidence of major extinction events, the disappearance and survival patterns vary significantly from episode to episode. 'If cyclicity is real and the consequence of a common causative agent,' says Prothero, in arguing against Raup-Sepkoski, 'then common biological patterns [of extinction] should be evident in the record. But that's not what we see.'

"Other refutational field evidence comes from a study reported in a mid-1986 Science by Frank T. Kyte and John T. Wasson of the Institute of Geophysics and Planetary Physics at the University of California in Los Angeles. They measured the concentration of iridium in samples from a 9-meter section of a deep-sea core dug up from the floor of the Pacific Ocean. The section covered the time span of 33 million to 67 million years ago, an interval embracing extinction events at the Cretaceous-Tertiary boundary and the late Eocene period. They found that iridium levels fell far short of what their calculations told them should have accumulated had the earth been barraged by cometary showers. Their conclusion: 'The evidence...casts serious doubts on the existence of periodicities in catastrophe-induced extinctions.'" (R96) One might add here that evidence from iridium spikes in the stratigraphic record have been subjected to criticism similar to that applied to extinction events. See ESC1.

The criticisms, however, have stimulated D. Raup to amass even more data. in a 1988 article in Science, he and G. Boyajian present an analysis of the ups and downs of 20,000 marine genera---that is, percent extinction over a period of 600 million years, as revealed in the fossil record. The graph of ten groups and 1000 genera each shows at least two things: (1) strong hints of periodicity; and (2) suggestions that extinctions, whatever they really are, "cut across functional, physiological, and ecological lines." Raup and Boyajian claim that whatever the cause, "major pulses of extinction result from geographically pervasive environomental disturbances." (R125)

Could the causative factors, after all, be purely terrestrial in nature? The frequent correlation of extinction events with magnetic field reversals, climatic changes, and various geological phenomena have suggested to D. E. Loper et al that cycles of activity within the earth's mantle and core may be the cause. "We propose that these cycles are due to variations in the thickness of the thermal boundary at the base of the mantle as the layer alternates between two phases of activity. In the quiescent phase little flow occurs and the layer thickens with time by thermal diffusion. The active phase begins when the thickening layer becomes dynamically unstable. Hot material erupts from the layer, causing it to become thinner. As the layer thins, the rate of energy supply to the geodynamo, and hence its reversal frequency, increases. The hot material rises to the surface, where it causes widespread basaltic volcanic eruptions. These eruptions release large amounts of CO_2 and sulfates which have a pronounced effect on the climate and biota." (R120) Again, Old Faithful provides a crude analogy of natural terrestrial periodicity. (WRC)

X5. Relationship between biological extinctions and biological explosions. A fixture of mainstream paleontology is that biological explosions and extinctions are causally con-



Periodicity in the fossil record, as illustrated by percent extinction for ten random groups of 1000 genera. (X4) (Adapted from R125)

nected, as stated clearly by A.N. Strahler:

> "Rapid extinctions of large groups of organisms lead to vacant environments, and these are rapidly filled by adaptive radiation of other groups. Major episodes of extinction followed by rapid evolutionary radiation seem to have marked the transitions from one geologic era to the next." (R124)

N.D. Newell has expanded a bit on this assertion by bringing in physical events or diastrophism:

> "It is believed that the evolutionary peaks coincide with times of rapid expansion into evolutionary niches previously vacated by extensive extinctions. Diastrophism influences the course of evolution by causing extinction, migrations and modifications in habitats, but there is no evidence that there is increased evolutionary activity during diastrophic disturbances; in fact, the converse may well be true." (R1)

This filling of vacant niches by biological speciation is, of course, consistent with the evolutionary dogma that life progresses by random mutation followed by natural selection. Anomalies that contradict this view are presented in the biological volumes of the Catalog of Anomalies. Here, our purpose is the identification of geological facts at odds with the belief that extinctions and explosions are causally related.

The unusual nature of the Cambrian explosion. First, there is the question as to whether a biological extinction really occurred at the Precambrian-Cambrian (P€/€) boundary. In the case of the metazoans, there seems to have been no extinction, although geochemical anomalies have definitely been recognized. (ESC1) S.K. Donovan remarks: "Whatever we read into the geochemical anomalies, our interpretation of mass extinction must depend upon changes seen in the fossil record. Both body and trace fossils, as well as carbon isotopes, show a pattern of distribution across the P€/€ boundary that suggests the early metazoan radiation was not punctuated by the hiccup of an extinction event." (R128)

It has also been pointed out that the Cambrian biological explosion, whether it was or was not preceded by an extinction, was dramatically different from all other explosion events. All existing phyla and many extinct phyla came into being at the Precambrian-Cambrian boundary. At no other geological juncture has there been such a major spate of macroscopic evolution. All new body plans were invented at this boundary; whereas biological innovation at other boundaries was confined to lower taxonomic levels. (R121)

Surges in diversification often precede extinctions. K. S. Thomson has plotted the number of genera for several groups of lower vertebrates as functions of geological time. Most of the plots are shaped like inverted Vs, indicating that diversification was usually as rapid as extinction. Indeed, he says, "Rapid extinction is thus a normal and immediate consequence of diversification for the groups shown." He does, however, exclude from this generalization the Permian-Triassic extinction. (R23) The fact of biological innovation actually preceding extinction would seem to confuse the role of external or environmental forces (diastrophism). (WRC)

A similar situation apparently prevailed in the plant kingdom: "...the succesive radiations of the trimerophytes, progymnosperms, pteridosperms and angiosperms preceded the extinctions of the rhyniophytes, trimerophytes, progymnosperms and many previously important gymnosperm groups respectively. Thus, animal extinctions permitted animal radiations, whereas plant radiations caused plant extinctions." (R55)

The question of periodicity. As expressed in X4, it is fashionable today to see the ups and downs in the fossil record as the consequence of physical events. True periodicity in the fossil record, if it exists, is thus due to periodic visitations of comets or, possibly, cyclic terrestrial climate changes. This view accords with evolutionary dogma, and it therefore escapes severe scrutiny. But as recently as 1952, G. G. Simpson wrote:

> "The real periodicity that does appear in vertebrate history seems to result from orderly evolutionary progression, succession, and replacement rather than being conditioned primarily by any periodic physical phenomena. Physical events in earth history are among the complex factors which, all together, produce and guide evolutionary change. Little support is found, however, for the theory of simultaneous, world-wide physical and biological climaxes at the period and era boundaries." (R129)

Of course, science has now found much more support for global physical catastrophes, but Simpson's thought that the cyclic character of evolution might be found in the character of life itself should not be ignored. We do not yet fully understand the mechanism of biological diversification, and species may die off quietly and naturally. Life-on-earth is a complex system. It may oscillate naturally as regards its diversity. (WRC)

X6. Correlation of biological extinction events with sealevel changes. Little has been found so far showing that extinctions occur in synchrony with sealevel changes. N. D. Newell has made the following generalization:

> "There is now considerable evidence that evolutionary diversification was greatest during times of maximum flooding of the continents, when the number of habitats was relatively large. Conversely, extinction and natural selection were most intense during major withdrawals of the sea." (R8)

A supportive paper by M. R. House maintains that the extinctions of mid-Paleozoic ammonoids correlated with sealevel changes. (R87)

In contrast to the assertions of Newell and House, P. Williamson has found that fossil molluscs, near Lake Turkana in northern Kenya, show just the opposite effect:

> "The most interesting observation comes at two points in geological history when the lake level dropped sharply. When this happened, all the species that Williamson studied underwent a brief period of change, at the end of which time clearly identifiable progeny species were established. By brief here is meant something between 5,000 and 50,000 years." (R38)

In other words, new species arose at low lake levels, and extinctions occurred during lake transgressions---just the opposite of what seems to occur in the ocean.

X7. Biological extinction events without geological unconformities. Massive extinction events, one would think, would be marked not only in the fossil record but also the sedimentary sequences; that is, there should be a geological unformity signifying a great terrestrial change of some kind. Usually, this is the case; but not at the Permian-Triassic boundary.

"The Trias, which succeeds the Permian, is regarded as the beginning of Mesozoic times. But in England the division seems most improper, for in the field (in South Lancashire, for example) it is impossible to decide when the Permian passes into the Trias, and indeed at no point in Britain is that junction recognizable. If it marks a major event in the history of life, an event which has commonly been believed to be associated with changes in the distribution of land and sea and the climatic alterations associated with widespread diastrophism, it should be most recognizable." (R3)

And again: "The Permo-Triassic rocks of Greenland, the Dolomite Alps, the Salt Range of Pakistan, and other regions show rock sequences which are not everywhere clearly divided at the systemic boundary by a visible unconformity. Nevertheless, there is a striking paleontological discontinuity, which occurs between the upper Permian and the overlying Triassic in all of these areas." (R2)

This is a remarkable anomaly, particularly when contrasted to the situation at the K-T boundary. No one seems to be trying to cope with this problem. (WRC)

X8. Correlation of biological extinction events with geomagnetic reversals. At least as early as the 1960s, some scientists noted an apparent correlation between the fossil record and the geomagnetic signatures in the same formations. Two questions have dominated the debate over these supposed correlations: (1) Are the correlations good enough to imply a causal relationship? and (2) Is there a reasonable causal connection, either direct or indirect?

The correlations. The early correlations linked radiolarian extinctions in the Southern Ocean with geomagnetic reversals over the past 10 million years. (R11, R13) Later writers extended the span of the inquiry geographically and temporally, as in this quotation from M. A. Whyte:

> "During the last 450 Myr there has been concomitant variation in the Earth's rotation rate, the polarity bias of the geomagnetic field, the amount of activity at ocean ridges, sea level and climate. At turning points when trends in the variables reverse themselves, climatic instabilities have disrupted biological ecosystems and led to mass extinctions." (R24)

All this sounds very reasonable, but in 1908 R. E. Plotnick dampened this sort of speculation by demonstrating that extinction-geomagnetic reversal correlations may be spurious:

> "Abstract. It has been repeatedly suggested that reversals of Earth's magnetic field play a controlling role in evolution. Empirical evidence put forward to support this hypothesis has come from comparisons of the stratigraphic positions of microfossil extinctions with individual reversals and from comparisons of various estimates of changes in Phanerozoic diversity or turnover rates to some measurement of polarity change. Published associations between microfossil extinctions and magnetic reversals are reanalyzed using probabilistic techniques. The interrelationships of Phanerozoic diversity and turnover rates to measurements of the magnetic field are examined through correlation analysis. Results indicate that no currently demonstrable relationship exists between faunal extinctions and geomagnetic reversals." (R36)

Even so, papers continue to be published on these correlations.

Possible causal mechanisms. Since correlations will not be believed unless causal mechanisms can be demonstrated, much of the literature deals with this topic. Interestingly enough, an early paper by J. F. Simpson correlated biological explosions with geomagnetic reversals, asserting that the increased cosmic ray flux during periods of reduced magnetic field would accelerate the mutation rate. (R8, R10) Most researchers, however, linked the magnetic reversals with extinctions and blamed cosmic rays and solar flares during period of low field for the decimation of terrestrial life. (R29) But other scientists demonstrated that the increased cosmic ray dosages would have been too small to cause wholesale extinctions. (R19) In 1971, I. K. Crain and others proposed that biological extinctions might be explained solely through the deleterious effects of low magnetic fields upon life forms. (R10, R17, R19) Although Crain cited some experimental work supporting his theory, the subject seems to have faded away.

Possible indirect connections between biological extinction events and geomagnetic reversals include clime changes, orogeny, widespread volcanism, and comet/asteroid impacts. (R14, R16, R19) In these correlations, both the extinctions and magnetic reversals have a common cause but no direct cause-and-effect relationship. Here, too, a general consensus has not yet been attained.

X9. Correlation of biological extinctions events with galactic events. In ESC1, this subject was treated in the context of astronomical events influencing the rates with which comets/asteroids impacted the earth, causing biological extinctions in the process. Here, we present an alternate mechanism:

"Abstract. Periodicity of mass extinctions in Earth history is correlated with the periodicity of the sun's orbit about the galactic center and its movements perpendicular in the galactic plane. Periodically increased doses of cosmic radiation related to the sun's position in the galaxy are suggested as a cause of recorded mass extinctions." (R12)

No further discussion of this proposal has been found to date.

X10. Correlations of biological extinction events with volcanism. The possible connection between chemical signatures in the stratigraphic record and widespread terrestrial volcanism was discussed in ESC1. Because extinction events were related there to the chemical signatures, there is an obvious link to volcanism, too. However, J.P. Kennett and N.D. Watkins eschew the chemical signature link:

"Studies of deep-sea sedimentary cores from Antarctic Pacific waters show that some volcanic maxima occurred when the geomagnetic polarity was changing. Upper mantle activity and geomagnetic polarity change may therefore be related. Coincidences of faunal extinction and geomagnetic polarity change may be explained by corresponding volcanically induced climatic changes." (R14)

Obviously, many factors could be involved. They are far from being sorted out. (WRC)

X11. Correlations of biological extinction events and chemical spikes. The temporal precision of this proposed correlation is dealt with in ESC1-X1D. Also of interest to anomalists, in view of the wide acceptance of the reality of an iridium-spike/biological-extinction connection, is the apparent lack of any chemical signatures at some well known extinction horizons. Specifically, negative results have been reported for the Late Cambrian (R71) and the Late Devonian (R65, R94). See ESC1-X1C for additional discussion.

X12. Correlation of biological extinction events with microtektites. Radiolarian extinctions in the late Eocene are apparently well-correlated with iridium spikes. A microtektite layer is also found here, but it seems to have been deposited later than the iridium layer. No causal connection seems indicated here. (R48, R88)

X13. List of possible causes of biological extinction events. Scientists, like most humans, like to speculate. One result of this tendency is a long list of possible causes of biological extinction events. In fact, a rather extensive listing was drawn up by H.F. Osborn as far back as 1906. (R127) We will not do much more than compile another list here, since the major focus of this Catalog is facts rather than theories. It is appropriate to begin with a paragraph from A.N. Strahler:

"Anyone hardy enough (and perhaps foolish enough, as well) to undertake a complete listing of possible causes of mass extinctions is immediately confronted with a discouraging variety of complications and contradictions. A given single-mechanism explanation may seem to fit well with extinction taking place in a single ecological environment or affecting a single taxonomic group. For example, cooling of the ocean may account nicely for several important extinctions of marine animals and plants, but will that same explanation apply to extinctions of many reptile groups on the lands? Many explanations have been offered for the disappearance of the dinosaurs---for example, that they died off in a great disease epidemic---but the same explanation cannot easily apply to mass extinctions of marine plankton." (R124)

A list of causes that is surely incomplete. Many of the situations and events listed below are obviously interrelated.

Disease (R18)
Climate changes (including temperature changes, greenhouse effect, storminess, etc.) (R18, R37, R51, R66, R93, R96, R118, R119, R113, R120)
Interspecies competition and predation (R18, R51, R52)
Parasites (R18)
Environmental poisoning (including acid rain, changes in atmospheric composition) (R18,

R51, R93)
Cosmic radiation (including solar flares and supernovas) (R21, R37, R45, R51)
Sealevel changes (R21, R51, R66)
Ocean composition (R27, R28, R45, R72, R105)
Overcrowding (R37)
Magnetic reversals (R37, R120)
Lunar volcanic eruptions (R37)
Comet/asteroid/meteorite impacts (R37, R45, R51, R66, R93, R96, R124)
Volcanism (including basalt flooding, orogeny) (R51, R96, R112, R120, R124)
Tsunamis (R51)
Constitpation! (R21, R37)

References

R1. Newell, Norman D.; "Periodicity in Vertebrate Evolution," Journal of Paleontology, 26:371, 1952. (X5)

R2. Newell, Norman D.; "Catastrophism and the Fossil Record," Evolution, 10:97, 1956. (X0, X7)

R3. Watson, David Meredith Seares; "The Two Great Breaks in the History of Life," Geological Society of London, Quarterly Journal, 112:435, 1956. (X7)

R4. Dewar, Douglas; "The Successions of the Faunas," The Transformist Illusion, Murfreesboro, 1957, p. 36. (X1)

R5. Newell, Norman D.; "The Nature of the Fossil Record," American Philosophical Society, Proceedings, 103:264, 1959. (X3)

R6. Shute, Evan; Flaws in the Theory of Evolution, Philadelphia, 1961. (X0)

R7. Velikovsky, Immanuel; Earth in Upheaval, New York, 1965. (X0)

R8. Newell, Norman D.; "Crises in the History of Life," Scientific American, 208:77, February 1963. (X0, X2, X3, X6)

R9. Bramlette, M.N.; "Massive Extinctions in Biota at the End of Mesozoic Time," Science, 148:1696, 1965. (X0)

R10. Simpson, John F.; "Evolutionary Pulsations and Geomagnetic Polarity," Geological Society of America, Bulletin, 77:197, 1966. (X0, X8)

R11. Hays, James D., and Opdyke, Neil D.; "Antarctic Radiolaria, Magnetic Reversals, and Climatic Change," Science, 158:1001, 1967. (X8)

R12. Hatfield, Craig B., and Camp, Mark J.; "Mass Extinctions Correlated with Periodic Galactic Events," Geological Society of America, Bulletin, 81:911, 1970. (X4, X9)

R13. Watkins, N.D., and Goodell, H.G.; "Geomagnetic Polarity Change and Faunal Extinction in the Southern Ocean," Science, 156:1083, 1967. (X8)

R14. Kennett, J.P., and Watkins, N.D.; "Geomagnetic Polarity Change, Volcanic Maxima and Faunal Extinction in the South Pacific," Nature, 227:930, 1970. (X8, X10)

R15. McLaren, D.J.; "Time, Life, and Boundaries," Journal of Paleontology, 44:801, 1970. (X0)

R16. Hays, James D.; "Faunal Extinctions and Reversals of the Earth's Magnetic Field," Geological Society of America, Bulletin, 82:2433, 1971. (X8)

R17. Crain, Ian K.; "Possible Direct Causal Relation between Geomagnetic Reversals and Biological Extinctions," Geological Society of America, Bulletin, 82:2603, 1971. (X8)

R18. Macbeth, Norman; "Extinction, A Mystery," Darwin Retried, Boston, 1971, p. 118. (X13)

R19. Purrett, Louise; "Magnetic Reversals and Biological Extinctions," Science News, 100:300, 1971. (X8)

R20. Ager, Derek V.; "The Fleeting Fossil," The Nature of the Stratigraphic Record, London, 1973, p. 15. (X3)

R21. Hallam, A.; "Mass Extinctions in the Fossil Record," Nature, 251:568, 1974. (X13)

R22. Hays, James D., and Shackleton, Nicholas J.; "Globally Synchronous Extinction of the Radiolarian Stylatractus Universus," Geology, 4:649, 1976. (X3)

R23. Thomson, Keith Stewart; "Explanation of Large Scale Extinctions of Lower Vertebrates," Nature, 261:578, 1976. (X5)

R24. Whyte, Martin; "Turning Points in Phanerozoic History," Nature, 267:679, 1977. (X8)

R25. Olsen, Paul E., and Galton, Peter M.; "Triassic-Jurassic Tetrapod Extinctions: Are They Real?" Science, 197:983, 1977. (X1)

R26. Lubenow, Marvin L.; "Reversals in the Fossil Record: The Latest Problem in Stratigraphy and Evolutionary Phylogeny," Creation Research Society Quarterly, 13:185, 1977. (X0)

R27. Gartner, Stefan, and Keany, John; "The Terminal Cretaceous Event: A Geologic Problem with an Oceanographic Solution," Geology, 6:708, 1978. (X13)

R28. Boucet, A.J., and Gray, Jane; "Comment on 'Catastrophe Theory: Application to the Permian Mass Extinction,'" Geology, 7:646, 1978. (X13)

R29. Wolfendale, Arnold; "Cosmic Rays and Ancient Catastrophes," New Scientist, 79:634, 1978. (X8)

R30. Hallam, A.; "The End of the Cretaceous,"

Nature, 281:430, 1979. (X1)
R31. Surlyk, Finn; "The Cretaceous-Tertiary Boundary Event," Nature, 285:187, 1980. (X0, X11)
R32. Smit, J., and Hertogen, J.; "An Extraterrestrial Event at the Cretaceous-Tertiary Boundary," Nature, 285:198, 1980. (X0, X11)
R33. Hsu, Kenneth J.; "Terrestrial Catastrophe Caused by Cometary Impact at the End of Cretaceous," Nature, 285:201, 1980. (X0, X2, X11)
R34. Alvarez, Luis W., et al; "Extraterrestrial Cause for the Cretaceous-Tertiary Extinction," Science, 208:1095, 1980. (X11)
R35. Kerr, Richard A.; "Asteroid Theory of Extinctions Strengthened," Science, 210: 514, 1980. (X1, X11)
R36. Plotnick, Roy E.; "Relationship between Biological Extinctions and Geomagnetic Reversals," Geology, 8:578, 1980. (X8)
R37. Fisher, Arthur; "The World's Great Dyings," Mosaic, 12:2, March/April 1981. (X0, X1, X11, X13)
R38. Lewin, Roger; "No Gap Here in the Fossil Record," Science, 214:645, 1981. (X6)
R39. Kerr, Richard A.; "Impact Looks Real, The Catastrophe Smaller," Science, 214: 896, 1981. (X0, X1, X2, X11)
R40. Futuyma, Douglas J.; "The Fossil Record," Science on Trial, New York, 1982, p. 82. (X0)
R41. "Asteroid Impact and Mass Extinction," Eos, 63:141, 1982. (X2)
R42. "Dinosaur Extinction Due to Asteroid?" Physics Today, 35:19, May 1982. (X0, X1)
R43. Russell, Dale A.; "The Mass Extinctions of the Late Mesozoic," Scientific American, 246:58, January 1982. (X2)
R44. Simon, C.; "Another Twist in the Story of Mass Extinctions," Science News, 122: 231, 1982. (X1)
R45. Archibald, J. David, and Clemens, William A.; "Late Cretaceous Extinctions," American Scientist, 70:377, 1982. (X1-X3, X13)
R46. Kerr, Richard A.; "Extinctions: Iridium and Who Went When," Science, 215:389, 1982. (X1)
R47. Raup, David M., and Sepkoski, J. John, Jr.; "Mass Extinctions in the Marine Fossil Record," Science, 215:1501, 1982. (X0)
R48. Ganapathy, R.; "Evidence for a Major Meteorite Impact on the Earth 34 Million Years Ago: Implication for Eocene Extinctions," Science, 216:885, 1982. (X11, X12)
R49. Jastrow, Robert; "The Dinosaur Massacre: A Double-Barreled Mystery," Science Digest, 91:51, September 1983. (X1)
R50. McLaren, Digby; "Impacts That Changed the Course of Evolution," New Scientist, 100:588, 1983. (X0)
R51. McLaren, Digby J.; "Bolides and Biostratigraphy," Geological Society of America, Bulletin, 94:313, 1983. (X0, X13)
R52. Ward, Peter; "The Extinction of the Ammonites," Scientific American, 249: 136, October 1983. (X2, X13)
R53. Wilford, John Noble; "Study Hints Extinctions Strike in Set Intervals," New York Times, December 11, 1983. (Cr. P. Gunkel) (X4)
R54. Simon, C.; "Pattern in Mass Extinction," Science News, 124:212, 1983. (X4)
R55. Diamond, Jared M.; "Extinctions, Catastrophic and Gradual," Nature, 304:396, 1983. (X2, X5)
R56. Officer, Charles B., and Drake, Charles L.; "The Cretaceous-Tertiary Transition," Science, 219:1383, 1983. (X1, X11)
R57. Lewin, Roger; "Extinctions and the History of Life," Science, 221:935, 1983. (X3, X4)
R58. Kauffman, Erle G.; "The Fabric of Cretaceous Marine Extinctions," in Catastrophes and Earth History, W. A. Berggren and John A. Van Couvering, eds., Princeton, 1984, p. 151. (X0, X2)
R59. Raup, David M., and Sepkoski, J. John, Jr.; "Periodicity of Extinctions in the Geologic Past," National Academy of Sciences, Proceedings, 81:801, 1984. (X4)
R60. Anderson, Ian; "Dinosaurs May Have Died Quietly, After All," New Scientist, p. 9, November 8, 1984. (X1, X2)
R61. Hallam, Tony; "Asteroids and Extinction---No Cause for Concern," New Scientist, p. 30, November 8, 1984. (X1, X4)
R62. Anderson, Ian; "Catastrophe Theory Rocks Evolution Debate," New Scientist, p. 9, March 15, 1984. (X4)
R63. Brownlee, Shannon; "Cycles of Extinction," Discover, 5:22, May 1984. (X4)
R64. Russell, Dale A.; "The Gradual Decline of the Dinosaurs---Fact or Fallacy?" Nature, 307:360, 1984. (X1)
R65. McGhee, George R., Jr., et al; "No Geochemical Evidence for an Asteroidal Impact at Late Devonian Mass Extinction Horizon," Nature, 308:629, 1984. (X11)
R66. Hallam, A.; "The Causes of Mass Extinctions," Nature, 308:686, 1984. (X4, X13)
R67. Schwartz, Richard D., and James, Philip B.; "Periodic Mass Extinctions and the Sun's Oscillation about the Galactic Plane," Nature, 308:710, 1984. (X4)
R68. Davis, Marc, et al; "Extinction of Species by Periodic Comet Showers,"

Nature, 308:715, 1984. (X4)
R69. Buffetaut, Eric; "Selective Extinctions and Terminal Cretaceous Events," Nature, 310:276, 1984. (X2)
R70. Van Valen, Leigh M.; "The Case against Impact Extinctions," Nature, 311:17, 1984. (X1, X2)
R71. Orth, Charles J., et al; "A Search for Iridium Abundance Anomalies at Two Late Cambrian Biomere Boundaries in Western Utah," Science, 223:163, 1984. (X11)
R72. Surlyk, Finn, and Johansen, Marianne Bagge; "End-Cretaceous Brachiopod Extinctions in the Chalk of Denmark," Science, 223:1174, 1984. (X13)
R73. Smit, J., and van der Kaars, S.; "Terminal Cretaceous Extinctions in the Hell Creek Area, Montana: Compatible with Catastrophic Extinction," Science, 223:1177, 1984. (X1)
R74. Alvarez, W., et al; "The End of the Cretaceous: Sharp Boundary or Gradual Transition?" Science, 223:1183, 1984. (X1)
R75. Kerr, Richard A.; "Periodic Impacts and Extinctions Reported," Science, 223:1277, 1984. (X4)
R76. Tschudy, R.H., et al; "Disruption of the Terrestrial Plant Ecosystem at the Cretaceous-Tertiary Boundary, Western Interior," Science, 225:1030, 1984. (X1)
R77. Kitchell, Jennifer A., and Pena, Daniel; "Periodicity of Extinctions in the Geologic Past: Deterministic Versus Stochastic Explanations," Science, 226:689, 1984. (X4)
R78. Corliss, Bruce H., et al; "The Eocene/Oligocene Boundary Event in the Deep Sea," Science, 226:806, 1984. (X1)
R79. Rampino, Michael R., and Stothers, Richard B.; "Geological Rhythms and Cometary Impact," Science, 226:1427, 1984. (X4)
R80. Weisburd, S.; "Could Dinosaurs Have Survived Asteroid?" Science News, 128:151, 1985. (X1)
R81. Goldsmith, Donald; Nemesis, New York, 1985. (X1, X4, X11)
R82. Feldmann, Rodney M.; "Extinction Hypotheses Gave a Focus in 1984," Geotimes, 30:12, April 1985. (X1, X3, X4)
R83. Leahy, Guy D., et al; "Linking Impacts and Plant Extinctions," Nature, 318:318, 1985. (X1)
R84. Bray, A.A.; "Will Impacts Become Extinct?" Modern Geology, 9:397, 1985. (X1)
R85. McLaren, Digby J.; "Mass Extinction and Iridium Anomaly in the Upper Devonian of Western Australia," Geology, 13:170, 1985. (X0, X11)
R86. Pal, Poorna C.; "Geomagnetic Reversals and the Periodic Episodes of Extra-Terrestrial Catastrophism," Eos, 66:946, 1985. (X4, X8)
R87. House, Michael R.; "Correlation of Mid-Palaeozoic Ammonoid Evolutionary Events with Global Sedimentary Perturbations," Nature, 313:17, 1985. (X6)
R88. Sanfilippo, Annika, et al; "Late Eocene Microtektites and Radiolarian Extinctions on Barbados," Nature, 314:614, 1985. (X11, X12)
R89. Raup, David M.; "Rise and Fall of Periodicity," Nature, 317:384, 1985. (X4)
R90. Officer, Charles B., and Drake, Charles L.; "Terminal Cretaceous Environmental Events," Science, 227:1161, 1985. (X1)
R91. Kerr, Richard A.; "Periodic Extinctions and Impacts Challenged," Science, 227:1451, 1985. (X4)
R92. Lewin, Roger; "Catastrophism Not Yet Dead," Science, 229:640, 1985. (X4)
R93. Weisburd, Stefi; "Extinction Wars," Science News, 129:75, 1986. (X1, X13)
R94. McGhee, George E., Jr., et al; "Late Devonian 'Kellwasser Event' Mass Extinction Horizon in Germany: No Geochemical Evidence for a Large-Body Impact," Geology, 14:776, 1986. (X11)
R95. Ward, Peter, et al; "Maastrichtian Molluscan Biostratigraphy and Extinction Patterns in a Cretaceous/Tertiary Boundary Section Exposed at Zumaya, Spain," Geology, 14:899, 1986. (X1)
R96. Patrusky, Ben; "Mass Extinctions: The Biological Side," Mosaic, 17:2, Winter 1986/1987. (X0, X1, X2, X4, X11, X13)
R97. Alvarez, Walter; "Toward a Theory of Impact Crises," Eos, 67:649, 1986. (X4)
R98. Sepkoski, J. John, et al; "Was There a 26-Myr Periodicity of Extinctions?" Nature, 321:533, 1986. (X4)
R99. Benton, Michael J.; "More Than One Event in the Late Triassic Mass Extinction," Nature, 321:857, 1986. (X1)
R100. Saito, Tsunemasa, et al; "End-Cretaceous Devastation of Terrestrial Flora in the Boreal Far East," Nature, 323:253, 1986. (X1)
R101. Collinson, Margaret E.; "Catastrophic Vegetation Changes," Nature, 324:112, 1986. (X2)
R102. Raup, David M., and Sepkoski, J. John, Jr.; "Periodic Extinction of Families and Genera," Science, 231:833, 1986. (X4)
R103. Retallack, Greg, et al; "Cretaceous-Tertiary Dinosaur Extinction," Science, 234:1170, 1986. (X1)
R104. Muller, Richard A., et al; "Comet Showers, Periodic Extinctions, and Iridium," Science, 234:1484, 1986. (X4)
R105. Morris, Simon Conway; "The Search for the Precambrian-Cambrian Boundary,"

American Scientist, 75:157, 1987. (X13)
R106. Lerbekmo, John F., et al; "The Relationship between the Iridium Anomaly and Palynological Floral Events at Three Cretaceous-Tertiary Boundary Localities in Western Canada," Geological Society of America, Bulletin, 99:325, 1987. (X2)
R107. Morton, G.R.; The Geology of the Flood, Dallas, 1987. (X0)
R108. Monastersky, R.; "K-T Extinctions: Abrupt or What?" Science News, 132:277, 1987. (X1)
R109. "New Find of Fossils Revives Asteroid Debate," New Scientist, p. 30, October 8, 1987. (X0)
R110. Van Valen, Leigh M., et al; "Comment and Reply on 'Phanerozoic Trends in Background Extinction: Consequence of an Aging Fauna,'" Geology, 15:875, 1987. (X2)
R111. Shaw, Herbert R.; "The Periodic Structure of the Natural Record, and Nonlinear Dynamics," Eos, 68:1651, 1987. (X4)
R112. Officer, Charles B., et al; "Late Cretaceous and Paroxysmal Cretaceous/Tertiary Extinctions," Nature, 326:143, 1987. (X0, X1, X2, X13)
R113. Donovan, Stephen K.; "How Sudden Is Sudden?" Nature, 328:109, 1987. (X1)
R114. Hut, Piet, et al; "Comet Showers as a Cause of Mass Extinctions," Nature, 329: 118, 1987. (X0, X1)
R115. Patterson, Colin, and Smith, Andrew B.; "Is the Periodicity of Extinctions a Taxonomic Artefact?" Nature, 330:248, 1987. (X4)
R116. Hallam, Anthony; "End-Cretaceous Mass Extinction Event: Argument for Terrestrial Causation," Scienee, 238: 1237, 1987. (X1, X2)
R117. Kollgaard, Ronald, et al; "Bolide Extinction Theory Makes an Impact," Physics Today, 41:13, January 1988. (X1, X2)
R118. Stanley, Steven M.; "Paleozoic Mass Extinctions: Shared Patterns Suggest Global Cooling as a Common Cause," American Journal of Science, 288:334, 1988. (X13)
R119. Monastersky, R.; "Heat Wave at K-T Boundary?" Science News, 133:164, 1988. (X13)
R120. Loper, David E.; "A Model of Correlated Episodicity in Magnetic-Field Reversals, Climate, and Mass Extinctions," Journal of Geology, 96:1, 1988. (X4, X8, X13)
R121. Lewin, Roger; "A Lopsided Look at Evolution," Science, 241:201, 1988. (X5)
R122. Kerr, Richard A.; "Was There a Prelude to the Dinosaurs' Demise?" Science, 239:729, 1988. (X1)
R123. Crowley, Thomas J., and North, Gerald R.; "Abrupt Climate Change and Extinction Events in Earth History," Science, 240:996, 1988. (X13)
R124. Strahler, Arthur N.; "Mass Extinctions in the Geologic Record," Science and Earth History, Buffalo, 1987, p. 450. (X5, X8)
R125. Lewin, Roger; "Pattern and Process in Extinctions," Science, 241:26, 1988. (X4)
R126. Raup, David M., et al; "Testing for Periodicity of Extinction," Science, 241: 94, 1988. (X4)
R127. Osborn, Henry Fairfield; "The Causes of Extinction of Mammalia," American Naturalist, 40:769, 40:829, 1906. (X13)
R128. Donovan, Stephen K.; "Confusion at the Boundary," Nature, 329:288, 1987. (X5)
R129. Simpson, George Gaylord; "Periodicity in Vertebrate Evolution," Journal of Paleontology, 26:359, 1952. (X5)
R130. Clemens, W. A.; "Patterns of Survival and Extinction in the Terrestrial Vertebrate Fauna," Eos, 66:813, 1985. (X1, X4)

ESB2 Paleontological Signatures during Biological Explosion Events

Description. The rapid increase in biological diversity, as measured at various taxonomic levels, at various positions in the stratigraphic record. Zones of particularly sharp increases are termed "explosions" or "radiations", although neither term seems well-defined. Biological explosions sometimes follow biological extinctions, but not always; and they may occur without any preceding extinction. Biological radiations may be correlated with climate and/or chemical changes discerned in the stratigraphic record.

Background. Biological radiations in the fossil record have been the subject of speculation for over a century. Darwin, especially, worried that these sudden spates of biological innovation on large scales might compromise his theory. Even today, biologists marvel at the Cambrian explosion of new life forms.

Data Evaluation. Paleontology is a well-developed field. Many biological explosions, particularly the Cambrian, have been studied closely. The fossil record, however, is incomplete in some areas, not clear-cut in others, and confusing in still others. Time and the action of the elements have made the record difficult to read. Rating: 2.

Anomaly Evaluation. Biological extinctions are easier to explain than biological radiations---death is simpler than the creation of a new life form! All explanations of biological explosions depend ultimately upon the prevailing theories of evolution and natural selection. Diversification, according to current thinking, is continually generated in a random fashion. During a biological explosion, changing environmental conditions in essence alter natural selection in such a way that many new life forms can now survive. If an extinction or some other phenomenon has opened up biological niches---both old and new---speciation will be rapid and diverse. Thus, biological explosions, in the most general way, are completely consistent with prevailing theories. In this sense, they are not anomalous, even though many details remain controversial. Rating: 3.

Possible Explanations. Mutation and natural selection under conditions of environmental stress.

Similar and Related Phenomena. Biological extinctions (ESB1); chemical signatures in the stratigraphic record (ESC1); evidence of catastrophic climate changes (ESB4). The Catalog volumes in the Biology series (B) will deal with observations that tend to contradict the present theories of evolution.

Examples

X0. Introduction to biological explosion events. Whereas biological extinction events (ESB1) have occupied the thoughts of most paleontologists recently, the converse phenomenon---the biological "explosion" or "radiation"--- has received much less attention. A. N. Strahler defines this type of phenomenon after remarking on the new phyla (the second highest taxonomic classification) that appeared suddenly in the early Cambrian:

> "The large increase in numbers and diversification of new groups within these phyla following their introduction is known as evolutionary radiation. A period of rapid radiation is followed by a much longer span of time in which the new groups persist with little change. The causes of evolutionary radiation are complex and not well understood, but it can be reasoned that the onset of a particularly favorable set of environmental conditions is partly responsible. In the case of the almost explosive radiation of the earliest Cambrian faunas, a rapid increase in atmospheric oxygen was possibly a major factor, along with crustal stability of extensive passive continental margins with broad continental shelves and large expanses of shallow inland (epicontinental) sea." (R22)

As the reader can readily discern, science has little insight as to how biological diversity is promoted. The creation of new life forms is not as easy to explain in cause-and-effect terms as biological extinction through asteroid impact!

In the literature examined so far, discussion is focussed primarily upon the Cambrian biological explosion to the near exclusion of other radiation events. Interestingly enough, the Cambrian radiation does not seem to have been preceded by an extinction event (ESB1-X5), although chemical perturbations seem obvious enough. (ESC1) The Precambrian-Cambrian boundary, in fact, is so remarkable that it deserves separate treatment.

The Cambrian biological explosion event. This "event" is qualitatively different from all other radiations in that all known phyla, extant and extinct, apparently originated during this period. In other times of rapidly increasing biological diversity, only new genera, families, species, and lower taxonomic levels were affected. The Cambrian explosion has been a great puzzle to paleontologists and biologists since before Darwin, as the following quotations will demonstrate:

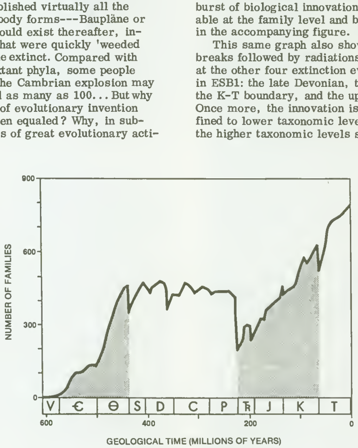
> "One of the greatest enigmas in paleontology is the relatively abrupt appearance

of hard skeletal parts in the fossil record near the beginning of the Cambrian. Of course, an event of such magnitude did not escape the notice of early geologists. They were well aware that fossils such as brachiopods, mollusks, trilobites, and echinoderms with skeletons robust enough to resist decay did not extend indefinitely downward through the geological column. Darwin was especially puzzled by this apparent discontinuity in the fossil record.... Despite subsequent proposals of a multitude of hypotheses supported by a much greater range of information, the problems set by the fossil record across the Precambrian-Cambrian boundary remain for the most part unsolved." (R20)

"Described recently as 'the most important evolutionary event during the entire history of the Metazoa,' the Cambrian explosion established virtually all the major animal body forms---Baupläne or phyla---that would exist thereafter, including many that were quickly 'weeded out' and became extinct. Compared with the 30 or so extant phyla, some people estimate that the Cambrian explosion may have generated as many as 100... But why has this burst of evolutionary invention never again been equaled? Why, in subsequent periods of great evolutionary activity when countless species, genera, and families arose, have there been no new animal body plans produced, no new phyla?" (R23)

Other biological explosion events. To discern other biological explosion events, in light of the preceding paragraph, that taxonomic levels lower than the phyla must be employed. Examining charts of biological diversity, of the type shown on this page, it is immediately apparent that: (1) extinction events are much sharper and of greater amplitude than explosion events (Actually, the word "event" was a poor choice here.); and (2) the second most vigorous and significant biological explosion occurred at the Permian-Triassic boundary, some 300 million years after the Cambrian explosion and following a well-established extinction event. This burst of biological innovation is most noticeable at the family level and below, as shown in the accompanying figure. (R23)

This same graph also shows extinction breaks followed by radiations of new families at the other four extinction events covered in ESB1: the late Devonian, the late Triassic, the K-T boundary, and the upper Devonian. Once more, the innovation is generally confined to lower taxonomic levels. A look at the higher taxonomic levels shows that some



The two major bursts of biological diversification (shaded areas) occurred 300 million years apart. They were quantitatively but not qualitatively comparable. (X0) major groups of animals originated and radiated well within the usual boundaries of the geological periods, rather than at the boundaries themselves. Reptiles, for example, seem to have commenced some time in the Pennsylvanian (Carboniferous), radiating vigorously after the Permian began. Mammals probably arose in the Triassic and then exploded in the Cretaceous. Such observations lead to a third generalization: (3) biological extinctions and explosions are not well correlated timewise at the higher taxonomic levels.

X1. Temporal structure of biological explosion events. When biological innovation occurs, it is not only sudden as geologists reckon time, it produces many new life forms in the same paroxysm of creativity, and sometimes at least it spans wide geographical regions.

D. J. Futuyma muses as follows on the 'suddeness' factor: "As far as we can tell, species possess no intrinsic drive to evolve, no impetus toward progress. If they are sufficiently adapted for an environment that persists through long stretches of time, their adaptations may also persist without change. A very common pattern, in fact, is for a group to evolve very rapidly at first, and then to level off after their new adaptations have been more or less stabilized in a final form. The lungfishes, for example, evolved rapidly in the Devonian, and by the beginning of the Permian they reached an adaptive 'plateau' that they have stayed on ever since. This pattern suggests that in order to trace the gradual evolution of a new major group, it is necessary to find fossils from that relatively brief period in which the new adaptations arise, before they become stabilized. This principle bears on one of the most striking and potentially embarrassing features of the fossil record. The majority of the major groups appear suddenly in the rocks, with virtually no evidence of transition from their ancestors. This is one of the major points of attacks by antievolutionists." (R11)

E. Shute, a creationist, emphasizes the great variety of organisms produced during an explosion: "There are many examples of the variety of organisms as they first appear. The Ammonites (an extinct order of Cephalopod Molluscs) appear in the Devonian in great variety, the fossils spread over no fewer than fifteen families. In the Carboniferous period the class Insecta appears for the first time, its fossils then representing no fewer than twelve orders. In that same Carboniferous period appear three of the six orders of the class Amphibia. In the Jura appear twelve new families of Pelycopod Molluscs, fourteen new families of Gastropod Molluscs and twenty new families of Ammonites, as well as eight new orders of Insects. In the Eocene appear twenty-seven new orders of Mammals." (R6)

The geographical persistence of certain fossils is one of the main points made by D. Ager in The Nature of the Stratigraphic Record. "In other words, we have fossils that just suddenly appear around the world at one moment in geological history and 'whence, and whither flown again, who knows?'" He gives as an example the Triassic brachiopod Halorella, which had no apparent direct ancestors or descendents, and yet appeared suddenly on all continents save Antarctica. (R8)

The cause(s) of these sudden bursts of creativity represent a major paleontological and biological anomaly. All that science can say at the moment is that they must have been synchronous with favorable environmental conditions, which is hardly an explanation. (WRC)

X2. Periodicity and relation of biological explosions and extinctions. Referring back to ESB1-X5, we find hints of a causal or, at the very least, a statistical correlation between biological explosions and extinctions. It is a mixed bag in one sense, because there is evidence for extinctions promoting explosions, and vice versa. A very popular view is that explosions follow extinctions because of the host of vacant niches created by the extinctions. (R3) On the other hand, K. S. Thomson's data show that rapid extinction is the "normal and immediate" consequence of diversification! (R7) After all, one cannot have a significant extinction unless one first has a well-populated, diverse biosphere. The implication is that the flowering of life contains the seeds of its demise. To further cloud the issue, we requote a few words of J. M. Diamond: "...animal extinctions permitted animal radiation, whereas plant radiations caused plant extinctions." (R12) For a fuller treatment, see ESB1-X5.

It must be remembered that the Cambrian biological explosion seems to have taken place without a preceding extinction. (R21)

Thus, extinction is not always a prerequisite for explosion, at least at the higher levels of taxonomy.

If biological extinction events are periodic then at least some explosion events must be, too. (For details, see ESB1-X4) Of course, the reality of periodicity apparently depends upon the taxonomic level being studied. The appearance of new phyla at the beginning of the Cambrian has never been duplicated, and therefore periodicity has not occurred at this level. (R23) It is interesting to note that in 1952, long before the general acceptance of catastrophic extinction by paleontologists, G. G. Simpson and N. D. Newell published papers on periodicity in vertebrate and invertebrate evolution. (R2, R3) Simpson, in particular, attributed these ups and downs to an intrinsic property of life itself. We quote now from his Abstract:

> "Graphs are presented showing the rates of known origin ('first appearances per million years') of orders, families, and genera in each of seven classes of vertebrates (omitting birds) for each period of their history from Ordovician to Tertiary. One, two, or three peaks occur in each class when these rates reached a high and after which they declined, usually sharply. Peaks in rate of origin of orders regularly precede those for genera by some 25 to 50 million years. A similar span intervenes between the first appearance of each new major adaptive type or structural grade and the ordinal peak that regularly follows such an event. Altogether, the sequence suggests a cycle in a continuous process.... The real periodicity that does appear in vertebrate history seems to result from orderly evolutionary progression, succession and replacement rather than being conditioned by any periodic physical phenomenon." (R2)

If the cycles of diversity are out-of-phase for different taxonomic levels, as Simpson suggests above, external forcing would be hard to accept.

Just what is anomalous here? Mainly, it is the fact that no scientific consensus yet exists as to the real causes of biological explosions. Are they intrinsic or extrinsic? Are empty niches required for biological innovation? Why was the Cambrian explosion different from those that followed? (WRC)

X3. Correlation of biological explosion events with diastrophism. Both G. G. Simpson and N. D. Newell, in their classic 1952 papers in the Journal of Paleontology, maintained that biological explosions are unrelated to diastrophism. (R2, R3) However, as already mentioned in ESB1, many scientists believe that the new niches that open up during marine transgressions promote biological diversification. (R22) But others point out that the isolation of populations and environmental stress caused by receding water levels are conducive to speciation. (R10)

X4. Correlation of biological explosion events with climate. Despite the confusion of opinion regarding diastrophism cited in X3, the pressure of climate is widely thought to be an important factor in driving evolution. However, good paleoclimatic data are available for only the past few million years, and the continental fossil record is very spotty during this same period. That the situation is still "fuzzy" is supported by the vagueness of this quotation:

> "Nevertheless, even with the continental evidence so far available it proved possible to identify times of apparent evolutionary activity since the beginning of the Neogene that coincided with strong signals of global cooling in the climatic record. The most striking correlations were around 15 million and 2.4 million years ago, with something clearly happening at around 5 million years before present too." (R14)

This is an embryonic field of research, and we have little more than the hopeful hypothesis of E. Vrba: "Many different lineages in the biota will respond by synchronous waves of speciation and extinction to global temperature extremes and attendant environmental changes." (R14)

X5. Correlation of biological explosion events with chemical spikes and changes. It was the discovery of a worldwide iridium deposit at the K-T boundary that greatly stengthened the hypothesis that an asteroid/comet wreaked havoc with the biosphere at this juncture in the fossil record. Other geological boundaries are also marked by chemical spikes of one sort or another. (ESC1) It is rather easy to imagine the biosphere being devastated by asteroid-impact fallout, soot from huge conflagrations, and changes in marine chemistry; but can chemical changes also be associated with biological explosions? The answer is apparently "yes", because, for example, increased biological activity (and presumably higher biological diversity) can be indicated by increases in organic carbon in the fossil record.

The only biological explosion with clearcut attendant chemical signals is that at the Precambrian-Cambrian boundary. Here one finds negative $\delta^{18}O$, positive $\delta^{34}S$, and both positive and negative $\delta^{13}C$ perturbations. (Details may be found in ESC1-X5, X6, and X3, respectively.) The precise meaning of these perturbations is not at all clear. K. J. Hsu refers to a "strangelove ocean" existing prior to the Cambrian explosion. (R15) Obviously, something was transpiring chemically, but that is about all one can state at the present time. (R17, R18, R20)

References

R1. Woodward, A. Smith; "The Imperfection of the Geological Record," Natural Science, 13:327, 1898. (X1)

R2. Simpson, George Gaylord; "Periodicity in Vertebrate Evolution," Journal of Paleontology, 26:359, 1952. (X2, X3)

R3. Newell, Norman D.; "Periodicity in Invertebrate Evolution," Journal of Paleontology, 26:371, 1952. (X2, X3)

R4. Dewar, Douglas; "The Lack of Precambrian Fossils," The Transformist Illusion, Murfreesboro, 1957, p. 19. (X1)

R5. Newell, Norman D.; "The Nature of the Fossil Record," American Philosophical Society, Proceedings, 103:264, 1959. (X0, X2)

R6. Shute, Evan; "Gaps in the Geological Record," Flaws in the Theory of Evolution, Philadelphia, 1961, p. 183. (X1)

R7. Thomson, Keith Stewart; "Explanation of Large Scale Extinctions of Lower Vertebrates," Nature, 261:578, 1976. (X2)

R8. Ager, Derek V.; "The Fleeting Fossil," The Nature of the Stratigraphic Record, London, 1973, p. 15. (X1)

R9. Gould, Stephen Jay; "Is the Cambrian Explosion a Sigmoid Fraud?" Ever Since Darwin, New York, 1977, p. 126. (X0)

R10. Lewin, Roger; "No Gap Here in the Fossil Record," Science, 214:645, 1981. (X3)

R11. Futuyma, Douglas J.; "The Fossil Record," Science on Trial, New York, 1982, p. 82. (X0)

R12. Diamond, Jared M.; "Extinctions, Catastrophic and Gradual," Nature, 304:396, 1983. (X2)

R13. Sunderland, Luther D.; "Cambrian Explosion," Darwin's Enigma, San Diego, 1984, p. 43. (X0)

R14. Lewin, Roger; "The Paleoclimatic Numbers Game," Science, 226:154, 1984. (X4)

R15. Hsu, Kenneth J., et al; "'Strangelove Ocean' before the Cambrian Explosion," Nature, 316:809, 1985. (X5)

R16. Gish, Duane T.; "The Fossil Record---from Microorganisms to Fish," Evolution: The Challenge of the Fossil Record, El Cajon, 1985, p. 54. (X0, X1)

R17. Awramik, Stanley M.; "The Precambrian-Cambrian Boundary and Geochemical Perturbations," Nature, 319:696, 1986. (X5)

R18. Tucker, Maurice E.; "Carbon Isotope Excursions in Precambrian/Cambrian Boundary Beds, Morocco," Nature, 319: 48, 1986. (X5)

R19. Morris, S. Conway, et al; "A Burgess Shale-Like Fauna from the Lower Cambrian of North Greenland," Nature, 326: 181, 1987. (X0)

R20. Morris, Simon Conway; "The Search for the Precambrian-Cambrian Boundary," American Scientist, 75:157, 1987. (X0, X5)

R21. Donovan, Stephen K.; "Confusion at the Boundary," Nature, 329:288, 1987. (X2)

R22. Strahler, Arthur N.; "The Fossil Record of the Phanerozoic Eon," Science and Earth History, Buffalo, 1987, p. 309. (X0, X1)

R23. Lewin, Roger; "A Lopsided Look at Evolution," Science, 241:201, 1988. (X0, X2)

ESB3 Recent Vegetation and Shallow-Water Fossils Found at Great Depths

Description. Masses of recent vegetation and shallow-water fossils discovered thousands of feet below today's sea level.

Data Evaluation. The discoveries of recent vegetation on the ocean's bottom are casual, unexpected observations reported in popular science publications; although there seems to be no reason for discounting them on this count. The shallow-water fossils, though, were procured during modern oceanographic explorations via drilling and research submersibles. Rating: 1.

Anomaly Evaluation. The masses of recent vegetation were doubtless rafted out to sea and then sank there---nothing anomalous here! The presence of recent (Cretaceous) fossils at depths of thousands of feet imply either great subsidence of near-surface features and/or great changes in sea level. Localized subsidences of thousands of feet in tens of millions of years are not considered anomalous today, although such changes are remarkable. Wide-area subsidences of such magnitude would, however, be anomalous, as discussed in connection with the Pacific guyots in ETH1. In this restricted view, the shallow-water fossils recorded below are very anomalous. Rating: 1.

Possible Explanations. Local subsidence in some cases. Possibly wide-area subsidence and/or rises in sea level in the case of extensive groups of guyots.

Similar and Related Phenomena. Shallow-water fossils at great altitudes (ESB6); guyots (ETH1); greatly elevated and submerged terraces and other geological features (ETE); buried, undecayed organic debris (ESB4).

Examples

X1. Recent vegetable debris at great depths in the ocean. This Catalog entry is more a cautionary note than a collection of anomalous observations. The phenomena reported are most interesting but almost surely explained in terms of debris rafting. Nevertheless, there may be a connection between rafted vegetable debris and the great masses of buried vegetable matter in the Arctic muck. (ESB4)

The Caribbean. "While dredging to the leeward of the Caribbean Islands, large accumulations of vegetable matter and of land debris were brought up from deep water, many miles from shore. It was not an uncommon thing to find, at a depth of over 1,000 fathoms, and some 10 or 15 miles from land, masses of leaves, pieces of bamboo and of sugar cane, dead land shells, and other land debris, which were undoubtedly all blown out to sea by the prevailing easterly trade winds, and frequently masses of vegetation, more or less waterlogged and ready to sink, were found floating on the surface of the sea. The contents of some of the trawls would, indeed, have sorely puzzled a palaeontologist if he had met them in a fossil state; amid deep water forms of fishes, crabs, echinoderms, sponges, etc., would be found orange and mango leaves mingled with branches of bamboo and nutmegs, so that it would have been difficult to decide whether the marine or the land fauna predominated." (R1)

The Pacific. "In repairing the cable of the West Coast of America Telegraph Co., the break was found some 400 nautical miles 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?" (R2)

X2. Fossils on the tops of guyots. In ETH1, the deeply submerged, flat-topped guyots were introduced as a potential topographical anomaly. Here, we review quickly the occurrence of relatively recent, shallow-water fossils on guyot tops---an indication that these seamounts were recently submerged by thousands of meters. Generally geologists are content with explaining guyots as wave-planed volcanic mountains that have subsided to great depths. Objections to this theory and contradicting observations may be found in ETH1.

Results of a 1950 survey of mid-Pacific guyots. "Five flat-topped seamounts (guyots) were dredged and cored in an area between 600 and 1100 miles west of Hawaii.

"The following faunas have been identified:

"Basaltic gravel layers in a core at 2050 fathoms near one of the guyots contain an Upper Cretaceous (Campanian-Maestrichtian) fauna including species of Globotruncana, striate Gumbelina, and Ventilabrella, mixed with Tertiary and Recent species.

"An upper Paleocene fauna dominated by Globorotalia velascoensis occurs in indurated Globigerina ooze on top of a second guyot.

"Two cores taken on top of another guyot contain a lower-middle Eocene Globigerina ooze planktonic assemblage dominated by Globorotalia aragonensis and with Hantkenina mexicana to within an inch of the top of the core.

"Conclusions are that the mixed Cretaceous-Recent fauna and the gravel were transported by turbidity currents to their present location and that the Eocene ooze on top of one guyot is due to non-accumulation of later planktonic sediments." (R3, R4)

A Rockall Trough guyot. The Anton Dohrn seamount, in the Atlantic, is topped by upper Cretaceous chalk. Depth: about 600 meters. (R7)

Guyots of the Mid-Pacific and Japanese seamounts. "Abstract. Reefs dredged on guyots of the Mid-Pacific Mountains and the Japanese Seamounts yield Middle Cretaceous fossils, indicating that submergence killed off the fauna of the reefs sometime during the Albian-Cenomanian. Eustatic rise of sea level is probably responsible." (R8) Note that the authors invoke a rise in sea level rather than subsidence.

The Atlantic guyots. The Atlantic seamounts are predominantly conical rather than truncated. Typical guyots are rare, and even some flat-topped Atlantic seamounts may not be wave-planed. Nevertheless, there is evidence of deep submergence.

The Mytilus seamount, one of a group called the New England Seamounts, was sampled in 1974 by the research submersible Alvin: "The Alvin traverse began on the north side of the seamount at a depth of 3,057 m and moved upward in a southerly direction, terminating at a depth of 2,722 m. Rocks sampled at 3,009 m support the reef hypothesis; they contained coral fragments, a mollusk fragment, foraminifera, and certain elongated microfossils that could not be precisely identified.

"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 outermost ridges of reef breccia platforms in less than 100 m of water. Its occurrence at the great depth offers firm evidence that this seamount has subsided by 3,000 m." The authors estimate the rate of subsidence at 40-60 meters per million years, adding that this rate is not excessive for some terrestrial features, but that "no land volcano is known to have subsided 3,000 m." (R10)

X3. Shallow-water fossils from the deepsea floors. The fossils cataloged here were discovered at depths much greater than the guyot tops of X2. Even greater subsidence is therefore indicated.

The Atlantic. "Dr. Bruce C. Heezen and Paul J. Fox found the fossil remains of shallow-water life, primarily corals, in rock that is under five miles of water off the eastern end of the Dominican Republic. The rock was dredged from the base of a 25,000-foot underwater limestone cliff forming the south wall of the Puerto Rico Trench.

"The corals and other organisms found grow only in shallow reefs and tropical lagoons. This means the area studied once had to be near sea level. Somehow, they say, this portion of the earth's crust sank by more than 20,000 feet during the past 150 million years." (R6)

Shallow-water limestone has also been reported along the Vema offset fault, in the middle of the Atlantic between Africa and South America, latitude 11°N. "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." Depth not given. (R9)

X4. Freshwater diatoms in deep Atlantic sediments. In 1957, R.W. Kolbe reported finding freshwater diatoms in the deep Atlantic, some 930 kilometers from Africa, roughly on the Equator. He offered three possible explanations: (1) African rivers carried the diatoms into the sea and ocean currents transported them the 930 kilometers; (2) the diatoms were present in dust blown out to sea from Africa; and (3) the section of the Atlantic where the fossil diatoms were found was once at the surface, and supported freshwater lakes. (R11) One is tempted here to recall the legend of Atlantis! (WRC)

The anomalousness of the mid-Atlantic diatoms was accentuated by K. K. Landes in an article in Geotimes, in 1959. We quote his second paragraph: "In case you haven't been reading Science lately, Kolbe, an authority on diatomology, described fresh-water diatoms in deep sea sediments, collected in the mid-Atlantic close to the Equator. Over 60 fresh-water species were found; the most abundant (Melosira granulata) ran as high as 3600 valves to a single slide. One level in core 234 'deserves special attention; it contained fresh-water diatoms exclusively, the only exception being a single fragment of a marine form. With regard to diatoms, this level gave the impression of belonging to a fresh-water sediment. In addition to the ever-present Melosira granulata, as many as 17 fresh-water species could be observed in this level. This 'fresh-water community' seemed to be confined to a thin stratum; the next higher level contained only a few individuals of Melosira granulata and the usual marine assemblage, while all the levels below this thin stratum and down to the end of the core were totally devoid of diatoms.' That this thin bed, containing thousands of fresh-water diatoms to one fragment of a marine form could have slid, slumped, flowed or blown into place is simply unbelievable. If there ever was a bed in situ, this is it." (R13)

Some geologists have attempted to account for these freshwater diatoms through the action of turbidity currents. However, Kolbe seriously doubted that turbidity currents could carry the diatoms 930 kilometers and then upwards more than 1000 meters to deposit them on top of a submarine hill. (R12)

References

R1. "A Puzzle for Future Geologists," Scientific American, 41:308, 1879. (X1)
R2. English Mechanic, 35:424, 1882. (X1)
R3. Hamilton, Edwin L.; "Upper Cretaceous, Tertiary, and Recent Plankton Foraminifera from Mid-Pacific Flat-Topped Seamounts," Journal of Paleontology, 27:204, 1953. (X2)
R4. Dietz, Robert S.; "Drowned Ancient Islands of the Pacific," New Scientist, 5:14, 1959. (X2)
R5. Pratt, R. M.; "Erratic Boulders from the Great Meteor Seamount," Deep-Sea Research, 8:152, 1961. (X2)
R6. "Deep Atlantic Was Once Shallow," Science News, 97:320, 1970. (X3)
R7. Jones, E. J. W., et al; "A Cretaceous Guyot in the Rockall Trough," Nature, 251:129, 1974. (X2)
R8. Matthews, J. L., et al; "Cretaceous Drowning of Reefs on Mid-Pacific and Japanese Guyots," Science, 184:462, 1974. (X2)
R9. "Concrete Evidence for Atlantis?" New Scientist, 66:540, 1975. (X3)
R10. Heirtzler, J. H., et al; "A Visit to the New England Seamounts," American Scientist, 65:466, 1977. (X2)
R11. Kolbe, R. W.; "Fresh-Water Diatoms from Atlantic Deep-Sea Sediments," Science, 126:1053, 1957. (X4)
R12. Rigby, J. Keith, et al; "Turbidity Currents and Displaced Fresh-Water Diatoms," Science, 127:1504, 1958. (X4)
R13. Landes, Kenneth K.; "Illogical Geology," Geotimes, 3:19, March 1959. (X4)

ESB4 Long-Buried, Undecomposed Organic Matter

Description. Animal and plant material, in relatively fresh condition, found buried in glacial debris, muck, and soil, dated from 10,000 to millions of years old. Such buried animal matter may, as in the case of the frozen Siberian mammoths, seem quite fresh. Vegetation is often green, and the wood burnable. Skeletons and bones are not included unless they are associated with skin, tissue, marrow, etc.

Data Evaluation. With the exception of the Siberian frozen mammoths, there has been little systematic scientific study of fresh-appearing, buried organic remains. Furthermore, much of the Siberian material is somewhat sensational in nature and written with the objective of proving some catastrophic scenario. The accounts of old explorers and ivory hunters are probably not too reliable. Outside the Siberian and Alaskan deposits, the data are often old and somewhat casual in character. Rating: 2.

Anomaly Evaluation. Scientists and laymen have long marvelled at the apparent survival of organic material for tens of thousands, even millions, of years. Several naturally occurring situations are conducive to such long survival: very dry conditions, favorable chemical environments (as in peat bogs), and quick-freezing. All of these conditions, particularly the last, have been invoked to explain the observations recorded below. Are these explanations believable in all the situations where they have been used? In some instances, questions do arise. For instance, with the frozen mammoth corpses, the remnant body heat should be sufficient to accomplish decomposition, unless the outside temperature suddenly fell by, say, 200°F! In another example, where questions arise, some of the Arctic buried forests seem to have survived shallow burial in a mild climate for many thousands of years. The survival of wood under temperate conditions for millions of years is also difficult-to-believe.

Related, possibly anomalous, features of the Siberian and Alaskan buried organic material are: (1) the immense quantities of buried animal and vegetable debris; (2) the dense concentration of this debris in some locations; and (3) the curious, multi-species mixture of torn, disarticulated skeletons and corpses. It is no wonder that so many catastrophic scenarios have been proposed.

Mainstream geologists categorically reject catastrophism as an element in the explanation, claiming that uniformitarian forces acting over thousands of years are quite sufficient. Deep-freezing, they suggest, has preserved organic debris in the Arctic, and river action has concentrated the remains. In the opinion of the compiler, uniformitarian explanations are not sufficient in all cases mentioned below. Rating: 1.

Possible Explanations. See the above discussion. Catastrophic theories include flooding, pole-shifts, meteorite impacts, dust clouds, etc. Scientific creationists and advocates of past planetary encounters à la Velikovsky rely heavily on the Siberian frozen mammoths. Some of the anomalously long survivals of organic matter may be the consequence of bad geological dating.

Similar and Related Phenomena. Biological extinction events (ESB1); inland remains of recent marine life (ESB5); marine fossils at high altitudes (ESB6); warm-climate-animal fossils in the polar regions (ESB10); polystrate trees (ESX1); bone caves (ESD1); bone beds (ESD2); flood legends (ESD4); high-altitude glacial erratics (ESG4); ancient artifacts in the California gravels (M).

Examples

X1. Siberia.

General observations. "The whole of north-east 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 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 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.'" (R25)

Descriptions such as that just recorded invoke theories of catastrophe. Nevertheless, as we shall see, mainstream science today opts for the slow, uniformitarian entombment of the mammoth and its allies, as well as the immense number of trees and masses of vegetable matter accompanying the animals. (WRC)

Quantity and concentration of mammoth bones. W.R. Farrand, defending the uniformitarian position on the frozen mammoths in 1961, mentioned a figure of "more than 50,000" as the probable total population of mammoths in Siberia. The number of frozen specimens, though, was set at 39, a figure Farrand stated was consistent with accidental burial. (R38)

The catastrophists' argument is supported by much larger estimates of the number of buried mammoth skeletons and also their dense concentrations. The 50,000 figure quoted by Farrand probably comes from a 1929 article by I.P. Tolmachoff. It is based on statistics from the trade in mammoth ivory during 2 1/2 centuries of Russian occupation of Siberia. (R27) That the number of buried mammoths is actually much larger seems likely because many skeletons still lie buried in the Siberian muck and on the unexplored floor of the Arctic Ocean. A.M. Rehwinkel, a creationist using the mammoth bones as evidence of the Biblical Flood, put the mammoth skeleton figure at 5,000,000. (R34)

Soviet scientists continue to find great accumulations of mammoth bones. In 1970, a an expedition headed by B. Rusanov was helicoptered to the banks of the Berelyakh river. "They found an extraordinary sight: thousands of gray bones lying on, or protruding from, the riverbank's alluvial deposit for more than 200 yards and so densely packed that they were protecting the bank from erosion. No such mammoth boneyard had ever been found before.

"With nets over heads and shoulders against the circling clouds of mosquitoes, Vereshchagin and his assistant counted some 3,500 bones, some of them notched or scratched, presumably with the implements of prehistoric hunters.

To excavate the area, they used a fire-engine pump to hose away the frozen ground with powerful jets of water which, on reaching buried tusks, ribs or short bones, threw up fountains of clods. Many smaller features were destroyed under the impact but there was little alternative. Beneath 6 to 12 feet of loam they found a layer of tightly packed bones three to four and a half-feet thick, stretching the full 200 yards of the surface bones: another 3,500 of them, the whole mass interwoven with veins, wedges and lenses of fossil ice." (R47)

Are floods or other catastrophes required to explain such dense concentrations of bones? Mainstream geology contends that these bone beds can be accounted for by the fluvial action of rivers collecting and piling up the bones. (WRC)

Distribution of the mammoth skeletons. The great assemblages of mammoth bones are usually explained as the consequence of concentration by river action or, possibly, the slumping of alluvial soil containing the bones. In actuality, mammoth remains are found far from rivers, in elevated terrains as well as on islands off the coast. I.P. Tolmachoff described the situation thus: "Everywhere carcasses of the mammoth and rhinoceros were found, they had been buried within the frozen ground of tundra near its upper surface and usually on comparatively elevated points, on the top of bluffs, etc. This has long been known and, according to Wrangel, 'The best mammoth bones are found at a certain depth below the surface' and 'more in elevations situated near higher hills than along the low coast, or on the flat tundra.' Often mammoth localities are on the highest points of the tundra. The occurrence of the mammoth at high levels was also noticed in Alaska on the cliffs in the Kotzebue Sound, which in their features closely correspond with the cliffs on the shores of the New Siberian Islands, or on the Arctic coast of Northeast Siberia.

Bones and tusks of the mammoth were also found protruding from the ground on a high tundra." (R27)

Farrand, however, maintains that the frozen mammoths are found close to rivers. (R37)

Upright position of the frozen mammoths. Catastrophists make much of the fact that some frozen mammoths have been discovered in an upright position, seemingly implying that they were frozen suddenly in that attitude. H. H. Howorth stated: "Lastly, a curious fact about the Mammoth carcases and skeletons in Siberia is that in several cases they have been found standing upright in the ground, as if they had sunk down where they lived in soft ground, and had been frozen in that position, a position apparently inconceivable in a floating carcase." (R11) Suggestive, but hardly a proof of anything. (WRC)

State of the mammoth corpses. Even conventional geologists have to marvel a bit at the presence of frozen mammoths and rhinoceroses, thousands of years old, in the Arctic muck. The real question, of course, is whether such preservation is anomalous in itself or in the implications it presents. Mainstream scientists, such as Farrand, first remind us that the mammoth corpses are not really that well preserved, being pretty rotten in most instances. Further, Farrand assures us that the better-preserved specimens all died by suffocation, falls, and other hazards of the Arctic milieu. In other words, they did not die from the cold! They were preserved by freezing, but they met their demise in unspectacular ways. (R38)

W. White has presented the facts as most scientists see them: "Of the preserved carcasses only some 10 per cent are substantially intact and even these few show signs of putrefaction that had commenced before freezing became complete. Thus, the internal organs are usually absent, the flesh and the (thawed) surrounding soil emit an odour characteristic of decomposition and histological examination shows the destruction of cellular structure following putrefaction." (R51)

White's description is quite different in tone from that of H. H. Howorth: "We are not dealing here with animal substances deposited in bogs, and changed into such organic compounds as adipocere, but of flesh so unchanged that it has all the characters of that of animals which have recently died, when examined under the microscope, while it is readily eaten by the wild animals that live on the tundra. The flesh is as fresh as if recently taken out of an Esquimaux cache or a Yakut subterranean meat-safe. There cannot be a moment's doubt that this condition was secured by one cause only, namely, that since the bodies were entombed they have been in a state of continuous congelation without a break." (R9)

The baby mammoth named Dima was discovered in Siberia in the late 1970s. It was extremely well-preserved. "It had died at the age of six months, probably by falling into a bog or small lake, and had been frozen for 9,000 to 12,000 years, with the smallest details preserved so perfectly that even its blood and protein can be analyzed." (R47)

I. Sanderson has argued that the mammoths were suddenly and deeply frozen, for the cells did not burst in some cases. (R37) We have never seen this statement elsewhere.

E. J. Butler and F. Hoyle, who belong to the catastrophist school have brought to the fore some modern observations of reindeer carcasses: "We are indebted to Dr. Clark Friend for informing us that reindeer which fall nowadays down crevasses in the Greenland ice are subsequently found to be in an unpleasantly putrified condition. The situation is that, no matter how cold the air temperature surrounding the carcass of the reindeer, the body heat of the dead animal is sufficient to promote bacterial decomposition of the interior. Yet in spite of the greater body weight of the Siberian mammoths, and of the consequent greater heat capacity of the mammoth, putrification did not take place within them. This is certain proof that the mammoths were robbed of their body heat at an extremely rapid rate, much quicker that conduction into cold air will give." (R52) See later.

Age of the mammoth corpses. The frozen mammoths are dated in two ways: (1) using the estimated age of the deposits in which they are found; and (2) directly via radiocarbon methods. The results span tens of thousands of years. A. N. Strahler, quoting R. F. Flint, dates the famous Berezovka mammoth at between 5,000 and 8,000 years. (R58) W. R. Farrand states that the mammoth corpses are found: "(i) in deposits related in time to the Last glaciation, most of them dating from a major interstadial prior to 10,500 years ago, and (ii) in deposits apparently of late Last-interglacial age (postmaximum Boreal transgression)." (R38) On the other hand, radiocarbon methods have generated dates of 30,000 years for the Lena delta mammoth (R38), 40,500-47,000 years for the Berezovka mammoth (R54), and 39,500-

44,000 years for the baby mammoth Dima (R34, R60). The situation became more confused when Dima was radiocarbon-dated using a tandem accelerator mass spectrometer at the University of Rochester. The result was only 27,000 years. (R54)

Probable causes of death. The mammoth and rhinoceros bones that are strewn all over northeastern Siberia, sometimes in prodigious concentrations, reveal little about the details of the animals' demise. They could have perished in a uniformitarian way, one by one, the victims of falls, drowning, and the like; or they could have been engulfed by some climatic disaster. The remains of the overwhelming majority (probably more than 99%) of the mammoths tell us little about what happened.

On the other hand, the frozen mammoth corpses provide numerous hints, as in this short description of the field excavation of the Berezovka mammoth early in this century:

> "According to the general report published by Dr. (O.) 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." (R22)

Such experience with corpses in the field lead to the following general consensus among scientists:

> "In the best-preserved specimens, death was almost exclusively the result of falls, landslides or drowning, although the most perfect specimen known, the 7 to 8 month-old discovered in Eastern Siberia in 1977 and since displayed at the recent USSR National Exhibition in London, is said to have died 'of exhaustion.'" (R51)

Advocates of the quick-freeze extinction of the mammoths point to the excellent state of preservation of some corpses (see above) and the expectation that bacteria and residual body heat would have demolished the corpses had their not been a sudden, very deep freeze. But, if such a sudden temperature change did occur, causing a localized extinction of mammoths and rhinoceroses, why do we not find more frozen corpses of these animals ---and other species as well? (WRC)

Climate of Siberia in mammoth times. All students of the frozen mammoth problem seem to concur that the Siberian climate was somewhat milder when the mammoths roamed to the shores of the Arctic Ocean. One item of contention is the presence of large trees in the region during the mammoth period.

H. H. Howorth states: "The views I have advanced on this subject are not my own. I have merely followed in the footsteps of almost every recent Continental authority, especially the authorities with the greatest claims to attention---namely, the Russian naturalists who have visited Northern Siberia. They maintain---and I think the position is unassailable---that during the Mammoth period that district which is now a bare tundra, on which neither in summer nor winter could herds of pachyderms find food or shelter, was marked by a temperate climate, and was probably occupied by forests to the very borders of the Arctic Ocean.

"This view, which is supported by so many facts, was finally established when it was shown by Schmidt and others that rooted trunks of trees are found in the beds containing Mammoth remains far north of the present range of trees, and that southern forms of fresh-water mollusks, such as the Cyrena fluminatlis, are also found preserved in the same beds in Siberia far to the north of any place where they now live. These facts are consistent only with the former existence of a temperate climate in Siberia." (R19)

W. R. Farrand argues that the climate was indeed milder but that: "There is absolutely no evidence of forests: all the tree species are dwarf and scrub forms." He does remark, though, that large trees have been associated with the Alaskan mammoth remains. (R38)

We shall see below that the Siberian muck does contain unfossilized large trees and much other vegetable matter in close association with the mammoth bones and corpses.

Curious distribution of frozen species and bones-only species. All of the literature examined agrees that the frozen corpses of

Siberia include <u>only</u> mammoths and rhinoceroses, with the former present in much greater numbers. If a climatic catastrophe, such as a flood, actually did occur in Siberia, one would expect to find other species of animals frozen, too. Voles, lemmings, hares, and other small mammals must have coexisted with the mammoths; but they are never found in frozen form. (R38)

On the other hand, the <u>bones</u> of some other species of mammals <u>are</u> found in quantity. H.H. Howorth, a flood proponent, discoursed at length on this subject: "We take it further that, if we are to interpret the past rigidly by the present, and invoke only such causes as operate now, it will be difficult to account for the immense deposits of bones which occur together. Travellers who have visited the ordinary haunts of the Elephant and Rhinoceros have frequently remarked on the extraordinary scarcity of their bones and other remains. When old and worn out, they apparently seek out the recesses of the forest and retire there to die. Here, on the contrary, we have remains of whole herds together; the bones equally preserved, the ivory equally fresh, and pointing to but one conclusion, that they perished in herds where they are found, and perished by some overwhelming cataclysm. The fact of so many of the remains being found in high ground seems to show that this high ground was a place of refuge where the beasts congregated in the presence of some common danger, such as a general inundation which threatened to annihilate them. In this way also we can best account for the heterogeneous character of the collections of bones, Mammoth and Rhinoceros, Bison and Bos Primigenius, Musk Sheep and Stag, etc., animals that do not naturally herd together, which cannot be supposed to have visited one particular bog at one time in their usual course of life to be engulfed, and would not perish from such a cause in vast herds of many hundreds together, as they must have done in new Siberia, on the Obi, at Canstadt, etc." (R10) Note that only large mammals are mentioned, and that the bones are "fresh". (WRC)

D. G. Whitley, in his paper on the "Ivory Islands" off the Siberian coast, confirms the presence of bones of other large mammals over 100 miles from the mainland: "All over the hills in the interior of the island, Sannikoff found the bones and tusks of elephants, rhinoceroses, buffaloes and horses in such vast numbers, that he concluded that these animals must have lived in the island in enormous herds, when the climate was milder." (R23) Again only large mammals are mentioned, although smaller bones may just have been ignored. (WRC)

Although these early expeditions to Siberia did not specifically mention the remains of small mammals, they may not have thought them worth reporting. In any case, the 1970 expedition of Vereshchasin to the Indigirka River did come across a few: "Almost all (bones) were of mammals, but there were very occasionally the bones of other Pleistocene animals:Arctic hare, wolf and wolverine (including one whole wolverine skeleton with skin and hair still attached to its head and paws), horse, bison, reindeer, woolly rhinoceros and cave lion (the still mysterious big cat of the Pleistocene era)." (R47)

<u>Marine fossils associated with mammoth remains</u>. Both I. P. Tolmachoff and W. R. Farrand are emphatic that marine fossils, such as shells, are <u>never</u> found in association with mammoth bones and corpses. (R27, R38) The only recent writer we have found who reports such marine fossils is A. O. Kelly, an advocate of past catastrophic marine transgressions engendered by meteorite impacts. Kelly quotes Lyell who, in turn, relies on the traveller Pallas, as saying that marine shells and fish teeth occur with Siberian mammoth remains. (R35) Obviously, we cannot assign much weight to an old,. third-hand account. It should be added, though, that <u>freshwater</u> shells <u>do</u> occur in the Siberian muck. This apparent lack of marine fossils is damaging to any theory relying on marine flooding. (WRC)

<u>Buried trees and logs</u>. The presence of buried trees and logs, still fresh enough to burn, in association with the mammoth remains suggests two possibilities: (1) The Siberian climate during mammoth times was temperate enough to allow the growth of great forests; and (2) Some form of catastrophism may have to be invoked to account for the large deposits of jumbled logs.

H. H. Howorth collected, over a century ago, several accounts of buried forests and logs. We quote below from two of his works.

"As I have said, we have direct evidence that forests in the Mammoth age did exist very far north of their present limits. Such remains form an excellent thermometer by which to define the isothermal lines of that period, and I will now collect some examples of the remains of trees found underground on the tundras. They consist of two series, those which are the result of drift, and those which clearly grew on the spot. The shrewd observers who lived in Siberia long ago discriminated between these kinds, and gave the name of Noashima to those which have drifted, and of Adamshina to the indigenous timber, and this division is supported by Goeppert who separates the trunks of timber found in North 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." (R16)

"Erman 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 Yana and the Indigirka, 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 furthest chain of the islands above mentioned (i.e. New Siberia, &c.), 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 to 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. They call both sorts of trees admamovchina, or adamitic things.'" (R16)

"Erman goes on to say: 'It is only in the lower strata of the New Siberian wood-hills that the trunks have that position which they would assume in swimming or sinking undisturbed. On the summit of the hills they lie flung upon one another in the wildest disorder, forced upright in spite of gravitation, and with their tops broken off or crushed as if they had been thrown with great violence from the south on a bank, and there heaped up. Now a smooth sea covering the tops of these hills on the islands, would, even with the present form of the interjacent ground, extend to Yakutsk, which is but 270 feet above the sea. But before the latest deposits of mud and sand had settled down, and had raised the ground more than 100 feet, the surface of such a sea as we have supposed would have reached much further up, even to the cliffs in the valley of the Lena. So it is clear that at the time when the elephants and trunks of trees were heaped up together, one flood extended from the centre of the continent to the further barrier existing in the sea as it now is. That flood may have poured down from the high mountains through the rocky valleys. The animals and trees which it carried off from above could sink but slowly in the muddy and rapid waves, but must have been thrown upon the older parts of Kotelnoi and New Siberia in the greatest number and with the greatest force, because these islands opposed the last bar to the diffusion of the waters.'" (R10) Erman's flood-from-the-interior scenario has overtones of the Spokane flood in the American northwest, which was apparently caused by the rupture of an ice dam. See ETM5. (WRC)

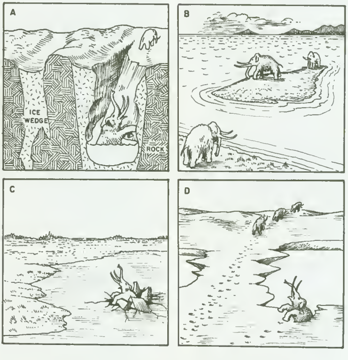
The New Siberian Islands have also provided more startling discoveries, as mentioned in Pursuit in 1969: "In the New Siberian Islands, for instance, whole trees have turned up; and trees of the family that includes the plums; and with their leaves and fruits. No such hardwood trees grow today anywhere 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." (R43) The requirement for a long growing season---longer than now possible in the Arctic---supports those theories involving a shift of the earth's poles in relatively recent times. See ESB10.

Mammoth freezing requirements. The data presented earlier about the state of the mammoth corpses included the observation that reindeer killed accidentally today in the Arctic soon decompose due to remnant body heat and consequent bacterial action. The same holds true for caribou; and it seems that the mammoths should also have decomposed rather quickly. Nevertheless, mammoth corpses have been found with stomachs full of undigested vegetation. The implication, considering heat conduction to the outside air, is that the outside temperature must have fallen to extremely low values to remove the body heat quickly enough to prevent the decomposition of the well-insulated stomach contents. J. Dillow has made the heat transfer calculations indicated. (R46) We quote below C. L. Ellenberger's review of the resulting paradox:

> "After obtaining expert opinion concerning how long plant parts would remain identifiable in a mammoth's stomach, Dillow concluded that the Beresovka mammoth died within half an hour of ingesting its last meal and that the stomach temperature was lowered to at least 40°F within ten hours. At 40°F digestive activity practically stops. Ten hours is the outside limit for buttercup preservation in the stomach. Assuming that the animal gradually froze to death, dying when its body temperature reached 74°F, Dillow determined that an air temperature of at least -150°F would be required to cool the stomach from 74°F to 40°F within ten hours. However, this is inconsistent with its dying a half hour after eating unless it continued to eat during its death throes because it takes longer than a half hour for the mammoth to cool down to 74°F. If the animal died immediately, then the initial body temperature would be 100°F. In this case, cooling to 40°F within ten hours would require an air temperature of at least -200°F. While issue may be taken with Dillow over details in his analysis, the results would not be significantly changed." (R54)

Some of the theories proposed to explain the Siberian buried wood and mammoth remains. First, the mainstream, uniformitarian explanation appeals to noncatastrophic forces acting over tens of thousands of years. The great accumulations of bones and wood were heaped together by fluvial actions over the centuries. A very few mammoths happened to be well-preserved by freezing. (R38, R47, R58)

Second, the catastrophists have proposed a list of possible terrestrial convulsions that might have caused wholesale flooding and/or



Many noncatastrophic death scenarios have been proposed for the Siberian mammoths: (a) falling into an ice shaft; (b) starvation after being stranded by a rise in sealevel; (c) falling through the ice and drowning; and (d) drowning after an eroding lake shore collapses. (X1) (Adapted from R47) sudden climate changes:

- The Biblical Flood (R16, R29, R34, R46, R53)
- Marine incursions resulting from a meteorite impact (R35)
- A sudden shift of the earth's poles (R44)
- An encounter with a large astronomical object, such as a wayward planet (R40)
- The envelopment of the earth in a cloud of cometary dust (R52)

It is not the purpose of these Catalogs to evaluate theories.

X2. Alaska. Alaska is adjacent to Siberia and also faces the Arctic Ocean. One would expect muck in Alaska then; and great quantities of it do exist. As in Siberia, the Alaskan muck is heavy with organic debris, much of it very fresh-appearing. Unlike Siberia, few mammoth corpses have been found, and they are always in very poor condition. In fact, all of the buried animal and vegetable debris in the Alaskan muck seems jumbled and rent by powerful natural forces.

F. C. Hibben has provided his impressions of the Alaskan muck and its contents: "Although the formation of the deposits of muck is not clear, there is ample evidence that at least portions of this material were deposited under catastrophic conditions. Mammal remains are for the most part dismembered and disarticulated, even though some fragments yet retain, in this frozen state, portions of ligaments, skin, hair, and flesh, Twisted and torn trees are piled in splintered masses concentrated in what must be regarded as ephemeral canyons or arroyo cuts. However, areas in which peat layers occur indicate a stabilization of certain portions of the muck for at least a period of several years, and forests of trees found in certain areas give evidence of even more lengthy periods of stabilization. It thus appears that the formation of the Alaskan mucks is complex and that all of these depositions were certainly not made at a single time. This evidence is even more convincing when it is noted that at least four considerable layers of volcanic ash may be traced in these deposits, although they are extremely warped and distorted by solifluction. Inasmuch as the remains of animals upon whose existence the Paleo-Indian was dependent for food are an integral part of the muck deposits, it follows that the history of Early Man in these regions is also intimately bound up with these deposits and explainable only in terms of the same climatic conditions and factors which governed and finally destroyed the other mammal life." (R32) We see here that the Alaskan muck differs in at least three ways from that in Siberia: (1) the presence of volcanic ash layers; (2) evidence of alternating periods of deposition and stabilization; (3) signs of early man. (WRC)

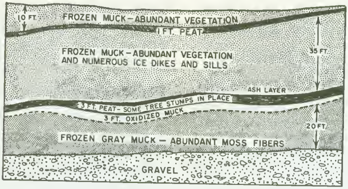
Geologist R. Tuck is a bit more restrained when he describes the muck around Fairbanks: "The muck covers the valley bottoms of all the streams in the district, with the exception of the Tanana River where gravel flats are exposed. From the surface, where it is covered only by the present-growing vegetation, 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.

.....

"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.

"Vertebrate remains---usually bones, but 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



Generalized section of the muck on Engineer Creek, Fairbanks, Alaska. (X2)

mammoth, mastadon, 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 trapped. 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." (R30) Catastrophic scenarios were not envisioned by Tuck.

In northern Alaska, oil drills have brought up unpetrified wood from almost 1,000 feet below the surface. (R43)

In the preceding accounts, mammoth remains are mentioned only in passing; they are not omnipresent as in Siberia. L. S. Quackenbush, however, has described the disinterment of a mammoth carcass at Eschscholtz Bay. We quote here J. Dillow's summary of Quackenbush (R24): "In 1908 the remains of a mammoth carcass were removed from a bluff at Elephant Point overlooking Eschscholtz Bay, Alaska (66° north latitude), just below the Arctic Circle. Pieces of soft flesh and tendons still clinging to the skeleton were found. A study of the area convinced Quackenbush, the leader of the expedition, that the animal could not have been caught in a bog. Underneath the mammoth they found some grass stalks that were still particularly green. Near the head, 'a small, thin sheet of chewed grass cut out of the frozen sandy silt close to the lower jaw was as brilliantly green as on the day it grew.' Here again, it appears, as in the case of the Beresovka mammoth, that the animal must have been in the process of chewing its last meal and did not even have time to swallow the food before it was suddenly killed." (R53) This situation is still a far cry from the Siberian mammoth corpses. In fact, the character and contents of the Alaskan muck seem substantially different from the Siberian muck. (WRC)

X3. The Canadian Arctic. Axel Heiberg Island is on the Arctic Ocean less that 700 miles from the North Pole. Dense forests seem unlikely at such high latitudes, but exploration of the island by J. Basinger, of the University of Saskatchewan, has revealed the stumps of a 45-million-year-old forest: "Basinger found 15 to 20 layers of slightly blackish stumps measuring up to one metre in diameter and several 10-m logs exposed on a 100-m slope of barren hillside within sight of the awesome ice cap that covers Axel Heiberg's central highland. After shovelling aside ancient soil and using brushes to delicately uncover the stumps, Basinger found himself in a time-frozen, once-lush forest similar to the present Cypress Swamp in Florida's Everglades. He estimates that some of the trees could have been as tall as 150 feet. Some of them remain rooted in the ancient soil amid a debris of leaves above the rock-hard permafrost. Said Basinger: 'We packed the leaves into a bag. They're like a handful of fresh leaves except they're blackish, a bit brittle." (R55) The leaves and the wood are incredibly fresh, even though dated geologically at 45 million years.

"The fossil forest has truly proven to be a paleobotanical treasure chest. The rich fossil sites contain a blend of the earlier Tertiary floras---dominated by the dawn redwood, swamp cypress, katsura and birch---and the later Tertiary floras, dominated by many members of the pine family, typical of a modern boreal forest. This change was brought about not only by a global climatic change, which was felt most strongly in the high latitudes, but also by the evolutionary changing of the guard, the inexorable replacement of the old by the new." (R57)

"Basinger found that the forest was indeed dense: the stumps are only about ten paces apart, and some are as much as six feet across. 'Along the edge of the hill and up on the crest,' he says, 'are dozens, maybe hundreds of stumps.' Basinger also made 'an incredible find'---up to 19 distinct layers of stumps. 'Each layer is a forest that developed, lived for many centuries and was overtaken by floods of sediments that killed the roots,' he says. 'They must have been killed off relatively quickly for the roots not to decay, and buried deeply enough to exclude oxygen but not so deeply as to turn them into coal. That process repeated and repeated itself over several hundreds of thousands of years.'" Asked how forests could grow so lushly at latitudes where the sun does not shine at all for five months, Basinger opined that the climate was much milder then, and the trees "grew like mad" when the sunlight did appear. (R56)

The stumps and logs of Axel Heiberg Island are not fossilized, rather they cut like fresh lumber and can be burned. (R55)

In the excerpts above, the 45-million-year age of the wood is not questioned. In warm climates, stumps decay within a few years. The closely spaced, successive layers of warm-climate stumps on Axel Heiberg testify that a warm climate prevailed for hundreds, perhaps many thousands of years. How, then, did the lower strata of stumps and wood survive shallow burial in a warm environment? Without a reasonable answer to this question, one must ask if the dating is correct. (WRC)

X4. Central United States. In this region, deeply buried, undecayed wood is rather common. Mammoth bones are also found, occasionally with remnants of skin and sinews attached.

Indiana. "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 lesser 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." The report goes on to describe a mastodon skeleton found in Iroquois County, Indiana. "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." (R61)

N. H. Winchell, in 1875, issued a long report on the vegetable remains buried in the glacial drift. "In the state of Indiana, I have been able to gather the following references to vegetable remains in the drift, from the annual reports of the State Geologist, Prof. E. T. Cox.

"In Franklin County, Dr. Rufus Hammond mentions, that in digging wells on the uplands, the roots and bodies of trees are frequently found at various depths, from ten to thirty feet; and occasionally limbs and leaves are found with vegetable mould, at various depths.

"In Vermillion County, reported by Mr. Frank H. Bradley, the prairie between Eugene and Perryville is underlain, at the depth of about sixty feet, with a layer of 'soft, sticky, bluish mud, filled with leaves, twigs, and trunks of trees, six to ten feet thick, locally known as Noah's barn yard.'" (R5) Many other specific examples are given in this paper.

Illinois. An account by a J. S. Bliss: "While passing through the county of Adams, in the State of Illinois, four years since, I learned of the existence of a well, which had been dug the year before, from which small branches of trees and twigs had been obtained. I repaired to the spot, and found the well to be twenty-five feet in depth; and was informed that, at a depth of twenty-three feet, the owner came upon a layer of fine black soil, two feet in thickness, in which were found branches an inch in diameter; I procured a shovel, and obtained several specimens three eighths of an inch through, in a tolerable state of preservation. Just above this bed of soil the material was clay.

.....

"Four miles from the first mentioned well, there was another, still more remarkable, which was 30 feet deep. At a depth of 27 feet, the diggers came square on a log, twelve inches in diameter; they cut it off on both sides of the well, and on taking it out pronounced it to be Black walnut; but I think that it was probably some other kind of timber, that had been dyed in consequence of having been submerged, and that caused the mistake." (R2)

Ohio. In his 1848 survey of the glacial drift of Ohio, C. Whittlesey recounted many occurrences of vegetable matter buried deeply in the alluvium. We quote only two of these instances: "Mr. Christy gives an instance of an upright tree on the land of R. Becket, Esq., eight miles east of Oxford College, Ohio, the roots fixed in the blue hard pan at a depth of thirty feet, the trunk surrounded by the 'gravel drift.'

.....

"At Cincinnati, in a well near the corner of Fourth and Vine streets, Judge Burnet, who was then the proprietor, struck at the depth of ninety-three feet, a partially decayed stump, with the roots attached, standing in an upright position." (R1)

X5. New Jersey. "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.

.....

"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. One of the mysterious characteristics of these long-sunken trees is that not one has even 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." (R17; R6, R12)

X6. California. A gold miner wrote to Scientific American in 1871 about unpetrified wood found at great depths in California gravels. "In the Scientific American of April 24th. I read an account of fossil trees in one of the lower counties of California. That is not the only place where they have been found. In the mining districts of Chalk Bluff and You Bet, Nevada county, Cal., they have been found in great numbers and quite large, though not so large as those described. They were found embedded in the gravel which overlies the slate, at a depth of from fifty to one hundred feet, and in some places still greater. In fact, when I was engaged in mining in those districts, there had been no bed rock found in many places, and the depth of the gravel was consequently unknown. These fossil trees were exhumed in washing away the gravel banks by what is known as the hydraulic mode of gold mining, much practiced at that time in California. The trunks and some of the largest branches (as for instance, where a tree would form a fork) were generally entire, but the roots and smaller branches were all gone, showing that they had been roughly handled by the water, and proving the pre-existence of strong currents at some remote period of time. These remains were mostly silicified, though I have found specimens that were not. I once found the remains of what had probably been a spruce tree, near the edge of one of these ancient channels, the bark of which was in a good state of preservation, though strongly impregnated with sulphur. I burned some of this bark, after drying it, on a blacksmith's forge by way of experiment. I succeeded in obtaining heat enough from it to bring steel to the proper temperature for working and tempering, but the sulphur fumes were anything but agreeable. These ancient relics of the forests of other ages seemed to comprise both the hard and soft woods, and in some instances the natural appearance of the wood was remarkably preserved. I have seen specimens of tar pine, exhumed at Chalk Bluff, that looked as if they might be easily ignited by holding them in a flame. I once found, fifty feet below the surface of the ground, and six feet from the bed rock, a piece of wood (apparently some kind of cedar) about five feet long by seven inches wide, worn quite thin, and sound enough to preserve its elasticity in a great measure." (R4)

More amazing was a buried log found near Portola, California. "A redwood log discovered near the Oroville Dam has been determined to be 10 million years old and still capable of burning.

"Crews of the California Department of Water Resources found the log imbedded in a 30-foot depth of soft rock with a fern, some fir needles and a leaf.

"Examination of the 50-pound log, which was three feet long and 15 inches in diameter, was made by Dr. D.I. Axelrod of the University of California at Los Angeles." The log was in a Miocene deposit, which explains the dating. (R45)

X7. England. Despite the examination of 200 years of English scientific literature, only one account of buried, unpetrified, undecomposed wood has been uncovered. The location of the discovery was Hull, where a new dock was being constructed in 1866: "At a depth of 40 feet below the level of the adjoining land, trees (chiefly oak) are found in all positions; those which are upright and still in situ having been broken off within 3 feet of the roots. One oak-tree, of noble dimensions, is perfectly straight, its trunk being 45 feet long, and in the thickest part measuring 12 1/2 feet in circumference; it is tolerably sound, but blackened in colour. This tree lies nearly north and south, but others which have also fallen, are to be met with in every direction.

.....

"The trees cannot be less than 3000 years old; and would require at least 300 years to attain the dimensions given." (R3)

X8. Great Lakes Region. In the August 17, 1883, issue of Science, J. W. Dawson listed some "unsolved problems of geology." Among these puzzles were the buried leaf beds on the Ottawa River and the drift trunks found in the boulder clay of Manitoba. Dawson thought that these deposits showed that throughout the glacial period forest oases existed far to the north of these regions. (R11)

Apostle Islands, Lake Superior Basin. Peat was "brought up from a depth of 54 feet and was covered by about 14 feet of lake sand. It is stated further, that upon analysis the peat was found to be very fresh and that the sand shows characteristics which indicated that it was deposited since the retreat of the last ice-sheet." Geological opinion was divided as to whether this peat was anomalous in the context of the accepted history of the Great Lakes. (R28)

Michigan. "In 1976-77, spruce and tamarack trees in growth position were exposed between six and eleven meters below the surface during construction of the Gribben tailings basin for the Cleveland-Cliffs Iron Company. The site, located sixteen kilometers southwest of Marquette, Michigan, lies within the outwash apron of the outer Marquette moraine. Throughout the excavation, there is no evidence that glacial override occurred following the period of growth, such as the presence of distorted strata, sheared trees, or intercalated till." The outer parts of two trees were radiocarbon-dated at about 10,000 years. The largest tree collected had a diameter of 60 centimeters. (R49)

The wood of these trees was "remarkably well preserved", with only the bark and less than an inch of the outer layer showing any carbonization. Similar buried forests have been found at Two Creeks, Wisconsin, and Cochrane, Ontario. (R48)

One of the several upright spruce and tamarack trees about 10,000 years old found 6 to 11 meters below the surface in Michigan. (X8) (J.D. Hughes)

X9. New York. In 1872, near Otisville, New York, a large mastodon was unearthed. No surviving skin or other non-skeletal material was mentioned. However: "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." (R62)

X10. South America. "In abundance of Pleistocene animal fossils, South America compares very well with Siberia and North America. Authorities are as one in stressing the freshness of a high proportion of the skeletal remains and associated substances found on a continent mostly within the tropical zone.

"Darwin observed, in Voyage of the Beagle (1876 edition), that some remains of a very large unknown mammal exhumed from Pleistocene deposits in the Banda Oriental District of Uruguay appeared so fresh that:

> '... it is difficult to believe that they have lain buried for ages underground. The bone contains so much animal matter, that when heated in the flame of a spirit-lamp it not only exhales a very strong animal odour, but likewise burns with a slight flame.'" (R44)

References

R1. Whittlesey, Charles; "Notes upon the Drift and Alluvium of Ohio and the West," American Journal of Science, 2:5:205, 1848. (X4)
R2. Bliss, J. S.; "On Buried Stems and Branches in Illinois," American Journal of Science, 2:39:95, 1865. (X4)
R3. Foster, F. M.; "On the Discovery of Ancient Trees below the Surface of the Land at the Western Dock Now under Construction at Hull," Report of the British Association, 1866, p. 52. (X4)
R4. "Fossil Trees in California," Scientific American, 25:5, 1871. (X6)
R5. Winchell, N. H.; "Vegetable Remains in the Drift Deposits of the Northwest," American Association for the Advancement of Science, Proceedings, 24:43, 1875. (X4)
R6. English Mechanic, 26:233, 1877. (X5)

R7. Howorth, Henry H.; "The Mammoth in Siberia," Report of the British Association, 1878, p. 571. (X1)
R8. Howorth, Henry H.; "The Mammoth in Siberia," Geological Magazine, 2:7:491, 1880. (X1)
R9. Howorth, Henry H.; "The Sudden Extinction of the Mammoth," Geological Magazine, 2:8:309 and 2:8:569, 1881. (X1)
R10. Howorth, Henry H.; "The Cause of the Mammoth's Extinction," Geological Magazine, 2:8:403, 1881. (X1)
R11. Dawson, J. W.; "Some Unsolved Problems in Geology," Science, 2:190, 1883. (X8)
R12. "Subterranean Woods," Scientific American, 52:22, 1885. (X5)
R13. "The Mammoth and the Flood," Nature, 37:123, 1887. (X1)
R14. Howorth, Henry H.; "'The Mammoth and the Flood'," Nature, 37:200, 1887. (X1)
R15. Howorth, Henry H.; "The Mammoth and the Flood," Nature, 37:295, 1888. (X1)
R16. Howorth, Henry H.; The Mammoth and the Flood, London, 1887. (X1, X2, X4)
R17. "The Buried Forests of New Jersey," Scientific American, 59:265, 1888. (X5)
R18. "The Mammoth and the Flood," Saturday Review, 65:52, January 14, 1888. (X1)
R19. Howorth, Henry H.; "The Climate of Siberia in the Mammoth Age," Nature, 39:294, 1889. (X1)
R20. Howorth, Henry H.; "The Climate of Siberia in the Mammoth Age," Nature, 39:365, 1889. (X1)
R21. Bell, Robert; "On the Occurrence of Mammoth and Mastodon Remains around Hudson Bay," Geological Society of America, Bulletin, 9:369, 1898. (X1)
R22. "The New Mammoth at St. Petersburg," Nature, 68:297, 1903. (X1)
R23. Whitley, D. Gath; "The Ivory Islands in the Arctic Ocean," Victoria Institute, Journal of the Transactions, 42:35, 1909. (X1)
R24. Quackenbush, L. S.; "Notes on Alaskan Mammoth Expeditions of 1907 and 1908," American Museum of Natural History, Bulletin, 26:87, 1909. (X2)
R25. "The Glaciated Grave of the Mammoth in Siberia," Current Opinion, 61:330, 1916. (X1)
R26. Lang, Herbert; "Frozen Siberian Mammoths," New York Zoological Society, Bulletin, 28:43, 1925. (X1)
R27. Tolmachoff, I. P.; "The Carcasses of the Mammoth and Rhinoceros in the Frozen Ground of Siberia," American Philosophical Society, Transactions, 23:11, 1929. (X1)
R28. Taylor, Frank Bursley; "Submerged Peat Beds among the Apostle Islands," Science, 74:265, 1931. (X8)
R29. Porsild, A. E.; "Earth Mounds in Unglaciated Arctic Northwestern America," Geographical Review, 28:46, 1938. (X2)
R30. Tuck, Ralph; "Origin of the Muck-Silt Deposits at Fairbanks, Alaska," Geological Society of America, Bulletin, 51:1295, 1940. (X2)
R31. Rainey, Froelich; "Archaeological Investigation in Central Alaska," American Antiquity, 5:299, 1940. (X2)
R32. Hibben, Frank C.; "Evidences of Early Man in Alaska," American Antiquity, 8:256, 1943. (X2)
R33. Taber, Stephen; "Perennially Frozen Ground in Alaska: Its Origin and History," Geological Society of America, Bulletin, 54:1433, 1943. (X2)
R34. Rehwinkel, Alfred M.; "The Mammoth and the Flood," The Flood, Saint Louis, 1951, p. 238. (X1)
R35. Kelly, Allan O., and Dachille, Frank; "Refrigerated Animals," Target Earth, Carlsbad, 1953, p. 224. (X1, X2)
R36. Hapgood, Charles H.; "The Great Extinctions," Earth's Shifting Crust, New York, 1958, p. 227. (X2, X8)
R37. Sanderson, Ivan T.; "Riddle of the Frozen Giants," Saturday Evening Post, 232:39, January 16, 1960. (X1, X2)
R38. Farrand, William R.; "Frozen Mammoths and Modern Geology," Science, 133:729, 1961. (X1, X2)
R39. Lippman, Harold F., and Farrand, William R.; "Frozen Mammoths," Science, 137:449, 1962. (X1)
R40. Velikovsky, Immanuel; "In the North," Earth in Upheaval, New York, 1965, p. 1. (X1, X2)
R41. Patten, Donald Wesley; "Glaciogenesis: The Cause of the Ice Epoch," The Biblical Flood and the Ice Epoch, Seattle, 1966, p. 101. (X1)
R42. Pewe, T. L., and Hopkins, D. M.; "Mammal Remains of Pre-Wisconsin Age in Alaska," in The Bering Land Bridge, David M. Hopkins, ed., Stanford, 1967, p. 266. (X2)
R43. "Much about Muck," Pursuit, 2:68, October 1969. (X1, X2)
R44. Hapgood, Charles H.; The Path of the Pole, Philadelphia, 1970, pp. 249 and 280. (X1, X10)
R45. "Log Rated 10 Million Years Old," Phoenix Gazette, May 6, 1974. (X6)
R46. Dillow, Jody; "The Catastrophic Deep-Freeze of the Beresovka Mammoth," Creation Research Society Quarterly, 14:

5, 1977. (X1)
R47. Stewart, John Massey; "Frozen Mammoths from Siberia Bring the Ice Ages to Vivid Life," Smithsonian Magazine, 8:61, December 1977. (X1)
R48. "Buried Forest Tells Glacial Tale," Science News, 113:229, 1978. (X8)
R49. Hughes, John D.; "Post Two Creeks Buried Forest near Marquette, Michigan," unpublished paper, 1978. (X8)
R50. "Mammoth Support for Cometary Ice Ages," New Scientist, 82:543, 1979. (X1)
R51. White, William; "Mammoth Cock-Up," New Scientist, 82:939, 1979. (X1)
R52. Butler, Elizabeth J., and Hoyle, Fred; "On the Effects of a Sudden Change in the Albedo of the Earth," Astrophysics and Space Science, 60:505, 1979. (X1)
R53. Dillow, Joseph C.; "The Riddle of the Frozen Giants," The Waters Above, Chicago, 1981, p. 311. (X1, X2)
R54. White, William, and Ellenberger, C. Leroy; "Mammoth Update: A Reply to Ellenberger," Kronos, 7:62, 1982. (X1, X2)
R55. Howse, John; "Forestry Frozen in Time," Maclean's Magazine, p. 55, September 8, 1986. (Cr. B. Ickes) (X3)
R56. Lemonick, Michael D.; "Unearthing a Frozen Forest," Time, 128:64, September 22, 1986. (X3)
R57. Basinger, James F.; "Our 'Tropical' Arctic," Canadian Geographic, 106:28, December/January 1987. (X3)
R58. Strahler, Arthur N.; "Fossils and Flood Strata---A Hydraulic Stratigraphy," Science and Earth History, Buffalo, 1987, p. 371. (X1)
R59. "Flesh Remains of Ancient Animals Dug Up in Alaska," Science News Letter, 55:403, 1949. (X2)
R60. "Baby Mammoth Carcass 44,000 Years Old," New Scientist, 77:215, 1978. (X1)
R61. "On the Existence of the Mammoth in Recent Times in North America," Geological Magazine, 2:8:373, 1881. (X4, X9)
R62. "A Gigantic Mastodon," Scientific American, 26:264, 1872. (X9)
R63. Cardona, Dwardu; "The Problem of the Frozen Mammoths," Kronos, 1:77, 1976. (X1)
R64. Ellenberger, L.; "Problem, Riddle, Mystery: A Mammoth Update," Kronos, 5:94, 1980. (X1)

ESB5 Living and Fossil Marine Organisms Found Far Inland

Description. Organisms of undisputed marine origin, such as seals, fish, and sponges, that are found alive in fresh water lakes or as fossils on or near the surface far from the sea.

Data Evaluation. Except for the marine organisms found on the ice shelves and in the dry valleys of Antarctica, there has been little attention paid to these phenomena. Most references are old and sketchy. Rating: 2.

Anomaly Evaluation. The potential anomaly here is the appearance of marine life forms in localities where no theoretically acceptable means of transport from the sea seem to be available. In most, but not all, instances, the explanations proposed by the scientific community are quite reasonable, thus erasing any superficial anomalousness. The key exceptions are the marine organisms in Lake Baikal and Lake Tanganyika. These suggest past unrecognized marine transgressions or connections with the sea. Rating: 2.

Possible Explanations. Marine transgressions or links to the sea caused by changes in sea-level.

Similar and Related Phenomena. Marine fossils at very high altitudes (ESB6); shallow-water fossils at great depths (ESB3); bone caves and fissures (ESD1); raised beaches and terraces (ETE); seawater in lake bottoms (ESC12).

Examples

X1. Seals. Whenever these marine mammals appear alive in freshwater lakes or recent carcasses are found far inland, those with catastrophe proclivities think in terms of large marine incursions. It seems, though, that less radical explanations are sufficient in most instances.

U. S. S. R. The freshwater seals of Lake Baikal are widely known and have even been seen in a television documentary in the 1980s. Nevertheless, the literature checked so far mentions these seals only once in passing. (R1) The existence of these seals so far inland raises the question of whether the Lake was once connected to the sea.

Antarctica. Mummified seals were first noted in Antarctica during Scott's expedition of 1901-1904. Since then hundreds of dried bodies have been found, some over 100 kilometers from the coast and at altitudes up to 1,200 meters. In 1966, a live crabeater seal was captured in Marie Byrd Land 113 kilometers from the coast at 920 meters altitude. Most seal carcasses are those of crabeater seal pups. (R18)

T. L. Pewe et al provided the following abstract of their investigation of this phenomenon in the McMurdo Sound region: "Mummified carcasses of the 'crabeater' seal lie scattered over the landscape 1 to 30 miles from the sea are up to 3000 feet above sealevel in the ice-free areas of the McMurdo Sound region, Antarctica. The writers collected information on 90 carcasses.

"The carcasses are hard and dry, and lie on the surface of the ground, mostly in valley bottoms. They range from relatively well-preserved bodies to merely old, twisted, wind-dissected fragments and tissue. One carcass dated by radiocarbon analysis is between 1600 and 2600 years old.

"The writers believe that, in Antarctica, seals that occasionally wander inland find no food in the fresh or alkaline lakes and therefore die. Because the arid and cold climate is ideal for retarding organic decay, the bodies do not rot and weather away, as in other climates, but are preserved an incredible length of time. The remains of all seals that have wandered inland during the last 2000 years probably still exist. (R9; R11)

W. Dort, Jr., during his research on the seal problem, determined that radiocarbon dates for the mummies can be in serious error due to the lower quantity of carbon-14 in the Antarctic waters. For example, a freshly killed seal was radiocarbon dated at 1300 years! In Dort's view, most mummified seals are less than 200-300 years old. (R18)

X2. Whales. Unlike seals, whales cannot travel overland, so whale skeletons found very far from the sea and at high altitudes inevitably suggest marine flooding and/or great, relatively recent changes in sealevel.

Vermont. In 1849, between Vergennes and Middlebury, Vermonters located a whale skeleton embedded in clay. (R2) This was probably glacial clay near the surface. (WRC)

Ontario. "The bones of a whale closely allied to the white whale (Beluga leucas) of the Gulf of St. Lawrence, have been discovered at Cornwall, Ontario County, Canada. It seems to be the same as the B. Vermontana of Thompson." (R3)

Sweden. "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." (R4)

Norway. Part of whale carcass was found entombed in the ice-cored moraine at Sveabreen, Ekmanfjord, in Vestspitzbergen. "The ice-core of the moraine rises to about 20 ft. above the high-water mark and the dirt cover is 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 the ice, possibly the floating ice-front of Sveabreen, and held there. Advance of the ice pushed the whale, together with sediment and the enclosing 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." (R10)

Michigan. "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 covered northern North America. The whales caught in the rivers could not turn around and find their way out, and Professor Hussey believes that they must have died of starvation. Their bones were cast upon the beaches of those times and are found today 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." (R7)

I. Velikovsky, apparently refering to the same whales, stated that the skeletons were located in bogs covering glacial deposits. He pointed out that Lake Michigan is now 582 feet above sealevel. Either anomalously great changes in sealevel or a colossal marine incursion must have occurred as the ice ages were ending. (R15; R19)

Alabama. "A species of Tertiary whale, Zeuglodon, left its bones in great numbers in Alabama and other Gulf States. The bones of these creatures covered the fields in such abundance and were 'so much of a nuisance on the top of the ground that the farmers piled them up to make fences.' There was no ice cover in the Gulf States; then what had caused the submergence and emergence of the land there." (R15)

Quebec. In the Montreal area, at 600 feet above sealevel, a whale skeleton was found. (R15)

X3. Marine invertebrates. As a type of life, marine invertebrates are relatively immobile. Yet, a few are found in fresh water far from the oceans.

Lake Tanganyika. Early explorers of the great African Lakes remarked on the fact that Lake Tanganyika supported a marine-like fauna in addition to the fresh-water fauna typical of nearby lakes. For example: "Mr. Moore, as a result of his first journey in 1896, found 'that in Nyassa and Shirwa there were no jellyfishes, nor anything except purely fresh-water forms; while in Tanganyika there were not only jellyfishes, 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." (R6; R5)

Lake Baikal. Without giving a reference, A. O. Kelly informs us that Lake Baikal supports marine sponges. (R8)

Lake Onondaga, New York. Squids inhabit this fresh-water lake near Syracuse. They may have been introduced accidentally by man, or they could have entered naturally in post-glacial times when the lake was connected to the sea via the St. Lawrence. (R21)

Ross Ice Shelf, Antarctica. Dead fish (often curiously headless) are occasionally found on the Ross Ice Shelf, near McMurdo Sound. (See X4 following.) So are some invertebrates: "On this same ice-sheet in McMurdo Sound there are to be found other strange things besides long-dead fish. These include deep-water shells, huge siliceous sponges a foot in height, and other sea-bottom material. In 1911 a Scott party found on top of the ice a patch of sea-bottom intact and perfectly preserved, as large as a dining-room carpet. It had a tiny cup-coral the size and shape of a liqueur glass, so delicate that its stem broke as it was being wrapped up. The patch was less than six inches deep and resting on clear ice. How could it have got there, removed through 100 feet of ice to a site some fifteen feet above sea-level?" (R12; R13) The presence of these invertebrates on the ice surface may be explained by assuming that the ice sheet freezes all the way to the bottom in the winter, where it "captures" bottom-dwelling organisms. As the ice sheet moves seaward and its top melts in the summer and bottom refreezes in the winter, its organic cargo in effect "rises" through the ice, eventually appearing on the surface. (R12)

Lake Titicaca. Mollusks and other marine invertebrates are said to inhabit Lake Titicaca, over 12,000 feet up in the Andes. The truth of these claims is controversial and will be covered in the next section (ESB6). (R17)

X4. Marine fish. "Land-locked" salmon are known in several northern lakes, such as Lake Champlain. Other oceanic species, such as cod, also seem to have been trapped in bodies of fresh water near the sea when sea levels were higher. The discussion below will be limited to cases that are more difficult to explain.

Lake Nicaragua. This lake is connected to the Atlantic by the 110-mile-long Rio San Juan, which in places has rapids and strong currents. Yet, this fresh-water lake supports sharks and sawfish, both cartilaginous fish which normally avoid fresh water. The origin of the Lake Nicaragua sharks was controversial at first. Originally, it was thought to be a unique species, but later it was shown to be essentially identical to an Atlantic shark. The first theory was that these sharks were trapped in the lake when it was first cut off from the Pacific. Recent investigations, though, indicate that sharks are to be found all along the Rio San Juan, despite the currents and rapids. Apparently, the sharks invaded Lake Nicaragua during times of high water. In this light, these sharks can hardly be called anomalous. (R16, R20)

Lake Baikal. Besides seals and sponges, Lake Baikal harbors herring and salmon. Since the lake is almost 1,000 miles from the Pacific, the usual land-locked argument seems weak here. (R8)

Lake Titicaca. The reports of seahorses (which are true fish) are denied by some scientists. See ESB6.

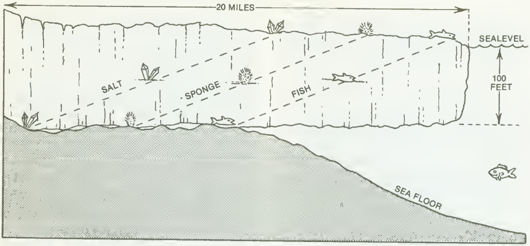
Ross Ice Shelf. In addition to sponges, explorers of the Ross Ice Shelf have occasionally come across dead fish. F. Debenham has summarized recent findings of C. Swithinbank: "This discovery consisted of a number of corpses of giant fish, together with other marine specimens, which they found on the surface of an ice-sheet over 100 feet thick and more than a mile from its seaward edge. The fish were up to six feet in length and well preserved, though some had lost their heads and had been pecked by skua gulls.

"Samples were sent back for dating by Carbon-14, an electrochemical method which measures the deterioration of the carbon in the bones. From these it is now known that the corpses are about 1000 years old. This is very reminiscent of the wooly mammoths, dug up in the past in Siberia, whole and fully fleshed, frozen for thousands of years in the muds of the Arctic coast.

"Interest quickens when we learn that no less than six of these large fish were found by the two Scott Expeditions over fifty years ago, five in 1902-3, and one in 1911. Five of them were on top of the ice and headless, and quite recognizable though obviously a long time dead.

"The sixth was caught by accident in the spring of 1903, and was also headless through a strange coincidence. One of Scott's seamen was waiting at a seal-hole when he saw the flash of a large silvery fish amongst the loose ice in the hole. He flung his harpoon and called for help in hauling out something very large and lively at the end of the line. When landed it proved to be a large seal. The seaman stuck to his story of a large fish, and after hunting about in the ice he produced it; but alas, it had no head, which it must have parted with, either to the seal or to the harpoon, at the instant of capture. The body was four feet long, weighed 40 lb without its head and furnished a fish supper for the whole ship's company." (R12) Recall from X1 the fact that radiocarbon dating of Antarctic seal carcasses is distorted by the low level of carbon-14 in these waters. Also, if the Ross Ice Shelf is 100 feet and more thick, where do the seal holes come from? (WRC)

Other exploring parties have come across



A diagram illustrating a possible origin of the Glauber's Salts, sponges, and fish found on the surface of the McMurdo Ice Sheet, Antarctica. (X3, X4) (Adapted from R12)

small "schools" of headless fish on the surface and (shades of Charles Fort) fish heads sans bodies! The accepted explanation for fish parts is the same as that for bottom-dwelling sponges, as presented in X3. (R12; R13, R14) This explanation, as is obvious, fails to deal with fish dismemberments.

References

R1. "Lake Baikal," American Journal of Science, 2:5:295, 1848. (X1)
R2. "A Whale in Vermont," Scientific American, 5:42, 1849. (X2)
R3. "Fossil Whale in the Drift," American Naturalist, 5:125, 1871. (X2)
R4. Nature, 38:134, 1888. (X2)
R5. "Organisms of Marine Type in Lake Tanganyika," Geographical Journal, 7:663, 1896. (X3)
R6. Hudleston, W. H.; "On the Origin of the Marine (Halolimnic) Fauna of Lake Tanganyika," Victoria Institute, Journal of the Transactions, 36:300, 1904. (X3)
R7. Science, 72:sup xiv, November 7, 1930. (X2)
R8. Kelly, Allan O., and Dachille, Frank; "Prehistoric and Modern Lakes," Target Earth, Carlsbad, 1953, p. 172. (X3, X4)
R9. Pewe, Troy L., et al; "Mummified Seal Carcasses in the McMurdo Sound Region, Antarctica," Geological Society of America, Bulletin, 70:1797, 1959. (X1)
R10. Dineley, D. L., and Garrett, P. A.; "Whale Remains in Glacier Ice," Nature, 183:272, 1959. (X2)
R11. Pewe, Troy L., et al; "Mummified Seal Carcasses in the McMurdo Sound Region, Antarctica," Science, 130:716, 1959. (X1)
R12. Debenham, Frank; "A Fish Story from the Antarctic," Geographical Magazine, 34:360, 1961. (X3, X4)
R13. "Discovery in Antarctic Puzzles Scientists," Discovery, 22:46, 1961. (X3, X4)
R14. "Fish Remains Support Polar Ice Theory," Science Digest, 49:30, March 1961. (X4)
R15. Velikovsky, Immanuel; "Whales in the Mountains," Earth in Upheaval, New York, 1965, p. 46. (X2)
R16. "How the Sharks Got into the Lake," New Scientist, 32:667, 1966. (X4)
R17. Delair, J. B.; "The Lost Sea of the Andes," in The Path of the Pole, C. H. Hapgood, ed., Philadelphia, 1970, p. 281 281. (X3)
R18. Dort, Wakefield, Jr.; "Mummified Seals of Southern Victoria Land," Antarctic Journal, 6:210, 1971. (X1)
R19. Casson, Margarethe; "The Fossil Mystery," Rocks and Minerals, 47:532, 1972. (X2)
R20. "Fresh-Water Sharks of Nicaragua," Scientific Monthly, 57:187, 1943. (X4)
R21. "The Squids from Onondaga Lake, N. Y." Science, 16:947, 1902. (X3)

ESB6 Living Organisms and Recent Fossils Found at Anomalously High Altitudes

Description. The presence at very high altitudes of living organisms and recent fossils that are typical of sealevel and low-altitude environments.

Background. The implication here is that great elevations of land have occurred more recently than envisaged by mainstream geology. The recency and rate of elevation constitute the possible anomalous factors.

Data Evaluation. Evidence for such recent elevation of land exists only for the Andes, and even this is not particularly impressive. The data on living marine creatures (seahorses) and recent shells in very high shorelines are sketchy and controversial. Data on recent low-altitude plant fossils found at very high altitudes seem more secure. Rating: 3.

Anomaly Evaluation. The geological anomalousness of the Andes depends upon how fast and how recently they may have risen. If, as some contend, Lake Titicaca had a marine connection as recently as the Pleistocene, mainstream geological opinion will be severely challenged. Rating: 1.

Possible Explanations. The data may be in error or misinterpreted, as generally maintained by most geologists. The Andes actually did rise thousands of feet within the time of man.

Similar and Related Phenomena. Land and shallow-water fossils now at great depths (ESB5); greatly raised beaches and other topographical indicators of anomalous emergence and submergence of land (ETE).

Examples

X1. High raised beaches. At many places around the world---Great Britain, some Pacific islands---beaches exist at altitudes between 1,200 and 1,300 feet above present sea level. The marine character of these beaches and their recency are attested to by their seashells. Since the "raised beach" phenomenon is dealt with in detail in ETE1, it will be bypassed here. (Refer to Catalog volume Carolina Bays, Mima Mounds, Submarine Canyons.)

X2. The Andes. Many travelers, scientists and laymen alike, have ventured subjectively that the Andes "look young" geologically and paleontologically. Here, "young" means that the Andes might have acquired most of their stature within the last few million years. The objective evidence cited is threefold: the putative Lake Titicaca seahorse, very high beaches with recent marine shells, and recent plant fossils at very high altitudes.

Seahorses. Typical of the assertions that the seahorse occupies Lake Titicaca is this by Delair and Oppe: "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 landlocked 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." (R7) So far, we have not tracked down the "other oceanic forms." (WRC)

H. F. Garner does not believe in the Lake Titicaca seahorse: "References to a seahorse in Lake Titicaca have an even less secure basis than the aforementioned features. Welter states, 'A fish Hippocampus 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 maintains that a Senor Poznansky of La Paz, Bolivia, received a dried example of Hippocampus from an Aymara Indian but neglects to state its origin. Welter adds that a Sr. L. Sundt believes that the seahorse occurs in Lake Titicaca, whereas a Sr. G. Steinmann disbelieves this occurrence. Welter adds nothing more positive than that 27 years earlier he observed '. . . at least 20 examples [of Hippocampus (?)] 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 seems to attach little importance to the failure of a British scientific expedition under Moon to achieve its major purpose of collecting specimens of Hippocampus from Lake Titicaca. " (R6)

Raised beaches with recent marine shells. H. F. Garner continued his attack on proponents of a recent, radical upthrusting of the Andes by trying to pick apart the purported observations of marine shells on high beaches: "The inferred extension of the 'beaches' from 2300-3500 m elevation is based on the unsubstantiated idea that the shells are marine. . . . " The observer here, as in the case of the seahorse, was O. Welter. Welter claimed that the shells he found at 2, 300 meters were Pliocene in age and had shapes typical of those in surf zones. Because he had no paleontological library, he could not identify them. (R6) It would seem that these questions should have been answered long ago by paleontologists, but no clarification has yet been found. (WRC)

Mammals. The situation is also unclear in the case of mammalian fossils found at high altitudes. The only information at hand is this: quotation from J. A. Douglas: "With regard to the date and extent of recent uplift there is conflicting evidence. It has already been argued that the presence of an extinct mammalian fauna at 13, 000 feet in the Desaguadero district of Bolivia can only be explained by the assumption of a considerable post-Pleistocene elevation. . . " (R4)

Plants. Plant fossils have provided more positive support for recent Andean upthrusts: "In a paper of only three pages (by E. W. Berry (R2)), 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 tropical trees allied to those now living in 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 conclues 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. " (R1; R2, R3)

Despite H. F. Garner's doubts about the Lake Titicaca seahorse and greatly elevated beaches (R6), the several lines of evidence do concur. (WRC)

References

R1. "The Age of the Bolivian Andes, " Geographical Record, 4:59, 1917. (X1)
R2. Berry, Edward W. ; "The Age of the Bolivian Andes, " National Academy of Sciences, Proceedings, 3:283, 1917. (X1)
R3. Berry, Edward W. ; "Fossil Plants from Bolivia and Their Bearing upon the Age of Uplift of the Eastern Andes, " U. S. National Museum, Proceedings, 54:103, 1919. (X1)
R4. Douglas, James Archibald; "Geological Sections through the Andes of Peru and Bolivia: II, " Geological Society of London, Quarterly Journal, 76:1, 1920. (X1)
R5. "The Extreme Youthfulness of the Central Andes, " Geographical Review, 13:615, 1923. (X1)
R6. Garner, H. F. ; "Mountains from Molehills, " Geological Society of America, Bulletin, 74:195, 1963. (X1)
R7. Delair, J. B., and Oppe, E. F. ; "The Lost Sea of the Andes, " in The Path of the Pole, Charles H. Hapgood, ed., Philadelphia, 1970, p. 281. (X1)
R8. Berry, Edward W. ; "Bolivia's Least Known Mountain Range, " Natural History, 23:73, 1923. (X2)

ESB7 Environment-Related Growth Structures on Marine Organisms and Their Fossils

Description. Growth bands, growth ridges, and physical heights of marine organisms and their fossils, including corals, molluscs, stromatolites, and other life forms. In some cases, these phenomena can be correlated with the solar day, the lunar synodic month, the terrestrial year, and other astronomical cycles.

Data Evaluation. The pertinent organisms and their fossils are abundant, as are the counts and measurements of their structures. Daily growth structures, however, are not wholly reliable measures of the solar day, since growth ridges may be absent. Stromatolite heights, too, are not always good indicators of tidal amplitudes. Caution is the watchword in using these data and in evaluating their implications. Rating: 2.

Anomaly Evaluation. The major impact of paleontological geochronology is in its implications regarding the supposed capture of the moon, its close approach to the earth in times past, and the consequent geological phenomena resulting from tidal forces generated. The notion that the moon was captured by the earth is no longer heretical, but the time of capture is widely debated, as is the distance of closest approach. Some paleontological data suggest a very close approach (less than half its present distance), with the generation of strong lunar tides in the ocean and atmosphere. The development of hard skeletons in marine creatures has even been linked to the moon's close approach. This sort of catastrophism is only mildly anomalous in today's scientific climate. Other paleontological evidence suggests unexplained "kinks" in the tidally induced deceleration of the earth's rotation. Rating: 2.

Possible Explanation. Some of the apparent anomalies may be only the consequence of bad data.

Similar and Related Phenomena. Radiometric dating (ESP1); anomalies in the dynamics of the earth-moon system (ALB).

Similar and Related Phenomena. Radiometric dating (ESP1, ESP12); anomalies in the dynamics of the earth-moon system (ALB).

Examples

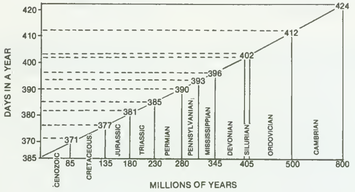
X0. Background. In the early 1960s, J. W. Wells was instrumental in establishing a new type of geochronology---one that has revealed the possible existence of anomalies in the history of the earth and its moon.

The opening paragraph of Wells' 1963 Nature paper serves as a good preamble:

> "Absolute age determinations of points on the geological time-scale, based on radioactivity, are generally accepted as the best approximations now known, even though they rest on a series of assumptions, any one of which may be upset at any time. At present there is no means of confirming or denying the accuracy of these determinations by independent methods. Can paleontology provide anything by way of verifying the pronouncements now emanating, at very considerable expense, from the black boxes? Can paleontology give any support to the shaky chronometric creation of the geophysicists and astronomers?"(R1)

Of course, Wells thought that paleontology could contribute to geochronology. It could do so by estimating the number of earth days in an astronomical year. Corals, for example, display what are assumed to to annual growth bands which, when studied more closely, reveal even finer growth ridges---a few hundred per band. Wells surmised that these might be daily growth ridges. If they were, the number of days per annum could be determined simply by counting the number of ridges in each annual growth band. Wells was careful to emphasize that he was assuming the annual nature of the bands and the daily origin of the ridges. His assumptions have been accepted by geochronologists.

In his influential 1963 paper (R1), Wells presented a graph of geological time versus days in the terrestrial year. The first variable could be computed through radiometric measurements; the second, by calculating the deceleration of the earth's rate of rotation due to tidal friction. Taking the figure



Relation between the number of days in each year and geological time. (X0)

of 2 seconds per 100,000 years for tidal braking and working backwards in time from today's 365-plus days per year, he obtained the accompanying graph.

Would counting the growth ridges on fossil corals produce points on the line drawn from radiometric and astronomical considerations? Wells' preliminary counts confirmed a general increase in the number of days per year as he worked backwards in time. A great deal more has happened since.

X1. Corals and brachiopods. Corals have been a favorite of the geochronologists. Not only are annual bands recognizable, but so are smaller bands that are thought to represent lunar synodic months. Thus, corals can give both the number of days per year and days per synodic month.

However, many factors, such as weather conditions, local topography, latitude, etc., doubtless affect the number of growth lines on corals (and other marine species, too). J. W. Wells, for example, tested modern corals from the West Indies and counted an average of only 360 days per year. Corals in Norwegian fjords seem to add only 28 lines per 29.5-day synodic month. So, care must be taken in using such data. (R2)

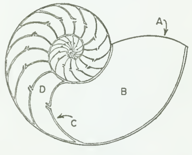
Lunar capture catastrophe. Given the length of the lunar synodic month over geological time from coral data, astronomers can calculate the distance separating the earth and and moon. They can also deduce that the moon was captured and afterwards closely approached the earth before it began receding. D. L. Lamar and P. M. Merifield have studied this sort of scenario:

"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 catastrophic 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." (R4)

Other authors are more definite and precise, saying that the time of closest approach for the captured moon was 700 million years ago and that the event stimulated the Cambrian biological explosion. (R9, R12) See ESB2 for further discussion of the paleontology of the Precambrian-Cambrian boundary.

Effects of past high rotation rates. B. G. Hunt has examined the possible effects of the late Precambrian rotation rate of the earth on atmospheric dynamics. Given a rotation rate 2-2.5 times faster than now, Hunt related this to the genesis and termination of the Precambrian ice age. He also suggested that ocean circulation would have been affected, too, with substantial implications for the evolution of life forms. (R17)

X2. Molluscs. The molluscs (including the nautiloids) also display periodic growth structures. The analysis of the fossils of these organisms has led to additional "problems" in interpreting the history of the earth-moon system.



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. (X2)*

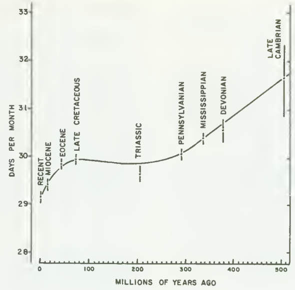
Kinks in the earth's deceleration curve. "Abstract. The values of length of synodic month, obtained from tidally controlled periodical growth patterns in mollusks and stromatolites for several geologic periods, indicate that the deceleration rate of the earth's rotation has not been constant. Two breaks in slope, in the Pennsylvanian and Cretaceous, may be related to changes in distribution of continents, oceans, and adjacent shallow seas." (R5) See accompanying graph. (R6)

Anomalously close approach of the moon. In 1978, P. G. K. Kahn and S. M. Pompea introduced the study of nautiloid growth lines to geochronology. A fierce debate followed because the nautiloids implied a different earth-moon history. We commence with the Abstract of the paper submitted to Nature by Kahn and Pompea: "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." (R14)

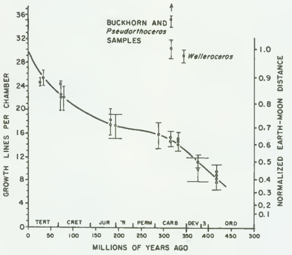
For example, during the late Cretaceous, the deceleration of the earth's rotation turned out to be 17 times greater than the amount estimated from 3,000 years of astronomical observations. In the upper Ordovician, the moon would have been only 0.4 of its present distance from earth. Using the nautiloid data, the moon would have touched the earth about 750 million years ago. (R21) Obviously, this radical scenario had to be challenged.

Nature received many critiques of the Kahn-Pompea paper. Their astronomical calculations were questioned. The question of whether nautiloid growth structures really represented daily growths was asked. One of the more interesting consequences of a close lunar approach was the generation of huge amounts of heat in the earth due to tidal friction. Kahn and Pompea provided responses to all critics. (R15) A later letter to Nature pointed out that the heating problem could be eliminated if the earth originally had two moons, with the smaller one making the indicated close approach and then either being ejected from the earth-moon system altogether or aggregating with the present moon. (R16)

X3. Stromatolites. Fossil corals and molluscs exist in the fossil record only back to the beginning of the Cambrian, some 570 million years ago by present reckoning. To extend paleontological clocks back farther than this, scientists examine stromatolites, which go back almost to the beginning of life on earth. Daily growth structures are found on stromatolites, and they tell us that at one point in the Proterozoic the year had about 435 days ---in good agreement with astronomical pro-



Variations in the length of the synodic month through geological time as measured by fossil clocks. (X2)



Number of growth lines per chamber length and the earth-moon distance versus geological time. (X2) jections based on tidal friction. (R20) Note that one needs a moon to generate this tidal friction.

Confusion over the time of the moon's acquisition. A more controversial use of stromatolites makes use of their heights as measures of tidal amplitude, as related by N. Wade:

"...the more ancient fossil tide gauges lie nearer to the Moon's possible time of capture. These are stromatolites, a kind of marine algae which grows between the high and low water mark and the length of which is probably related to the height of contemporary tides. (P.) Cloud had noticed that many pre-Paleozoic stromatolites have amplitudes from 2.5 to 6 metres, which implies that tides too great to be raised by Sun alone existed at least two aeons ago. Ripple-marked sandstone in rocks about 3 aeons old also points to high tides at this time, from which Cloud infers that the Moon must have been in orbit at least 3 aeons ago.

"The stromatolite data are otherwise interpreted by Alfven and Arrhenius. The oldest known stromatolites, which lived at least 2.7 aeons ago, are only a few centimetres in length, suggesting that lunar tidal forces were practically absent at this time. These and the fossils cited by Cloud point to a steady increase in the height of the tides from 2.3 aeons or so, when the Moon may have been captured, until Late Pre-Cambrian when maximum stromatolites of 6 metres are recorded." (R7)

The debate over what the stromatolites actually tell us about the time-of-origin of the moon may have its origin in the unreliability of stromatolites as tide gauges. M.R. Walter has questioned the uncritical use of stromatolites. First, he remarks that the largest known stromatolites are up to 15 meters high and come from near Lake Baikal. These stromatolites are about 515 million years old, well into the Cambrian. P. Cloud has discounted the possibility of a very close approach of the moon to earth at this time. Walter goes on: "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 meters." (R8)

In sum, then, the utility of stromatolites as tide gauges is still questionable, and interpretations differ as to what they tell us.

X4. Oxygen variations in shells. A different way of using fossil shells as clocks attracted the attention of scientists in 1982: "University of Cincinnati geologist Madeline Briskin, investigating seafloor core samples, has found that sediment is a reliable archive or both orbital and magnetic history." (R19)

A climatic cycle 430,000 years in length. "Trapped in the aquatic muck are shells of tiny sea creatures millions of years old. Within the shells are oxygen molecules that vary in composition according to the climate of the era in which the animals lived. Thus, by studying the age and molecular design of the ocean fossils, Briskin was able to learn much about the planet's long-range climatic patterns. Principal among her findings was the fact that the Earth's climate follows a repetitive cycle of changes, approximately 413,000 years in duration." The same sediments also revealed a magnetic cycle of 430,000 years. (R19)

Details of Briskin's technique, the identities of the shells, and the way in which oxygen composition varied are not given in the cited article. The subject of correlations between climate and geomagnetism is treated in another section of the Catalog of Anomalies (EZ). (WRC)

References

R1. Wells, John W.; "Coral Growth and Geochronometry," Nature, 197:948, 1963. (X0, X1)
R2. Lamar, D.L., and Merifield, P.M.; "Length of Devonian Day from Scrutton's Coral Data," Journal of Geophysical Research, 71:4429, 1966. (X1)
R3. Aveni, Anthony F.; "Middle Devonian Lunar Month," Science, 151:1221, 1966. (X1)
R4. Lamar, D.L., and Merifield, P.M.; "Cambrian Fossils and Origin of the Earth-Moon System," Geological Society of America, Bulletin, 78:1359, 1967. (X1)
R5. Pannella, Giorgio, et al; "Paleontological Evidence of Variations in Length of Synodic Month since Late Cambrian," Science, 162:792, 1968. (X2, X3)
R6. "A Kink in the Pattern of the Earth's

Slowing," New Scientist, 40:511, 1968. (X2, X3)
R7. Wade, Nicholas; "Three Origins of the Moon," Nature, 223:243, 1969. (X1-X3)
R8. Walter, M.R.; "Stromatolites Used to Determine the Time of Nearest Approach of Earth and Moon," Science, 170:1331, 1970. (X3)
R9. Olson, Walter S.; "Tidal Amplitudes in Geological History," New York Academy of Sciences, Transactions, 32:220, 1970. (X1-X3)
R10. Mazzullo, S.J.; "Length of the Year during the Silurian and Devonian Periods: New Values," Geological Society of America, Bulletin, 82:1085, 1971. (X1)
R11. "Rhythms and the Earth's Rotation," Nature, 247:428, 1974. (X2)
R12. Turcotte, D.L., et al; "Evolution of the Moon's Orbit and the Origin of Life," Nature, 251:124, 1974. (X1)
R13. Blake, G.M.; "The Rate of Change of G," Royal Astronomical Society, Monthly Notices, 178:41P, 1977. (X1, X2)
R14. Kahn, Peter G.K., and Pompea, Stephen M.; "Nautiloid Growth Rhythms and Dynamical Evolution of the Earth-Moon System," Nature, 275:606, 1978. (X2)
R15. Runcorn, S.K., et al; "Nautiloid Growth Rhythms and Lunar Dynamics," Nature, 279:452, 1979. (X2)
R16. Craig, Harmon; "Nautilus Records Earth's Second Moon," Nature, 280:536, 1979. (X2)
R17. Hunt, B.G.; "The Effects of Past Variations of the Earth's Rotation Rate on Climate," Nature, 281:188, 1979. (X1-X3)
R18. Runcorn, S.K.; "Nautiloids and the Rotation of the Earth," Eos, 61:79, 1980. (X2)
R19. "Muck Reveals Ancient Orbit," Science Digest, 90:18, September 1982. (X4)
R20. Weisburd, Stefi; "The Microbes That Loved the Sun," Science News, 129:108, 1986. (X3)
R21. Strahler, Arthur N.; "Creationist Arguments for a Young Age of the Solar System," Science and Earth History, Buffalo, 1987, p. 147. (X1-X3)
R22. Runcorn, S.K.; "Fossil Bivalve Shells and the Length of the Month in the Cretaceous," Nature, 218:459, 1968. (X2)
R23, West, Susan; "Moon History in a Seashell," Science News, 114:426, 1978. (X2)

ESB8 Animals Entombed in Rocks and Earth

Description. Animals, notably toads and frogs, supposedly discovered alive in solid stone or deep in compact earth. These animals usually seem to have occupied an appropriately sized cavity in said materials. Most die quickly after release.

Background. Given the derision accorded this purported phenomenon by mainstream science, it is tempting, from the standpoint of this book's prestige, to omit this entry completely. However, the sheer abundance of observations, in a wide range of publications over a period of two centuries, demands that we somehow recognize this "impossible" phenomenon, if only bibliographically. Actually, in this Catalog of Anomalies we have recorded many other observations that are just as impossible, although perhaps less scorned.

Data Evaluation. Several hundred observations of entombed animals have been collected by connoisseurs of this phenomenon. (R109) The question here is not the quantity of data but their quality. Almost all observations on record are very old and made by laymen under uncontrolled conditions. Most are not from mainstream journals. Furthermore, hoaxes are not unknown in this byway of science. As in the cases of UFOs and many psychic phenomena, delusions and misinterpretations are easily come by. Nevertheless, something real is observed in some instances; and there is a common group of rather bizarre characteristics that tie together many of the accounts---characteristics so unexpected that one would not expect them to be invented so frequently at different times and places. (X1 below) Having stated these things, it must be admitted that the data are very soft. Rating: 3½.

Anomaly Evaluation. The toad-in-hole phenomenon, as defined above, is without question highly anomalous. The reason behind this assessment is the implication that some animals can survive without air and sustenance for thousands and even millions of years in solid rocks and other geological prisons. And this is only the least radical interpretation. In Fortean circles, the teleportation and materialization of toads in awkward places is a well-received hypothesis! Rating: 1.

Possible Explanation. The easiest explanation is that all observations are in error, and that the phenomenon simply does not exist. More rational is the acceptance of a few of the cases and their explanation as accidental, recent, completely natural events, as described in X8.

Similar and Related Phenomena. Unusual aerial luminous phenomena, as phenomena that are also given short shrift by science (GLB, GLN); animals entombed in trees (B).

Examples

X1. Toads. The older scientific literature contains 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 the reptiles do possess marvelous powers of hibernation and suspended animation, but survival over millions of years? Impossible! Nevertheless, in the spirit of bibliographical completeness, we must at least touch lightly on these unbelievable data.

After reading through our collection of a hundred or so accounts of toads-in-holes, it becomes apparent that even though these tales were collected over a period of two centuries and come from several continents, there are several common elements---elements so unique or bizarre that one doubts that they were invented separately so many times. Some of these features are:

- Disinterred toads usually expire in only a few hours or days.
- Mouths are often nonexistent or sealed shut by a membrane.
- Exhumed toads frequently occupied a cavity roughly scuplted to their shape and size.
- Many reports remark on the "bright eyes of the toads.
- Freshly disinterred toads sometimes appear transparent.

This repetition of improbable characteristics does not prove the reality of the toad-in-hole phenomenon, but it does give pause for thought. This is particularly true because other (equally unacceptable) phenomena possess this same general characteristic; viz. ball lightning, UFOs, sasquatches, and various Fortean phenomena.

We proceed now to a few selected reports.

1791. A rather typical report from a quarry. "Some workmen, in a quarry at Boursire, in Gotha, having detached a large piece of stone from the mass, found, on breaking it, a live toad; they were desirous of separating the part that bore the shape of the animal, but it crumbled into sand. The toad was of a dark grey, its back a little speckled. The colour of its belly was brighter. Its eye, small and circular, emitted fire from beneath a tender membrane which covered them. They were of the colour of pale gold. When touched on the head with a stick, it closed its eyes, as if asleep, and gradually opened them again when the stick was taken away. It was incapable of any other motion. The aperture of the mouth was closed, by means of a yellowish membrane. Upon pressing it on the back, it discharged some clear water, and died. Under the membrane which covered the mouth, were found, both in the upper and lower jaw, two sharp teeth, which were stained with a little blood. How long it had been inclosed in this stone, is a question that cannot be solved." (R5)

1835. A report from an English engineer. A "more recent" observation was presented to the British Association for the Advancement of Science by a T. L. Gooch, Resident Engineer on the London and Birmingham Railway. "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 thick black deposit; on the 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 to 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." (R17)

1850. Toad found in a large French flint. The heyday of toads-in-holes was the mid-1800s. Many observations from this period come from the Zoologist, which was edited by E. Newman. Newman was skeptical but open-minded about the whole business. Here is a representative item from the Zoologist: "The Academie des Sciences was occupied in its last sitting with a grave question of what, in homely language, may be called a 'toad in a hole.' In digging a well at Blois, in June last, some workmen drew up from about a yard beneath the surface, a large flint, weighing about 14 lbs., and on striking it a blow with a pickaxe it split in two, and discovered, snugly ensconced in the very centre, a large toad. The toad seemed for a moment great astonished, but jumped out and rather rapidly crawled away. He was seized and replaced in the hole, where he settled himself down very quietly. The stone and toad, just as they were, were sent to the Society of Sciences at Blois, and became immediately the subject of curious attention. First of all, the flint, fitted together with the toad in the hole, was placed in a cellar and embedded in moss. There it was left for some time. It is not known if the toad ate, but it is certain that he made no discharge of any kind. It was found that if the top of the stone were cautiously removed in a dark place he did not stir, but that if the removal were effected in the light, he immediately got out and ran away. If he were placed on the edge of the flint, he would crawl into his hole and fix himself comfortably in. He gathered his legs beneath his body, and it was observed that he took especial care of one of his feet, which had been slightly hurt in one of his removals. The hole is not one bit larger than the body, except a little where the back is. There is a sort of ledge on which his mouth reposes, and the bones of the jaw are slightly indented, as if from long resting

Old sketch of a quarryman pulling a live toad from a cavity in solid rock. (X1) (Adapted from R109) on a hard substance. Not the slightest appearance of any communication whatsoever between the centre and the outside of the stone can be discovered, so that there is no reason to suppose that he could have drawn nourishment from the outside. The committee, consisting of three eminent naturalists, one of whom who has made toads his particular study for years, made no secret of their belief that the toad had been in that stone for hundreds, perhaps thousands of years; but how could he have lived without air, or food, or water, or movement, they made no attempt to explain. They accordingly contented themselves with proposing that the present should be considered another authentic case to be added to the few hundreds already existing, of toads being found alive embedded in stone, leaving it to some future savant to explain what now appears the wonderful miracle by which nature keeps them alive so long in such places. But the distinguished M. Magrendie suggested that it was just possible that an attempt was being made to hoax the Academy, by making it believe that the toad had been found in the hole, whereas it might only have been put in by the mischievous workmen after the stone was broken. Terrified at the idea of becoming the laughing-stock of the public, the Academy declined to take any formal resolution about the toad, but thanked the committee for its very interesting communication; and so the subject was dropped. One word, however:---if the toad had really not been embedded in the flint, how comes it that after being taken out, he always fixed himself exactly in the cavity, that the cavity fitted him to a hair's breadth, and that the hardness of the stone had made an impression on his jaw?" (R23)

1901. A "toad-in-coal." "The London Stereoscopic Company, 54, Cheapside, E.C.; are now publishing photographs of a 'Toad' discovered by Mr. W.J. Clarke, Bath-street, Rugby, in the centre of a lump of coal, after having been on the fire about an hour and a half. Mr. Clarke broke the coal with a poker, and noticing something moving, he picked it up, and found it was a living toad. It had no mouth, and was nearly transparent. It lived five weeks after being liberated, and is now on view in Cheapside." (R94) Reports such as this one have no real scientific value, being devoid of controls and supporting observers. (WRC)

1910. Another "toad-in-coal". The mainstream scientific journals have not completely neglected immured toads, although they are quite certain about their provenance. "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 assertions 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 neighbors 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 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 of 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!" (R97) This is an excellent summary of science's posture with respect to such "ephemeral" phenomena; and, in view of many reports from the general public, not unwise. (WRC)

1928. A toad in Ohio sandstone. In spite of science's denial of the phenomenon, toad-in-hole reports continue---sometimes with a bit of distrust of science itself. "At the very time that scientists were explaining some years ago that ballplayers could not throw curved balls, a ballplayer was doing it at Cincinnati, Ohio. Many years ago, when I was a young man in Columbiana County, Ohio, one of the workmen in a small stone quarry, in splitting a large solid sandstone, accidentally liberated, in my presence and in the presence of others, a toad that on being given air and sunlight, immediately became alive. This sandstone had been blasted out from under ten to fifteen feet of earth, after which it was then split open. The imprint of the toad was impressed in the solid sandstone. The toad had evidently been embedded in the stone for thousands of years." (R98)

1935. Extended hibernation in toads. But wait, toads may be able to "hibernate" for anomalously long periods of time. "The writer believes he has an example of extended hibernation in the common toad, Bufo americanus. In 1908, the W.E. Caldwell Company, Louisville, Kentucky, constructed a structural steel plant over some filled swampy land. On November 1, 1934, twenty-six years later, while digging in one of the buildings for the placing of a new furnace, two toads were exhumed. The first was about four and one-half feet and the second nearly eight feet below the clay floor of the building. An examination of the walls of the pit showed the fill to be of yellow clay with an occasional small air space, none over one-half inch in diameter. There was no indication of any type of passage-way by which the toads may have entered. The closest distance from the pit to the wall of the building was twenty-five feet. The foundation of the building is fourteen inches thick and extends four and one-half feet below the clay floor of the building.

"The workmen placed the first toad on the edge of the pit, believing it to be dead, but in a short time it hopped away. The second toad was saved. It was so thin that little remained but skin and bones. It revived to such an extent that it was able to hop and to turn over when placed on its back. When it was brought into the warm laboratory, it died within two hours." (R105)

X2. Worms. Worms enclosed in solid rock have been reported only once in the literature at hand; and the story is hardly convincing. It is almost two centuries old and reads like an old wive's tale.

1791. Living worms in marble! "Two living worms were found in Spain, in the middle of a block of marble which a sculptor was carving into a lion of the natural colour for the royal family. These worms occupied two small cavities, to which there was no inlet that could possibly admit air. They subsisted probably on the substance of the marble, as they were of the same colour. This fact is verified by captain Ulloa, a famous Spaniard, who accompanied the French academicians in their voyage to Peru, to ascertain the figure of the earth. He asserts that he saw these two worms." (R5) No comment seems necessary. (WRC)

X3. Frogs. After the toads, frogs are the most common animal found immured in solid rock---or at least the stories about frogs about frogs are the second-most-common. In fact, the circumstances of these putative discoveries and the characteristics of the interred frogs are virtually identical to those of the toads. Following the toad-in-the-hole format of X1, we now present some selected accounts of frogs-in-holes.

1858. A living frog in freestone rock. "There is at present to be seen, at Messrs. Sanderson and Sons, George Street, Edinburgh, an extraordinary specimen of Natural History, ---a frog which had been discovered alive in freestone rock. A few months ago, while some colliers in the employ of Mr. James Nasmyth...were engaged in taking out the pavement of the seam of coal, which was freestone, they discovered a cavity in which a frog was lying. On touching it the frog jumped about for some time, and a bucket of water being procured it was put into it, and taken to the surface. On reaching it the animal was found to be dead. It was at the depth of forty-five fathoms, or ninety yards from the surface, in a perpendicular line of strata, consisting of alternate layers of coal and freestone, with ironstone, and about four hundred yards from the out crop surface. The frog seems to have much of the same character as the present species. It is very attenuated, which cannot be wondered at considering its domicile for so many ages, its original extistence being of course considered contemporaneous with the formation of the freestone rock in which it was contained." (R33)

1890. White frog in limestone. "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 Narley & 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 his 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 downtown, 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." (R88)

1895. A deeply buried frog. "The resurrection of a frog from its rocky grave has, it is said, been proven by the borough surveyor of Gateshead. On the 1st inst., in making excavations for a new street in the suburbs, a cutting 9ft. deep was made through a bank of rock and clay. At the extreme depth a frog was found embedded, the grayish-brown of which was exactly the same as his surroundings, while its shape was moulded in the hard, rocky matter. The borough engineer put the frog in a box along with loose earth similar to that in which it had been found, and it came to life and motion in a few days. The mouth seems quite closed from want of use, and how the creature has survived, or how long it has been entombed, is a mystery." (R90) Again and again, these entombed animals have sealed mouths, and their color matches the surroundings. (WRC)

X4. Bees. The only reference to bees found in solid rock is so vague as to be useless.

1898. A "story" from Crindan, Newport. "The latest 'story' is that some masons, sawing through a piece of 'Bath stone,' at Crindan, Newport, Mon., came upon a 'square cavity lined with spur.' In this cavity, strange to say, there were six bees, and two of them reached the local newspaper office 'still quite active.' It is said that their presence in the stone is a 'mystery.'" (R91) By their use of quotation marks around the word "story" the editors of the English Mechanic demonstrated their lack of faith in the bee tale! (WRC)

X5. Lizards. Lizards finish third, after toads and frogs, in the list of the most frequently found rock-imprisoned animals.

1853. An imprisoned horned toad. "Not long since, a number of specimens of mineral and animal products were received at the Smithsonian Institute, Washington, from New Mexico, and among other things was a horned lizzard (sic), accompanied by a letter from Judge Houghton, of that Territory, stating that the animal was taken alive from a block of stone, so solid as to preclude the entrance of the smallest insect; the lizzard lived forty-eight hours after it was released from its long imprisonment. The letter states that this lizzard must have been in the position in which it was found since the commencement of the formation of the rocks, and which, if true, must make it a very old animal indeed." (R29) The horned toad is a true lizard.

1928. The famous Eastland horned toad. "Much attention has been attracted recently to a Horned 'Toad' (Phrynosoma cornutum) which is alleged to have been placed in the corner stone of the Eastland County courthouse, Eastland, Texas, in the year 1897. The animal, it is claimed, remained entombed in the granite corner stone until February 18, 1928, a period of thirty-one years. On the latter date it is said to have been removed from the stone alive, before a large crowd of spectators which gathered for the occasion.

"On February 22, 1928, the writer had the opportunity to go to Eastland and make an examination of the animal in question. It appeared to be a perfectly normal specimen which had undergone winter hibernation. It was probably an old one for the horns about the head region were considerably worn and the right hind leg had been broken but was healed. Otherwise it appeared no different from a normal Horned 'Toad' at this season of the year." (R100)

1898. A lizard in coal. "Stories of 'toads-in-holes,' rock-bound creatures that have been immured for years without access to light or food, are continually cropping up, and in Northumberland the well-known toad of Chillingham is historic. But the most extraordinary instance of the kind is probably that just reported from Teddington, the genuineness of which is vouched for by a medical man. Dr. Pippett, of Wildhurst, Coleshill-road, Teddington, is now in possession of a lizard which has been buried in coal for an unknown period. The lizard was discovered by Mrs. Pippett. The page was breaking lumps of coal, and inside one lump, which contained a cavity, was a lizard unlike any English lizard of the present day. The coal was a lump of 'Darby brights,' and the lizard almost exactly fitted the cavity. It was in a comatose state when brought to light, but was put, by Dr. Pippett's directions, into hot sand, and under the treatment it revived and ultimately regained full animation. Its length is 6 in. from head to tail, of a curious black in colour, with yellow streaked belly, and skin of a 'knobby,' though quite soft, texture. Its head and its feet are its most remarkable points. It has a broad, flat head, its mouth and nostrils are sealed tightly as if they had grown so with disuse, and its eyes, dark green in colour, only emerged the day after its liberation from its coaly cell from a heavy lid skin which hung over them. Its feet resemble the hands of a monkey, and it has five toes on each of the hind feet and four on the front two ones." (R93) Even with the lizards, the sealed mouth characteristic persists. It is strange that this (and other) common element(s) crop up at far-separated locations and different time periods. Animals with sealed mouths are not found often in the natural state, if at all; and why should "workmen" and "laymen" invent such peculiar features? (WRC)

X6. Caterpillars.

1848. Live caterpillars in a piece of coal! "Recently, the men employed in opening a new colliery at Northup, near Hawarden, Flintshire, Eng., brought up a piece of solid coal. It happened to get broken when a shell was discovered inside containing a live caterpillar. We understand that this extraordinary reptile (?) remained alive for two days after it was rescued from the prison in which it had been confined from the time when the coal was overwhelmed and buried in the bowels of the earth. The shell and remains of the caterpillar have been sent to the museum of the King's College, London." (R22) This account is difficult to interpret. Presumably, the shell was a fossil of some sort. (WRC)

X7. Terrapins. Lastly, J. Michell and R. J. M. Rickard have reproduced in their book Living Wonders a photograph of a terrapin together with the impression of its shell in a concrete slab. Tha caption reads: "In August 1975, during construction work at Fort Worth, Texas, a green terrapin was found embedded under a mound of hardened concrete which had presumably been poured over it. It was thought to have been there for at least a year. It died 36 hours after its rescue." (R109)

X8. Experiments with live toads. During the 1800s, when interest in the toad-in-the-hole phenomenon was most intense, a few "natural philosophers" (i.e., amateur scientists) experimented by burying live toads, often with intriguing results.

1860. A toad-in-a-pot. "Twenty-three years ago Mr. Wray, of the Duchy Farm, Pendleton, in the presence of Mr. Birch, put a frog into an old pint pot, covered it with a piece of plate, united them by plaster of Paris, and buried all about two-and-a-half feet underground, wet clay being rammed closely round. On Tuesday week the creature was exhumed; the frog was alive, but died in a few minutes after exposure to the air." (R37) We are using the word "toad" here in a generic fashion to indicate all amphibians.

1875. A five-year incarceration. "On the 15th of January, in the year 1870, M. Margelidot caused a cavity to be hollowed in a large stone, put a toad into the cavity, and then sealed up the mouth of the cavity with impermeable cement. On the 15th of last January, five years, day for day, since he had put the poor creature into durance vile, he broke open the cavity, at the Paris Museum of Natural History, and found the toad within alive and well, though in a torpid condition. Nor has it since its release taken any nourishment whatever." (R70)

1825. Buckland's famous experiments. What was the scientific community (such as it was in those days) doing about the toad-in-the-hole phenomenon during the 1800s? Then, as in our present century, scientists avoided the subject as one given substance by outright hoaxes or naive observers. The entire phenomenon was manifestly impossible; it was contrary to all the laws of nature.

The only systematic study by a scientist in the past 200 years seems to be that of W. Buckland, Fellow of the Royal Society, the Linnean Society, the Geological Society, etc.

Excerpts from his 1833 report follow.

"In the month of November 1825, I commenced the following experiments with a view to explain the frequent discoveries of toads enclosed within blocks of stone and wood, in cavities that are said to have no communication with the external air.

"In one large block of coarse oolitic limestone (the Oxford oolite from the quarries of Heddington) twelve circular cells were prepared, each about one foot deep and five inches in diameter, and having a groove or shoulder at its upper margin fitted to receive a circular plate of glass, and a circular slate to protect the glass; the margin of this double cover was closed round, and rendered impenetrable to air and water by a luting of soft clay. Twelve smaller cells, each six inches deep and five inches in diameter, were made in another block of compact siliceous sandstone, viz. the Pennant Grit of the Coal formation near Bristol; these cells also were covered with similar plates of glass and slate cemented at the edge by clay. The object of the glass covers was to allow the animals to be inspected, without disturbing the clay so as to admit external air or insects into the cell. The limestone is so porous that it is easily permeable by water, and probably also by air; the sandstone in very compact.

"On the 26th of November 1825, one live toad was placed in each of the above-mentioned twenty four cells, and the double cover of glass and slate placed over each of them and cemented down by the luting of clay; the weight of each toad in grains was ascertained and noted by Dr. Daubeny and Mr. Dillwyn, at the time of their being placed in the cells; that of the smallest was one hundred fifteen grains, and of the largest one thousand one hundred and eighty five grains. The large and small animals were distributed in equal proportion between the limestone and the sandstone cells.

"These blocks of stone were buried together in my garden beneath three feet of earth, and remained unopened until the 10th of December 1826, on which day they were examined. Every toad in the smaller cells of the compact sandstone was dead, and the bodies of most of them so much decayed, that they must have been dead some months. The greater number of those in the larger cells of porous limestone were alive. No. 1, whose weight when immured was nine hundred twenty four grains, now weighed only six hundred ninety eight grains. No. 5, whose weight when immured was one thousand one hundred and eight five grains, now weighed one thousand two hundred and sixty five grains. The glass cover over this cell was slightly cracked, so that minute insects might have entered; none, however, were discovered in this cell; but in another cell, whose glass was broken, and the animal within it dead, there was a large assemblage of minute insects, and a similar assemblage also on the outside of the glass of a third cell. In the cell No. 9, a toad which, when put in, weighed nine hundred eighty eight grains, had increased to one thousand one hundred and sixteen grains, and the glass over it was entire; but as the luting of the cell within which this toad had increased in weight was not particularly examined, it is probable that there was some aperture in it, by which small insects found admission. No. 11, had decreased from nine hundred thirty six grains to six hundred fifty two grains.

"When they were first examined in December 1826, not only were all the small toads dead, but the larger ones appeared much emaciated, with the two exceptions above mentioned. We have already stated that these probably owed their increased weight to the insects, which had found access to the cells and become their food.

"The death of every individual of every size in the smaller cells of compact sandstone, appears to have resulted from a deficiency in the supply of air, in consequence of the smallness of the cells, and the impermeable nature of the stone; the larger volume of air originally enclosed in the cells of the limestone, and the porous nature of the stone itself (permeable as it is slowly by water and probably also by air) seems to have favored the duration of life to the animals enclosed in them without food.

.....

"The results of our experiments amount to this; all the toads both large and small inclosed in sandstone, and the small toads in the limestone also, were dead at the end of thirteen months. Before the expiration of the second year, all the large ones were also dead; these were examined several times during the second year through the glass covers of the cells, but without removing them to admit air; they appeared always awake with their eyes open, and never in a state of torpor, their meagreness increasing at each interval in which they were examined, until at length they were found dead; those two also, which had gained an accession of weight at the end of the first year, and were then carefully closed up again, were emaciated and dead before the expiration of the second year." (R13) Buckland further concluded that any toads found alive in rocks (observations he did not deny) must somehow have had access to air and sustenance.

It was the negative outcome of Buckland's experiments that apparently set the tone for the centuries yet to come. They reinforced the conclusions that the scientific community had already arrived at and, to be rational, the conclusions any educated person would arrive at today. To our knowledge experiments on the scale of Buckland's have never been repeated. Who can imagine any government grant or university-sponsored project addressing this phenomenon! (WRC)

X9. General observations. The "general observations" in the literature are many, and we can accomodate only a few. Opinion is usually expressed at three levels:

1. Outright denial of the legitimacy of any observations of toads-in-holes. Today, most scientists and educated laymen belong to this school.
2. Admission that some toads are really found sealed up in holes, but that the phenomenon can be easily explained by the longevity of toads in rigorous environments and the probability that some air and nutrients probably found their way into the cavity.
3. Admission of toads-in-holes to the Fortean galaxy of supposedly unexplainable phenomena. Modern Forteanism thrives on observations, which if true would embarrass science. Forteans often suggest frivolous explanations, such as teleportation, to account for things being where they ought not to be!

The first two attitudes were well-expressed over a century ago, as follows:

1853. John Plant's position. "One may well feel surprise to find another of these marvelous relations (of toads in stone) in the pages of the Zoologist, especially as it is one that supplies not a fraction of additional proof of the fact, or of the possibility of such occurrences against the well known laws of Nature. I generally find these second-hand relations all of a kind, and taking place under a pretty similar routine of circumstances. There is the same 'simple tale' from the guileless miners, who show the broken stone with the hole in the center, and talk about the toad or frog, with its lively sense of self-preservation as soon as it is liberated, so lively, in fact, that he always escapes, or is unfortunately smashed; then, they never think of preserving it; and so runs their 'simple tale.' Now, I am a total unbeliever in these 'simple tales,' for in my geological rambles I have never lost an opportunity of searching for cases amongst the very men who pretend to have witnessed them, and the result of my several examinations has been, in many cases, I am sorry to say, to find an amount of downright imposition among the miners, or a mere repetition of hearsay accounts of how Mikey, who has always left for some distant quarry, once was breaking a stone, and found a toad; and then follow the usual particulars. I can relate one of my experiences, which the readers of the Zoologist may perhaps consider sufficient to establish my disbelief in the tales of 'toads in blocks of stone,' quite independently of any scientific consideration on the subject. A few years ago I was geologizing in the neighborhood of Chesterfield, and came upon a quarryman, who related to me, while we drank a bottle of porter, that toads were plentiful in the stone thereabout. He said he had often found them, and that he knew a stone before it was broken that would contain a toad; giving me long and circumstantial accounts of the whole phenomenon: and to convince me of the truth of his statement, he took me to the quarry (a carboniferous sandstone) that I might see the stones out of which he said the toads had been released. I examined the stones and the whole quarry very attentively, and listened to the emphatic testimony of other miners present. After complying in an agreeable manner to their remark that the day was warm, and the water of the quarry not much in favour, I made a simple proposal of this nature:---I promised to pay any one of them the sum of twenty shillings for the next stone in which they found a frog or toad when the stone was broken in two. They should catch the frog if he bolted out of the hole, replace him, and fit the stones together again, afterwards dispatching it to me in that condition. I further promised to pay the sum of forty shillings to any one of them who should procure me a stone, unbroken, in which he considered a toad or frog was imprisoned, if, on breaking it myself, such turned out to be the case. These conditions were to remain in force for twelve months; and as the means of conveyance to my address, which I gave them, would occasion little or no trouble, the offer was readily accepted by the miners; who also, to express their confidence in soon being able to supply the order, proposed that it would be all safe if I advanced a little cash on account, which however I resolutely declined doing. And now, what will the credulous believers in these 'toads in stone' who read the Zoologist say, when they learn that I visited the quarry twice during the twelve months, in order to fetch the toads which never came by rail? I always found the men there blasting tons of new rock, splitting stones for every building purpose, yet dry-throated and sullen; for, alas! most unaccountably during that long twelve months they found plenty of holes---not toad holes ---in the sandstone, but the reptiles had been banished as effectively as ever they were from the Emerald Isle." (R30) Such opinion and even monetary rewards are frequently offered today for hard proofs of USOs, ESP, etc. (WRC)

1871. A different assessment by A.H. Worthen. "It is well known to all naturalists that none of the existing species of animals were in existence during either the paleozoic or mesozoic periods, and hence the reported occurrence of frogs or toads in a torpid but living state, embedded in solid limestone strata, has not been generally credited by scientific men as worthy of serious consideration. Nevertheless it is not uncommon to hear persons assert that such occurrences have taken place within their own personal knowledge, and it seems hardly probable that such reports, should arise in various and different localities, without some apparent foundation in fact.

"In the winter of 1853 the writer was informed by a gentleman of undoubted veracity, that in laying the foundation walls for a warehouse in the town of Naples on the Illinois river, a living toad was found entombed in the limestone, which on coming in contact with the atmosphere soon resumed its wonted activity, though torpid when first discovered.

"Having occasion to pass through Naples a few days afterwards, I examined the walls of the buildings to see if I could discover any clue that might serve to explain so improbable an occurrence. I found the walls constructed out of the brown dolomite of the lower St. Louis, or Warsaw limestone, and observed that the rock had been more or less fissured, the fissures cutting the strata at right angles to the lines of bedding, and varying from a mere line to an inch or more in width. Many of these fissures had been filled wholly or partially with a deposit of stalagmite, and in some places the exposed surface of the rock had been coated for an inch or more in thickness with the same material.

"These facts seemed to me to afford an easy explanation of the reported phenomena; the toad had sought shelter in one of these crevices as his home for the winter, where he remained in a dormant condition, until the constant dripping of water holding carbonate of lime in solution sealed him in completely. Here he remained until he was released by the hammer of the workman, which broke the crust of his stony mausoleum, and restored him to liberty." (R65)

This latter writer, like Buckland in X7, accepted some of the "tales" as true, and then searched for possible explanations. This is a more scientific approach, since all quarrymen are not liars, just as all UFO observers are not hoaxers. (WRC)

References

R1. Graeberg, I.M.; "Report on a Living Toad, Found in the Quarry of Burgsvic, on Gotland, at a Depth of Eight Cubits, inside the Solid Stone," Analecta Transalpine, 1:177, 1741. (X1)
R2. Malpas, John; "Another Instance of the Same Kind," Gentlemens Magazine, 1:26:240, 1756. (X1)
R3. le Cat, M.; "On Living Animals Found in the Centre of the Hardest Stones, without any Pervious Passage from Without," Gentlemens Magazine, 1:26:279, 1756. (X1, X2)
R4. Gentlemens Magazine, 1:43:197, 1773. (X1)
R5. "Instance of Living Animals Found Inclosed in Solid Bodies," Annual Register, 341, 1791. (X1, X2, X7)
R6. "Living Toads Found in Stones Are Productions of the Former World," Blackwood's Magazine, 6:437, 1820. (X1, X8)
R7. "Toad in a Solid Rock," Edinburgh Philosophical Journal, 8:402, 1823. (X1)
R8. Vallot, M.; "Memoir on Living Animals Found in Solid Bodies," American Journal of Science, 1:12:395, 1827. (X1)
R9. "Torpidity of Frogs," Magazine of Natural History, 4:147, 1831. (X1, X3)
R10. Thomas, David; "On Frogs and Toads in Stone and Solid Earth," American Journal of Science, 1:19:167, 1831. (X1, X3)
R11. Buckland, W.; "On the Vitality of Toads Enclosed in Stone and Wood," Edinburgh New Philosophical Journal, 13:26, 1832. (X7)
R12. Magazine of Natural History, 6:458, 1833. (X1)
R13. Buckland, W.; "On the Vitality of Toads Enclosed in Stone and Wood," American Journal of Science, 1:23:272, 1833. (X7)

R14. Bloxam, A.; "Toads Have the Power of Compressing Themselves so as to Pass through a Small Aperture," Magazine of Natural History, 7:519, 1834. (X1)
R15. "Toads Found Incarcerated," Magazine of Natural History, 7:549, 1834. (X1)
R16. Thompson, Wm. A.; "On the Vitality of Toads, &c. Enclosed in Firm Materials," American Journal of Science, 1:25:41, 1834. (X1, X8)
R17. Gooch, T.L.; "Account of a Toad Found Alive Imbedded in a Solid Mass of New Red Sandstone," Report of the British Association, 1835, p. 72. (X1)
R18. "A Toad in Sandstone," American Journal of Science, 1:29:353, 1836. (X1)
R19. "Incarcerated Toads," Magazine of Natural History, 9:316, 1836. (X1)
R20. "Lizards in Chalk," American Journal of Science, 1:37:402, 1839. (X5)
R21. Bree, T.; "Note on Toads Found in Blocks of Stone," Zoologist, 2:769, 1844. (X1)
R22. "Extraordinary," Scientific American, 3:163, 1848. (X8)
R23. "Toad Found in a Flint," Zoologist, 9:3265, 1851. (X1)
R24. Ross, F.W.L.; "Toads Buried Alive," Zoologist, 9:3266, 1851. (X1)
R25. Monins, M.; "Living Toad Found in a Flint," Comptes Rendus, 33:60, 1851. (X1)
R26. de Beaumont, Elie, et al; "Report on a Toad Found Alive inside a Cavity in a Big Flint," Comptes Rendus, 33:103, 1851. (X1, X8)
R27. Turner, William; "Curious Propensity of a Toad," Zoologist, 10:3389, 1852. (X1)
R28. Evans, John; "Occurrence of a Toad in a Block of Iron Ore," Zoologist, 10:3632, 1852. (X1)
R29. "Imprisoned Reptiles," Scientific American, 8:366, 1853. (X5, X6)
R30. Plant, John; "Occurrence of Toads in Stone," Zoologist, 11:3808, 1853. (X8)
R31. Hussey, Arthur; "Note on Frogs and Toads Inclosed in Stones," Zoologist, 11:3848, 1853. (X3)
R32. Smith, W.J. Bernhard; "The Toad," Notes and Queries, 2:24:466, 1856. (X1)
R33. "Discovery of a Living Frog in the Solid Rock," Zoologist, 16:5959, 1858. (X3)
R34. Clark, Thomas; "Occurrence of Live Toads underneath a Bed of Clay," Zoologist, 17:6537, 1859. (X1)
R35. "Sur les Pluies de Crapauds & les Crapauds Vivant Trouvés dans des Pierres," Science pour Tous, 5:222, 1859. (X1)
R36. "Toads Found in Stones," Notes and Queries, 2:10:56, 1860. (X1)
R37. "Toads Found in Stone," Notes and Queries, 2:10:135, 1860. (X7)
R38. Kelly, William; "Toads Found in Stone," Notes and Queries, 2:10:276, 1860. (X1)
R39. Dumeril, M.; "Toads Found Alive in Closed Cavities," Comptes Rendus, 50:973, 1860. (X1)
R40. "A Toad in a Hole," The Field, 18:250, 1861. (X1)
R41. Hutchinson, P.; "Toads in Rocks," Notes and Queries, 3:2:55, 1862. (X1)
R42. Moody, Henry; "Toads in Rocks," Notes and Queries, 3:2:97, 1862. (X1)
R43. "Toads in Rocks," Notes and Queries, 3:2:175, 1862. (X1)
R44. "A Living Toad Found in Coal," Zoologist, 20:8007, 1862. (X3)
R45. "Interesting Discoveries," The Field, 19:300, 1862. (X3)
R46. Buckland, F.T.; "A Living Frog Found in Coal," The Field, 19:387, 1862. (X3)
R47. Baker, W.B.; "A Living Frog Found in a Coal Pit," The Field, 19:469, 1862. (X3)
R48. Bree, C.R.; "Toads in Holes," The Field, 19:494, 1862. (X8)
R49. "The 'Toad in the Hole' Question Again," The Field, 20:299, 1862. (X1)
R50. Smith, Eldred; "The 'Toad in the Hole' Question," The Field, 20:320, 1862. (X1, X7)
R51. "Toads," The Field, 20:340, 1862. (X1)
R52. Cumming, Alexander P.G., et al; "Toads in the Hole," Zoologist, 21:8641, 1863. (X1)
R53. Gosse, P.H.; "Toads in Stone," Zoologist, 21:8726, 1863. (X8)
R54. "Toad," Notes and Queries, 3:6:521, 1864. (X1)
R55. "A Toad in a Rock Forty Feet below Ground," Zoologist, 22:9295, 1864. (X1)
R56. Birchall, E.; "An Extraordinary Toad," Zoologist, 23:9630, 1865. (X1)
R57. "Toad in Stone," Notes and Queries, 3:7:339, 1865. (X1)
R58. Wetherell, J.; "Toad in Stone," Notes and Queries, 3:7:388, 1865. (X1)
R59. Johnson, E.; "Toads in Stone," Notes and Queries, 3:7:428, 1865. (X1)
R60. Chappell, W.; "Toads in Stone," Notes and Queries, 3:7:469, 1865. (X1)
R61. "A Frog Found in a Clay Bed," Science Gossip, 2:141, 1866. (X3)
R62. Hutchinson, Simon; "Frog in Oolite," Science Gossip, 3:45, 1867. (X3)
R63. Benenden, S.G.; "Incarcerated Frogs," Science Gossip, 3:207, 1867. (X3)
R64. Horton, W.I.S.; "Toads in the Hole," Notes and Queries, 3:3:325, 1868. (X1)
R65. Worthen, A.H.; "How Living Toads May Occur in Limestone," American Naturalist, 5:786, 1871. (X8)

R66. Pengelly, W.; "But Is It a Fact?" Devonshire Association, Transactions, 5:201, 1872. (X8)
R67. "Living Toad Found in a Bed of Clay," Land and Water, 13:259, 1872. (X1)
R68. Reid, W.; "Live Toad Found in a Bed of Clay," Land and Water, 13:290, 1872. (X7)
R69. Arnold, A.W.; "A Toad in the Solid Rock," Scientific American, 29:212, 1873. (X1)
R70. Mayer, S.; "Live Toads in Stone," English Mechanic, 21:13, 1875. (X7)
R71. Sutton, E.B.; "Live Toads in Stones," English Mechanic, 21:38, 1875. (X7)
R72. "Live Toads in Stones," English Mechanic, 21:94, 1875. (X7)
R73. Allan, F.J.; "Longevity of Toads," Science Gossip, 11:166, 1875. (X1)
R74. Silvester, J.; "Live Toad in Flints," Land and Water, 23:307, 1877. (X1)
R75. Downes, W.; "Live Toads in Limestone Rocks," Science Gossip, 14:199, 1878. (X1)
R76. Penny, W.; "Toad in Clay," Land and Water, 27:400, 1879. (X1)
R77. "Prolonged Torpidity of Toads," Scientific American, 40:87, 1879. (X1)
R78. Wilson, A.; "Toad in a Hole," Knowledge, 1:136, 1881. (X8)
R79. "Vitality of Toads," Knowledge, 1:202, 1882. (X7)
R80. "Toads, &c," Knowledge, 1:231, 1882. (X8)
R81. Livingstone, W.P.; "On the Vitality of Frogs and Toads," in The Field Naturalist and Scientific Student, William E.A. Axon, ed., Manchester, 1883, p. 184 and p. 202. (X1, X3, X8)
R82. Yates, James; "Toads in Rocks," North Staffordshire Naturalists Field Club, Report, 1883, p. 68. (X8)
R83. Norman, F.M.; "Embedded Reptiles," History of the Berwickshire Naturalists Club, 1884, p. 491. (X1, X3, X8)
R84. Shufeldt, R.W.; "A Mummified Frog," Science, 8:279, 1886. (X3)
R85. Kegan, P. Quin; "Toads in Rocks," Science Gossip, 22:262, 1886. (X1)
R86. Sykes, Mark L.; "Toads in Rocks," Science Gossip, 23:22, 1887. (X3, X8)
R87. "Toads in Rocks," Science Gossip, 23:94, 1887. (X1)
R88. "Toads in Rocks," Scientific American, 63:180, 1890. (X3)
R89. Masefield, John R.B.; "An Introductory Paper on Our Local Reptilia and Amphibia," North Staffordshire Field Club and Archaeological Society, Transactions, 26:71, 1892. (X8)
R90. "Frogs in Rock," English Mechanic, 62:314, 1895. (X3)
R91. English Mechanic, 66:551, 1898. (X4)
R92. Player, Jenner; "Toads in Holes," English Mechanic, 67:65, 1898. (X1)
R93. "The 'Toad in the Hole'," English Mechanic, 68:441, 1898. (X1, X5)
R94. "A Toad in the Coal," English Mechanic, 73:260, 1901. (X1)
R95. "Live Frog in a Coal Lump," New York Times, December 24, 1906. (X3)
R96. Caradoc and Severn Valley Field Club, Transactions, 79, 1906. (X1)
R97. Nature, 83:406, 1910. (X1)
R98. "Tests for Toads," New York Times, March 4, 1928. (X1, X5, X8)
R99. "Assert 'Glacial' Toad Is Only Two Years Old," New York Times, April 2, 1928. (X1)
R100. Hewatt, Willis G.; "The Eastland Horned Toad," Science, 67:348, 1928. (X5, X7)
R101. "Miners Find Clawed Frog," New York Times, November 17, 1929. (X3)
R102. "Three Toads, Buried 300 Years, Hop When Dug Out of Mound," New York Times, September 30, 1930. (X1)
R103. "Pennsylvanians Say Toad Lived 63 Years Buried Alive," New York Times, July 13, 1931. (X1)
R104. "Toad, Sealed in Wall 50 Years, Lives When Freed in Jersey," New York Times, March 5, 1932. (X1)
R105. Davies, P.A.; "Extended Hibernation in the Toad," Science, 81:617, 1935. (X1)
R106. Garnett, D.G.M.; "Toads Underground," Suffolk Naturalists Society, Transactions, 7:136, part 3, 1951. (X1)
R107. "Living Animals, Locked in Stone," Mysteries of the Unexplained, Pleasantville, 1982, p. 43. (X1, X5)
R108. Michell, John, and Rickard, Robert J.M.; "Toads in the Solid Rock," Living Wonders, New York, 1983, p. 97. (X1, X5, X8)
R109. Skinner, Bob; Toad in the Hole, London, 1986. (X1-X8)

ESB9 Living Organisms Found at Great Depths in the Earth

Description. The existence of living organisms, usually bacteria, hundreds and even tens of thousands of feet below the earth's surface.

Data Evaluation. All data collected so far have originated in scientific and commercial drilling programs. Although these data are considered quite reliable, they come from newspapers and popular science publications. Rating: 2.

Anomaly Evaluation. Bacteria are extremely hardy and can survive very high pressures and temperatures. Their survival at great depths in the earth, therefore, is more unexpected than scientifically anomalous; that is, no laws are challenged, just prevailing opinion. Rating: 3.

Possible Explanations. Bacteria and perhaps other life forms have been carried wherever fluids circulating beneath the surface penetrate---providing, of course, that environmental conditions are not too severe. It may be highly speculative, but the possibility exists that life originated in the energy-rich chemicals beneath the earth's surface.

Similar and Related Phenomena. Origin of terrestrial life (B).

Examples

X1. Kola Peninsula, USSR. Preliminary findings of the Soviet deep-drilling program have been published in Western newspapers. "...the Soviet press reported that the drilling effort thus far had identified evidence of life in rocks more than two billion years old and that some of the characteristics of deep-seated rocks, such as temperature and density, did not conform to predictions.

.....

"According to (Y.) Yakovlev, however, the evidence of life at great depths had not been expected. He said accumulations of gas, fissure waters and bromine and iodine brines all testified to some biological activity as the drill penetrated through alternating layers of igneous rocks emanating from the earth's interior and rocks of marine origin laid down during the Late Precambrian Era some two billion years ago." (R1; R2)

X2. Water aquifers. "In recent years, scientists have found bacteria, as far down as 1,150 feet, in wells that penetrate deeply buried aquifers---porous layers of rock that hold underground water. Such finds have forced hydrologists to question their traditional belief that deep aquifers were void of life. But it was not clear whether these bacteria were native residents of the aquifers or just contaminants from the world above, living solely within the wells. Moreover, no one had established how the bacteria were affecting their environment, if at all.

"Experiments are now demonstrating for the first time that bacteria are indigenous to deep aquifers and that they actively change the chemistry of the groundwater." (R4)

X3. Petroleum. "All crude oils also contain live, active bacteria. These are able to withstand high pressures, relatively high temperatures and a complete absence of air. The products of their activity contribute, of course, to the total content of the oil, and could account for all its biological properties. Those who do not believe in abiogenic oil claim that these bacteria are responsible for converting the organic matter found in sediments into oil. Those who do not believe in biogenic oil claim the bacteria alter the constitution of the oil, producing more odd-carbon molecules and making it optically active. They also claim that the porphyrins and other nitrogenous compounds found in oil are formed by the bacteria." (R3) See also ESC13.

X4. Coal. "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 water 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." (R5)

X5. Limestone. "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 of 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." (R6)

References

R1. "Journey to Earth's Center, San Diego Union, October 9, 1981, p. A-30. (X1)
R2. Rebeyrol, Yvonne; "Un Puits de 10 Kilometres," Le Monde, April 4, 1986, p. 14. (Cr. C. Maugé) (X2)
R3. Sylvester-Bradley, P.; "The Origin of Oil---and Life," Discovery, 25:37, May 1964. (X3)
R4. Monastersky, R.; "Bacteria Alive and Thriving at Depth," Science News, 133: 149, 1988. (X2)
R5. "Doubt Cast on Antiquity of Bacteria Found in Coal," Science News Letter, 22:196, 1932. (X4)
R6. "New Claim to Have Revived 'Fossil' Bacteria," New Scientist, 23:575, 1964. (X5)

ESB10 Fossils of Warm-Climate, Light-Dependent Organisms Found in the Polar Regions

Description. The existence in the Arctic and Antarctic of organisms usually considered to be dependent upon a mild climate and abundant sunlight. A closely related observation is that of evolutionary innovation in the polar regions, a process usually associated with ample sunlight, warmth, and water.

Data Evaluation. Almost all of the data at hand come from recent geological and paleontological work in the polar regions. Rating: 1.

Anomaly Evaluation. If the polar lands have not wandered far during the past 100 million years, the present phenomenon is highly anomalous. Even the past existence of gentler polar climates does not explain the survival of dinosaurs, corals, and diatoms during months of darkness---unless these organisms adapted in some unrecognized way. Taken collectively, the examples below (X1-X5) paint a picture of a fecund, life-rich polar environment; a picture very much at variance with current geological scenarios for the past 100 million years. Rating: 2.

Possible Explanations. The polar lands did move appreciably relatively recently from warmer, sunnier climes to their present positions, either through continental drift or crustal slippage stimulated by asteroid impact. (Note, though, that geomagnetic data do not support such large movements.) Another possibility is that dinosaurs, corals, etc., were able to adapt in some unrecognized way to the long polar nights.

Similar and Related Phenomena. The frozen mammoths and other fossils in the Arctic muck (ESB4).

Examples

X1. Wood, coal, fossil plants. Geologists and paleontologists find ample evidence for the existence of substantial forests close to the poles in the past. All that would be required here is a more benign climate, for plants can and have adapted to the long polar nights. The temperatures involved, though, are troublesome. A rise of 30°F above the Arctic and Antarctic circles would be needed for luxuriant plant growth; but if the temperatures in the tropics rose by the same amount, did the fauna and flora there prosper? I. Velikovsky has stated that there is no evidence in the fossil record for much hotter tropical environments. (R1) His assertion has not been confirmed by any of the scientific literature surveyed so far.

North polar region. The subjects of buried wood and unfossilized tree stumps in this region has already been mentioned in ESB4.

I. Velikovsky adopted the deposits of Arctic coal to bolster his catastrophic scenario. Specifically, he mentioned the thick coal beds, covered with black shale and fossilized land plants, located on the northern tip of the Spitzbergen Archipelago. Velikovsky quotes A. Geikie, the noted geologist, on this coal deposit:

> "When we remember that this vegetation grew luxuriantly within 8°15' of the North Pole, in a region which is in darkness for half of the year and is now almost continuously buried under snow and ice, we can realize the difficulty of the problem in the distribution of climate which these facts present to the geologist."

Velikovsky then elaborates: "There must have been great forests on Spitzbergen to produce a bed of coal thirty feet thick. And even if Spitzbergen, almost one thousand miles inside the Arctic Circle, for some unknown reason had the warm climate of the French Riviera on the Mediterranean, still these thick forests could not have grown there, because the place is six months in continuous night. The rest of the year the sun stands low over the horizon." (R1) As intimated above, plants might have adapted to these severe conditions. (WRC)

South polar region. Something is wrong with our recent history of Antarctica. Conventional wisdom insists that the continent has been ice-covered for over 15 million years. But now P. Webb and his coworkers have found pollen and the remains of roots and stems of plants in an area stretching some 1300 kilometers along the Transantarctic Mountains. This Antarctic wood is so recent that it floats and burns with ease. Webb's group postulates that a shrub-like forest grew in Antarctica as recently as 3 million years ago. The dating, of course, is critical, and is certain to be subjected to scientific scrutiny. Nevertheless, these deposits of fresh-looking wood do suggest that trees recently grew only 400 miles from the South Pole." (R7, R10) Note the similarities between the Antarctic "fossil" wood and that found on Axel Heiberg and Ellesmere islands in the Arctic. Both woods are reckoned as ancient, yet they "look" fresh and burn surprisingly easily. (WRC)

X2. Fossil corals. Corals are animals which need the sun and warm waters to survive. Given much warmer waters in the polar regions, could they live during the months of darkness? The answer seems to be "yes."

North polar region. Again we refer to Velikovsky's fully documented description. He first mentioned Spitzbergen, where large coral formations are seen amid the snow and ice. Then, he goes on: "At some time in the remote past corals grew and are still found on the entire fringe of polar North America ---in Alaska, Canada, and Greenland. In later times (Tertiary) fig palms bloomed within the Arctic Circle; forests of *Sequoia gigantea*, the giant tree of California, grew from Bering Strait to north of Labrador. 'It is difficult to imagine any possible conditions of climate in which these plants could grow so near the pole, deprived of sunlight for many months of the year '" (R1) In the last sentence, Velikovsky quotes D.H. Campbell. Note also that corals are coelenterates (animals) which are usually allied with algae (plants) in a symbiotic relationship. Thus, coral reefs require sunlight to live. (WRC)

X3. Dinosaur fossils. The presence of dinosaur bones in the polar regions requires that those regions once had climate mild enough to support the abundant vegetation needed by herbivorous dinosaurs. Another question raised by such dinosaur fossils is how the dinosaurs survived during long periods of darkness when vegetation could not grow.

North polar region. Somewhere west of Deadhorse, a small town on Prudhoe Bay in northern Alaska, paleontologists have found the bones of at least three species of dinosaurs. These finds are at a latitude of 70° north and, according to paleomagnetic measurements, the latitude has changed but little since the dinosaurs met their demise. At these high latitudes, the dinosaurs either had to contend with two months of darkness each year or they had to migrate many hundreds of miles over the rough Alaskan landscape. The visions of dinosaurs groping for tons of vegetable food during the polar night is about as incongruous as imagining them trekking over Alaskan mountains to milder climes to the south.

Scientists maintain that the polar dinosaurs were able to prosper on the shores of the Arctic Ocean, even in the dark, because the climate then was temperate or even semitropical. In fact, the climate of the entire planet is thought to have been milder and more uniform in the late Cretaceous.

The paleontologists were further surprised by the "fresh" appearance of the bones they found in the Arctic. There is little mineral deposition in the dinosaur fossils, and they seem "modern"!

The apparent survival of the polar dinosaurs during two months of darkness is being used as an argument against asteroidal catastrophism, which it is claimed wiped out the dinosaurs with a long-lived dust cloud that blocked the sunlight they needed. (R6, R8, R11)

In ESB4, one finds repeated testimony that the mammoth bones, as well as those of other creatures, found in Siberia and Alaska are very fresh. Of course, these are thought to be only a few thousands of years old, while the dinosaur bones must be tens of millions of years old. (WRC)

X4. Diatoms. Diatoms are plants which require sunlight to survive.

South polar region. In 1978, a Soviet team of scientists drilled through the Ross Ice Shelf. The top 1345 feet was found to be continental ice that had been pushed off Antarctica onto the ocean. The bottom 33 feet, however, consisted of frozen seawater which had been added to the freshwater ice. This sea ice contained many small inclusions. "The inclusions, examined by Dr. Floyd H. Burckle of the Lamont Observatory, have turned out to be the remains of microscopic diatoms dependent on sunlight. They must have lived in the open ocean. 'We didn't expect this at all,' Dr. Burckle said last week. Some are from contemporary species but others became extinct as far back as nine million years ago. These fossils presumably were in some manner swept up from the ocean flood." (R7; R10) The implication if that these polar seas were free of ice when the diatoms grew, died, and their skeletons sank to the seafloor.

See ESB5 for treatment of fish corpses found on the surface of the Antarctic ice.

X5. High-latitude heterochroneity. This rather awkward term is applied to the curious fact that some polar fossils, closely resembling those found at lower latitudes, seem to be much older. The implication: new life forms were able to evolve in the polar regions despite the colder climate and lack of sunlight part of the year. From there they migrated towards the Equator. Biologists tend to think that warm tropical shores and wet rainforests are the cradles of evolution; at least this is where one would expect speciation to occur. Were the earth's polar regions somehow different in the past that they stimulated evolutionary processes? (WRC)

North polar region. "Abstract. Magnetostratigraphic correlation of the Eureka Sound Formation in the Canadian high Arctic reveals profound difference between the time of appearance of fossil land plants and vertebrates in the Arctic and in mid-northern latitudes. Latest Cretaceous plant fossils in the Arctic predate mid-latitude occurrences by as much as 18 million years, while typical Eocene vertebrate fossils appear some 2 to 4 million years early." (R3; R2) The results just quoted are highly controversial, particularly the magnetostratigraphic dating, which is thought to be inaccurate. (R4)

South polar region. Observations of marine invertebrates in the Antarctic corroborate the discoveries made in the Arctic. Thus, high-latitude heterochroneity has been detected in both polar regions. More specifically, the distribution of fossils within the Mollusca, Echinodermata, and Arthropoda suggests that "the high latitude region of the Southern Hemisphere acted as a center of origin and dispersal for a broad spectrum of taxa." (R5)

References

R1. Velikovsky, Immanuel; "Ice," Earth in Upheaval, New York, 1965, p. 44. (X1, X2)
R2. Simon, C.; "Arctic Evolution for Land Plants, Animals?" Science News, 124: 197, 1983. (X5)
R3. Hickey, Leo J., et al; "Arctic Terrestrial Biota: Paleomagnetic Evidence of Age Disparity with Mid-Northern Latitudes during the Late Cretaceous and Early Tertiary," Science, 221:1153, 1983. (X5)
R4. Kent, Dennis V., et al; "Arctic Biostratigraphic Heterochroneity," Science, 224: 173, 1984. (X5)
R5. Zinsmeister, William J., and Feldmann, Rodney M.; "Cenozoic High Latitude Heterochroneity of Southern Hemisphere Marine Faunas," Science, 224: 281, 1984. (X5)
R6. Anderson, Ian; "Alaskan Dinosaurs Confound Catastrophe Theorists," New Scientist, p. 18, August 22, 1985. (X3)
R7. "Frozen History," New York Times, May 28, 1985. (Cr. J. Covey) (X4)
R8. Dusheck, J.; "Arctic Dinosaurs Raise Questions," Science News, 128:135, 1985. (X3)
R9. Weisburd, S.; "A Forest Grows in Antarctica," Science News, 129:148, 1986. (X1)
R10. Anderson, Ian; "A Glimpse of the Green Hills of Antarctica," New Scientist, p. 22, July 3, 1986. (X1, X4)
R11. Brouwers, Elisabeth M.; "Dinosaurs on the North Slope, Alaska: High Latitude Latest Cretaceous Environments," Science, 237:1608, 1987. (X3)

ESB11 Time-Wise Anomalous Fossils

Description. Fossils discovered in strata that are dated either as too old or too young for the age of the fossil, as determined by the conventional evolutionary timetable. The strata themselves are dated either by index fossils or by radiometric methods or both.

Data Evaluation. Hundreds of observations of this phenomenon have accumulated for microfossils, such as pollen and spores. In some cases, at least, good arguments can be made for contamination of the strata under scrutiny by microfossils from younger or older deposits. On the other hand, time-displaced larger fossils are more rare, though much more difficult to explain in terms of contamination. In sum, the most abundant cases are weak and vice versa. Rating: 3.

Anomaly Evaluation. The reality of this phenomenon would be traumatic for the accepted view of evolution. It could not survive the confirmed, frequent appearance of "advanced" organisms in the fossil record long before they should. Rating: 1.

Possible Explanations. Some anomalies can be eliminated by redefining the stratigraphic range of the involved organisms; the residue must be the consequence of contamination---so goes the mainstream position. Alternatively, the theory of evolution, which sketches out the "tree of life", must be incorrect. Possibly facetitious is the suggestion that time-displaced fossils are the product of future time travel!

Similar and Related Phenomena. Skipping in the fossil record (ESB12); anomalies of radiometric dating (ESP1, ESP12); living organisms in rocks (ESB8); biological evidence contradicting the theory of evolution (B).

Examples

X1. Spores and pollen. These "microfossils" are not only common in the stratigraphic record but they are also ubiquitous in today's environment. Their small sizes and frustrating ability to contaminate geological samples (meteorites also) complicate scientific research on them. Whenever fossil pollen and spores are found in anomalous places; viz., pollen of vascular plants in Precambrian deposits; the immediate reaction is to claim contamination from today's air or ancient groundwater. Nevertheless, the study of fossil spores and pollen, which has been dubbed "palynology", has become a refined science in recent years, allowing an extension of research back into the very oldest of rocks:

"Results of this extension have been rather startling. One can usually find statements in texts implying that the Cambrian plants are the simplest possible---namely, all algae, or that the whole life record of the Cambrian is marine. Museum displays give the same message in their beautiful but imaginative reconstruction of Cambrian life.

"But within the last 15 years, spores of vascular plants have been discovered in the Lower Cambrian of Kunda in Estonia; the Pre-Baltique of the U.S.S.R.; the Upper Cambrian of Kashmir, and the Salt Range of India. (See R2 for the Indian paper.) Such reports were usually met with skepticism and suspicions of contamination.

However, in 1953 Krychtofowitch reported the discovery of lycopodiaceous shoots in the Cambrian of East-Siberia. In addition, various workers report the findings of small fragments of tracheids which show simple and bordered pits." (R5)

The author of the foregoing three paragraphs was W. Rusch, Sr., a scientific creationist. The interest of scientific creationists in Precambrian palynology is not surprising due to their philosophical rejection of the evolutionary timetable.

R. L. Wysong, another scientific creationist, states the situation more dramatically:

"Pollen from Angiosperm and Gymnosperm trees has been found in 'Pre-Cambrian' rocks. This would place, according to evolutionary ideas, the reproductive pollen hundreds of millions of years prior to the existence of the mother trees. Some spores are stained with red oxide from the surrounding rocks, thus proving they are not from present-day contamination. The evolutionists, Leclerq and Axelrod, have found spores and fragments of woody plants representing dozens of genera (Axelrod found 60 genera) in 'Cambrian' rocks. Woody plants supposedly did not arrive on the evolutionary scene until over 200 million years after the 'Cambrian.'" (R8)

Most of the discoveries to which the scientific creationists refer have been made by mainstream scientists, with appropriate controls being taken against contamination. The field and laboratory results are hotly debated, as described in R. M. Stainforth's 1966 paper in Nature.

Discovery of and reactions to pollen and spores in a Precambrian formation. "Late in 1963 G.C.K. Dunsterville made an expedition to collect orchids around Cerro Venamo, at the westernmost point on the frontier between Venezuela and British Guiana (where this mountain is known as Wenamu Head). He noted some shale-like beds at the base of a towering cliff of Roraima sandstone and collected samples for their possible paleontological interest.

"G. Fournier, palynologist of the Mene Grande Oil Company, processed the samples and recovered well-preserved pollen and spores. Subsequently, L. Nijssen and J.A. Sulck, palynologists of Compania Shell of Venezuela and Creole Petroleum Corporation, respectively, processed other pieces and recovered identical plant microfossils.

"This discovery of pollen and spores in a formation of supposed Precambrian age was so remarkable that a reconnaissance expedition of qualified geologists was organized to verify the facts of the case." The facts were confirmed by the expedition. (R4)

The interpretation of these facts was sharply divided. Stainforth's summary of opposing opinions is very revealing: "One group adopts the attitude that the radiometric dating of the dolerites and a hornfels within the Roraima Formation as Precambrian in beyond dispute, hence the pollen (and spores) must have entered as secondary contamination. The improbability that pollen could withstand the baking process, which converted shale to hornfels, is adduced as further evidence that the pollen must be allochthonous. The absence of macroscopic plant remains in the Roraima Formation is also noted, despite its assumed continental (? fluviatile) origin. It is admitted that entry of the pollen into its present site defies simple explanation, though some form of washing in by meteoric waters in the geological past via joints in the overlying sandstone seems the most probable cause.

"The second group holds that by no conceivable physical means could the pollen (and spores) have entered the metamorphosed sediments from the outside. They are dense impermeable rocks compressed by overburden of hundreds of feet of the overlying Roraima sandstones. The undercutting at Cerro Venamo suggests that the cliff has been steadily retreating, hence the face which was sampled must have been deep within the formation until quite recent times. The Roraima sandstones are quartzite, of low permeability, hence carriage of extraneous pollen through them by percolating water seems highly improbable. Even if this process could occur, entry of such pollen and spores into the nonporous hornfels lacks an explanation. Furthermore, if the plausibility of this process be granted, it would have been operative for a long period, and a mixed suite of spores and pollen would be expected." This latter group questions the radiometric dating of the formation. (R4)

There are many, many instances of microfossils, particularly pollen and spores, being found in the "wrong" strata---that is, "wrong" time-wise. The scope of this problem will be presented below in X5.

For the sake of completeness, we must mention some field and lab work done by C. L. Burdick, a creationist, even though its validity has been challenged by palynologists. Burdick has claimed the discovery of pollen from seed plants in the Precambrian Hakatai shale deep in the Grand Canyon. (R12, R14, R15) However, other scientists cannot verify his results. (R16)

X2. Arthropods. "Arthropod fossils have been found by a U.S.G.S. team in proterozoic--younger Pre-Cambrian rocks age-dated at 1.2 billion years. This discovery from the Sierra Ancha area of northern Arizona, puts the Arthropods hundreds of millions of years before they were supposed to have evolved." (R8) The photograph accompanying this unreferenced paragraph is captioned "Proterozoic fossils tentatively identified as Arthropods..." No further information on these fossils has been found, nor have any other records of Precambrian arthropods. (WRC)

X3. Fish. In 1912, near Ohio City, Colorado, numerous fragments of fish remains were identified in Ordovician strata. These fish fossils, if found by themselves, would have been classified as Devonian; but the rocks in which they were found are manifestly Ordovician by virtue of their invertebrate fossils. The first Devonian deposits in the area are, in fact, 100 feet above these Ordovician rocks. The Silurian era, normally sandwiched between the Devonian and Ordovician, is not represented in this part of Colorado. (R2) Note that some primitive fishes are known from the Ordovician, but the remains cited here were clearly Devonian. (WRC)

Another example of time-displaced fish fossils was briefly alluded to by R. Daly. (R7) He stated, without reference, that Devonian teleost fish fossils had been discovered mixed with Silurian corals and graptolites.

X4. Humans. Human bones turn up in the most unlikely places. Our classification scheme assigns displaced human fossils to the several archeological Catalog volumes (M) to be published later. There, one will find, for example, the famous Guadeloupe skeleton, the infamous Calaveras skull, the "abominable coalman," and human-made objects found in too-old deposits. However, as examples of the genres, two items seem appropriate here.

Human bones in a 100-million-year old Cretaceous formation. "Clifford Burdick has reported on his investigation of the find of two modern human skeletons in the Dakota Formation of the Cretaceous (supposedly 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 Rusch 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." (R10; R6)

A human artifact from the Miocene. "I have had the good fortune to discover, in the vicinity of the Dardanelles, conclusive proofs of the existence of man during the Miocene period of the Tertiary age. From the face of a cliff composed of strata of that period, at a geological depth of eight hundred feet, I have myself extracted a fragment of the joint of either a dinotherium or a mastodon, on the convex side of which is deeply incised the unmistakeable figure of a horned quadruped, with arched neck, lozenge-shaped chest, long body, straight fore-legs, and broad feet. There are also traces of seven or eight other figures which, together with the hind quarters of the first, are nearly obliterated. The whole design encircles the exterior portion of the fragment, which measures nine inches in diameter and five in thickness. I have also found in different parts of the same cliff, not far from the site of the engraved bone, a flint flake and some bones of animals, fractured longitudinally, obviously by the hand of man for the purpose of extracting the marrow, according to the practice of all primitive races." (R1)

X5. Surveys of timewise-anomalous fossils. J. Woodmorappe has collected over 200 instances where fossils (mostly microfossils) have been reported as existing in deposits of the "wrong" age; that is, the fossils "belonged" to a later or earlier age, usually the former. He substantiated his giant table of apparent anomalies with 238 references from the scientific literature. Often, the deviations from "proper" ages are not extreme, but there are enough large temporal displacements to cause concern.

Woodmorappe knows, of course what the accepted explanations are for these deviations from the established evolutionary scenario: (1) Small displacements are simply "extensions" of stratigraphic range (the organism in question evolved a bit earlier than previously thought); (2) Large differences are due either to "washing down" (young fossils are carried down into older rocks by ground fluids) or "reworking" (older fossils are eroded and redeposited in younger sediments). But Woodmorappe believes that the phenomenon is too widespread to be brushed off so easily; and he quotes some geological authorities who agree with him: "The occurrence of Carboniferous spores in Jurassic (deposits) is so common all over Europe that the author Windle proposed that it must have a unified continent-wide explanation. He suggested that it does not mean that hidden remnants of Carboniferous floras survived into the Jurassic but that continent-wide orogenesis during Jurassic times in Europe caused much Carboniferous strata to be eroded away in Jurassic times. Concerning "reworked" forms, Stanley said: 'These secondary grains usually are present in larger numbers in both marine and non-marine sediments than most workers would like to admit.' Comment: From all the statements cited above it can be seen that anomalous fossils cannot be dismissed as being rare or being only trivial localized occurrences." (R13)

References

R1. Calvert, Frank; "On the Probable Existence of Man during the Miocene Period," Anthropological Institute, Journal, 3:127, 1873. (X4)
R2. Cockerell, T.D.A.; "Ordovician (?) Fish Remains in Colorado," American Naturalist, 47:246, 1913. (X3)
R3. Jacob, K., et al; "Spores and Tracheids of Vascular Plants from the Vindhyan System, India," Nature, 172:166, 1953. (X1)
R4. Stainforth, R.M.; "Occurrence of Pollen

and Spores in the Roraima Formation of Venezuela and British Guiana," Nature, 210:292, 1966. (X1)
R5. Rusch, Wilbert, Sr.; "The Revelation of Palynology," in Why Not Creation? Walter E. Lammerts, ed., Grand Rapids, 1970, p. 180. (X1)
R6. Burdick, Clifford L.; "Discovery of Human Skeletons in Cretaceous Formation," Creation Research Society Quarterly, 10: 109, 1973. (X4)
R7. Daly, Reginald; "The 'Pioneer Colony' Theory," Earth's Most Challenging Mysteries, Nutley, 1975, p. 90. (X3)
R8. Wysong, R.L.; "Geologic Evidence," The Creation-Evolution Controversy, East Lansing, 1976, p. 370. (X1, X2)
R9. Burdick, Clifford L.; "Progress Report on Grand Canyon Palynology," Creation Research Society Quarterly, 9:25, 1972. (X1)
R10. Gish, Duane T.; "A Decade of Creationist Research," Creation Research Society Quarterly, 12:34, 1975. (X1, X4)
R11. Jefferson, T.H.; "Angiosperm Fossils in Supposed Jurassic Volcanogenic Shales, Antarctica," Nature, 285:157, 1980. (X1)
R12. Rusch, W.H., Sr.; "The Present Position of Pre-Cambrian Pollen," Creation Research Society Quarterly, 19:143, 1982. (X1)
R13. Woodmorappe, John; "An Anthology of Matters Significant to Creationism and Diluviology: Report 2," Creation Research Society Quarterly, 18:201, 1982. (X5)
R14. Howe, G.F., et al; "Pollen Research Update," Creation Research Society Quarterly, 22:181, 1986. (X1)
R15. Howe, George F.; "Creation Research Society Studies on Precambrian Pollen: Part I---A Review," Creation Research Society Quarterly, 23:99, 1986. (X1)
R16. Solomon, Allen M., and Morgan, Ralph A.; "A Challenge Taken Up," Geotimes, 18:9, June 1973. (X1)

ESB12 Skipping in the Fossil Record

Description. The complete disappearance and subsequent reappearance of a species in the fossil record. Some organisms seem to skip recent geological periods altogether and reappear as living animals. Skipping is different from the evolutionary gaps in the fossil record, where there seems to be an absence of transitional forms from one species to another.

Data Evaluation. Only a few examples of skipping have been mentioned by modern paleontologists. Except for G.M. Price's 1926 compilation, there seem to be no systematic surveys of studies of the phenomenon. In truth, the phenomenon could be very common; but little attention is paid to it, because it is tacitly assumed that skipping is only apparent, not real. Rating: 2.

Anomaly Evaluation. The mainstream view of skipping, as expressed above and adopted in this book, is that all examples of skipping would disappear if the fossil record were more forthcoming. This posture assumes implicitly that once a species is created it is never recreated, and that its absence in the fossil record is simply the result of low population levels, poor conditions for fossilization, and/or bad luck. In this view, no anomaly exists, although the great imperfection of the fossil record is underscored, as is the shakiness of any theory based upon it. Rating: 4.

Possible Explanations. One possibility is that the fossil record is a very poor mirror of the historical development of life forms. Geological periods may not be real but merely artifacts introduced by our assumption of the evolutionary scenario. Waxing speculatively and assuming that skipping really means that species are exterminated and then reappear, we are left with at least three remarkable possibilities: (1) species were recreated through divine intervention; (2) species were reintroduced extraterrestrially (not necessarily by aliens but possibly through F. Hoyle's "living comet" mechanism); and (3) once a species has evolved, it can reevolve quickly with the help of Sheldrake's morphogenetic fields!

Similar and Related Phenomena. Biological extinction and explosion events (ESB1, ESB2); evolutionary gaps in the fossil record due to the lack of transitional forms (B).

Examples

X0. Background. G. M. Price was apparently the first to make a scientific issue of the skipping phenomenon. Modern scientific creationists have drawn heavily on Price's work, not only with regard to skipping but catastrophism in general. In his book Evolutionary Geology and the New Catastrophism, Price begins his chapter on skipping with the following assertion:

> "There is a fossil world and there is a modern living world, the two resembling one another in various details as well as in a general way; but to get the ancestral representatives of many modern types, ---for example, an unknown number of invertebrates, with other forms of animals and plants, ---we must go clear back to the Mesozoic or the Paleozoic rocks, for they are not found in any of the 'more recent' deposits." (R1)

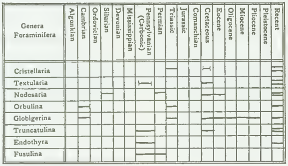
X1. Price's survey of the skipping phenomenon. Below are reproduced a few pertinent paragraphs from Price's 1926 book Evolutionary Geology and the New Catastrophism. Modern paleontology may have filled in some of the gaps he identified.

"For there are many kinds of invertebrates, both terrestrial and marine, alive in comparative abundance in our modern world, whose fossils are found only in some of the very oldest rocks, and have skipped all the rest! Others which date from 'Mesozoic times' are wholly absent from the Tertiary rocks, though found abundantly in our modern world. This I regard as another very crucial test of the rationality of this idea of life-succession." (R1) Quite obviously, Price does not regard the theory of evolution highly, and he was, in fact, a pioneer scientific creationist, although the term had not been invented in 1926. (WRC)

.....

Then, Price gets more specific: "But this jump from the 'Eocene period' to the present is nothing compared with the secular acrobatics of some of the fishes and especially of the invertebrates. The living Heterodonts, or Bullhead Sharks, (among which is the Port Jackson Shark), of which there are four species found in the seas between Japan and Australia, seem to disappear with the Cretaceous, skipping the whole Tertiary epoch, as do also a tribe of modern barnacles which, as Darwin says, 'coat the rocks all over the world in infinite numbers.' The dipnoans, or lungfishes (having lungs as well as gills, such as the Ceratodus and Lepidosiren), which are represented by several living species in Australia and South Africa, are the remains of a tribe found in whole shoals in the Carboniferous, Triassic, and Jurassic rocks, but not, so far as I know, in any of the subsequent rocks until the modern. The living Ceratodus was only discovered in 1870, and was regarded as a marvel of 'persistence.' On a pinch, as when his native streams dry up, this curious fellow can get along all right without water, breathing air by his lungs like a land animal. If, in the meantime he was off on a trip to the moon, he must have 'persisted' a few million years without either.

"But his cousin, the Polypterus of the Upper Nile, has a still more amazing record, for he has actually skipped all the formations from the Devonian down to the modern; while the limuloids, or sea scorpions, have jumped from the Carboniferous down.



G.M. Price's diagram illustrating the phenomenon of "skipping" in the fossil record in the case of the Foraminifera. (X1)

.....

"The mollusks and the brachiopods would afford us examples too numerous to mention. How is it possible that these numerous families disappear suddenly and completely with the Mesozoic or even the 'early' Paleozoic, and are not found in any 'later' deposits, though alive now in our modern world? Parts of Europe and America have, we are told, been down under the sea and up again a dozen times since then; why should we not expect to find abundant remains of these 'persistent' types in the Mesozoic and Tertiaries? Surely these feats of time-acrobatics show the folly of arranging contemporaneous, taxonomic groups in a single file and giving to each a time-value.

.....

"Here is a curious list of instances of skipping as given by Dana:

> 'A few land snails are found in the Carboniferous, but no land snails have been recognized from the Permian, Triassic, or Jurassic formations. In the Cretaceous they reappear, and from that time the series is substantially continuous. A few scorpions are found in the Upper Silurian; none have been recognized from the Devonian; but in the Carboniferous both scorpions and spiders occur. Both these groups appear to be missing from the Permian and from the whole series of Mesozoic strata. They reappear in the Tertiary. Amphibians of the order Labyrinthodonts appear in the Subcarboniferous (or, probably, in the Devonian), and continue through the Triassic, possibly into the beginning of the Jurassic. The class of amphibians then remains unrepresented until a salamander appears in the Lower Cretaceous.'" Price comments that some of the "missing" fossil amphibians had indeed been found since Dana wrote these words.

.....

"Speaking of the shrimp, Anaspides, Geoffrey Smith says:

> 'It was evidently a dominant form of shrimp at the time the Coal Measures were being deposited, but it is not met with in more recent deposits, and we have no clue to its history between the time that it peopled the Carboniferous seas and the present day when it survives in a few tarns and streams on isolated mountains in Tasmania.'" (R1)

X2. Coelacanths. More recent creationist writers often refer back to Price, Dana, and Smith, as quoted in X1. (R2, R3) However, they can now add some lines about the coelacanth: "Finally, you may recall the coelcanth or lobe-finned fish, Latimeria, which belongs to a group that was thought to have become extinct in the Devonian period. From the Devonian to the present day, not a single fossil of this form has been found in any rock. But by the end of 1958, nine had been found in the ocean off the island of Madagascar." (R3; R2)

X3. Insects. To modern scientists, however, skipping is simply a matter of "bad luck", as expressed by D. Raup: '"Some gaps in the fossil record are due to sheer bad luck,' says David Raup. 'For example, we know that insects have been around for at least 300 million years. But during the Cretaceous period (between approximately 135 million and 65 million years ago), their fossil record is all but absent. Conditions for their fossil preservation just happened to be virtually nonexistent for an enormous block of time.'" (R4) But fossils of other animals are common in the Cretaceous rocks. (WRC)

X4. Amphibians (Apoda). With no recent surveys of the skipping phenomenon on the scale of Price's (X1), we must rely upon a few isolated references: "For instance, concerning certain modern amphibians, Carroll wrote: 'There are approximately 34 genera and 160 species of living Apoda. None has a fossil record. A single vertebra from the Upper Paleocene of Brazil is the only known fossil.'" (R5)

X5. Order Multituberculata. Here, we quote M. Denton, who quotes T. Schopf: "Note the case of the Order Multituberculata, the longest lived mammalian order. It is considered to range from the middle Jurassic to the end of the Eocene, 160 m.y. duration. On a stage by stage basis, fossils of this order are known to occur in stages whose cumulative duration is only 87 m.y., just 54 per cent of the duration of the order. That is, 46 per cent of the time the Multituberculata existed, there has not yet been discovered a record of the order anywhere in the world. This simply underscores the vagaries of preservation and fossilization." (R5) It seems that skipping applies to whole orders as well as species. (WRC)

References

R1. Price, George McCready; "Skipping: Fact Number Five," Evolutionary Geology and the New Catastrophism, Mountain View, 1926, p. 196. (X1)

R2. Shute, Evan; "Gaps in the Geological Record," Flaws in the Theory of Evolution, Philadelphia, 1961, p. 190. (X1, X2)

R3. Rusch, Wilbert, Sr.; "Botanical and Zoological Evidence," in Why Not Creation? Walter E. Lammerts, ed., Grand Rapids, 1970, p. 345. (X1, X2)

R4. Fisher, Arthur; "The World's Great Dyings," Mosaic, 12:2, March/April 1981. (X3)

R5. Woodmorappe, John; "A Diluviological Treatise on the Stratigraphic Separation of Fossils," Creation Research Society Quarterly, 20:133, 1983. (X4)

R6. Denton, Michael; "The Fossil Record," Evolution: A Theory in Crisis, London, 1985, p. 189. (X5)

ESB13 The "Special" Nature of Fossil Deposits

Description. The absence in the modern world of geological processes and situations that are now forming the rich, often-near-perfect, often-species-limited fossil deposits commonly observed in the fossil record. Special environmental conditions atypical of today's earth seem indicated.

Data Evaluation. Instances of extensive strata packed with well-preserved, species-limited fossils are common in the geological literature. (See also ESD9) On the other hand, the literature surveyed so far says little about fossilization now occurring. Rating: 2.

Anomaly Evaluation. The anomaly of the situation described here lies in the implication that the fossil record consists mainly of organisms that were preserved by virtue of extraordinary environmental conditions and, probably, bad luck. This further implies that the whole evolutionary scenario or tree-of-life is based on skewed data; that is, only on those organisms that happened to have been trapped by unusual environmental events, such as chemical catastrophes in restricted areas of the globe. The anomalousness here is high, because much of our science and philosophical outlook is based upon our present evolutionary scenario. If this scenario is based on skewed observations, much is at risk. In reality, though, no one really knows how representative the fossil record is of life that prevailed in past ages. The "special" conditions required for fossilization, especially the remarkable assemblages of fossils mentioned below, suggest that we may be viewing ancient life through blinders---blinders that we cannot do much about! Rating: 1.

Possible Explanations. The environments and conditions under which the great fossil deposits of the past were laid down were radically different from those dominating today's planet.

Similar and Related Phenomena. Skipping in the fossil record (ESB12); time-wise anomalous fossils (ESB11); bone caves and bone beds (ESD1, ESD2); deposits of great areal extent (ESD9).

Examples

X1. The roles of "luck" and "special circumstances". That fossils are not created frequently in the normal operations of nature is evident in the following two quotations; the first by a scientist, the second by a scientific creationist:

A. Woodward, 1898. "We may, in fact, without exaggeration declare that every item of knowledge we possess concerning extinct plants and animals depends upon a chapter of accidents. Firstly, the organism must find its way into the water where sediment is being deposited and there escape all the dangers of being eaten; or it must be accidentally entombed in blown sand or a volcanic accumulation on land. Secondly, this sediment, if it eventually happens to enter into the composition of a land area, must escape the all-prevalent denudation (or destruction and removal by atmospheric and aqueous agencies) continually in progress. Thirdly, the skeleton of the buried organism must resist the solvent action of any waters which may percolate through the rock. Lastly, man must accidentally excavate at the precise spot where entombment took place, and someone must be at hand capable of appreciating the fossil and preserving it for study when discovered." (R1) The role of ever-present bacteria should have been mentioned. (WRC)

R. L. Wysong, 1976. "Consider for a moment the fact that the earth is surrounded by thousands of square miles of sedimentary strata. Sedimentary strata, by definition, speak to water deposition. It is within these strata that the vast majority of fossils are found. What causes fossilization? Practically every known mechanism for fossilization demands sudden catastrophic burial.

"Even Darwin recognized, as expressed in the conclusion to his second edition of the The Origin of Species, that fossilization required unique rapid processes, not slow uniformitarian ones:

> 'The accumulation of each great fossiliferous formation will be recognized as having depended on an unusual concurrence of favorable circumstances.'

"Giovanni Pinna, the Deputy Director of the Museum of Natural History in Milan, although a firm believer in uniformitarianism, wrote:

> 'In fact, when an organism dies, the substances that compose its soft parts undergo more or less rapid decay, due to such factors as attack by bacteria and erosion by water (particularly the sea)...If an organism is to be preserved, it must be protected from destructive agents as quickly as possible... And the sooner that this consolidation occurs, the more likely it is that the organism will be preserved ...there are also certain layers, such as those formed from extremely fine-grained calcareous rocks, which have consolidated so rapidly as to permit the preservation of the most delicate structures of many organisms.'

"In further testimony, consider this. Not many years ago there were millions of bison roaming the North American Continent. Today there is but a handful. What happened to the thousands killed by the infamous Buffalo Bill and his cohorts? Where are their fossils? There are none because the carcasses of the bison met the inevitable eventuality of all other dying things in the absence of sudden burial by catastrophe. They were scavengerized, they rotted, decayed are were slowly dissipated by the elements. There is no preservation by dust slowly blowing over a carcass or by a few leaves falling upon it." (R4)

Wysong and scientific creationists in general are impressed by facts that imply past catastrophes. However, today's scientists admit readily the reality of catastrophic events in geology. Thus, this implication of the fossilization process is no longer anomalous. (WRC)

X2. The problems of fossil purity, perfection, quantity, and areal extent. Many fossil deposits are not hodgepodges of miscellaneous organic debris; and this aspect makes them even more "special."

A specific example from South Africa. From a description of major South African geological features, by D. M. S. Watson: "Procolophon Zone.---These great sandstones are followed by a series of water-laid rocks still containing Lystrosaurus, until quite abruptly they are succeeded by the deep chocolate-coloured joint clays of the Procolophon Zone. These extraordinarily characteristic deposits present a problem. They contain at a number of places complete skeletons of Procolophon which retain perfectly preserved white bones, embedded in dark red nodules: and they contain, for practical purposes, nothing else. Their spread geographically is very considerable. They extend from a place in the Orange Free State between Bethulie and Aliwal North, around Tafelberg Station, and on to Donnybrook near Tarkastad, and this is a distance of some 200 miles ---the group of rocks being perhaps 100 feet thick, and the restricted fauna and physical conditions similar throughout, the animals being present everywhere as articulated skeletons. The creature is lizard-like in build, about a foot long, and certainly of terrestrial habitat. With the exception of the small labyrinthodont Micropholis and of a single specimen called Paliguana, no other animals are known." (R3) An excellent example of fossil deposit purity, fossil perfection, and great areal extent. (WRC)

An overview by G.M. Price. Price, the pioneer scientific creationist, recognized the difficulty of explaining great aggregations of nearly perfect fossils of a single or, perhaps, a very few species: "Thus to explain practically all the deposits found in the rocks, we are absolutely limited to the shore deposits and the mouths of large rivers. Here we certainly have alternations of sand, clay, and gravel, producing a truly bedded structure. But I ask, What kind of organic remains shall we get from these modern deposits? ---Certainly nothing like the crowded graveyards that we find everywhere in the ancient ones.

"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 the 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 on 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 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, require speedy burial after death, 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 entombed in whole shoals, 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." (R2)

One mainstream-geology explanation. Geologists have not ignored such fossil deposits; but their explanations often involve extraordinary situations, as in the following account presented by A.N. Strahler: "Dunbar and Waage give a full discussion of the various ways in which quick burial of animals and plants can take place, leading to their fossilization. Particularly interesting is the example of a slate formation of lower Jurassic age at Holzmaden, Germany, where fossils of hundreds of marine reptiles in an excellent state of preservation have been excavated. Here is the explanation of that fossil accumulation:

> 'The black muck of the sea bottom on which the ichthyosaur carcasses accumulated was obviously toxic. No scavengers were present to tear apart the bodies and scatter the bones; indeed the Holzmaden fauna lacks any kind of indigenous bottom-dwelling animals. Swimmers are dominant and include plesiosaurs, marine crocodiles, a few fish, squidlike cephalopods, and a few others in addition to the great numbers of ichthyosaurs... Sulfur compounds in the shale indicate that the bottom was made

toxic by hydrogen sulfide. Stagnant and toxic areas of black mud are known in areas of present-day seas where the bottom is in a depression or otherwise cut off from circulation of oxygen-bearing water. What attracted the ichthyosaurs and other animals into the stagnant bay that apparently existed at the Holzmaden site is not known, but their death was most likely due to toxic or poorly oxygenated water and their preservation was assured by the antiseptic mud that buried them. (Dunbar and Waage, 1969, p. 51)" (R5)

It is not easy to develop environmental conditions that account for all the characteristics of some fossil deposits. But the anomalousness of this phenomenon is not in the fossilization process itself nor in the environment that produces it but rather in the possibility that such special conditions catch only an unrepresentative fraction of the life forms existing at the time. (WRC)

References

R1. Woodward, A. Smith; "The Imperfection of the Geological Record," Natural Science, 13:327, 1898. (X1)

R2. Price, George McCready; "Graveyards," Evolutionary Geology and the New Catastrophism, Mountain View, 1926, p. 234. (X2)

R3. Watson, David Meredith Seares; "The Two Great Breaks in the History of Life," Geological Society of London, Quarterly Journal, 112:435, 1956. (X2)

R4. Wysong, R. L.; "Geologic Evidence," The Creation-Evolution Controversy, East Lansing, 1976, p. 355. (X1)

R5. Strahler, Arthur N.; "Fossils and Flood Strata---A Hydraulic Stratigraphy," Science and Earth History, Buffalo, 1987, p. 380. (X2)

ESC ANOMALOUS CHEMICAL PHENOMENA IN GEOLOGY

Key to Phenomena

ESC0 Introduction

The purpose of this chapter is not the cataloging of the multitudinous day-to-day problems of the geochemists, but rather the highlighting of geochemical phenomena that have the potential to change the way we think about geology and the chemical processes that have produced the rocks and minerals we see today. But it must also be admitted that some of the entries below are more curious than anomalous. Such digressions reflect the fascination of the Compiler for the oddities of nature. the reader is, of course, free to skip over these intrusions; but, then again, he may be smitten, too.

The list of chemical phenomena introducing this chapter does, despite its apparent diversity, focus on several themes. The first and foremost of these is that of origin. How were such common substances as oil, coal, methane, seawater, and many other well-known materials formed? Of course, most geologists and especially the geology textbooks consider the origins of these substances already well-explained. Would that this were so! The anomalies that are cataloged below do not, in the Compiler's opinion, allow this comfortable view. Further, the countertheories proposed are often heretical and, if any of them should gain general acceptance, geology will be radically transformed.

A second major theme, one that is very popular these days, is that of episodic catastrophism, as indicated here by chemical spikes in the sedimentary record. (This subject is also mentioned in the ESB and ESP chapters in this volume.)

One final generality seems indicated by our collection of chemical anomalies. The earth's crust and mantle form a giant chemical retort, complete with prodigious flows of liquids and gases. Of course, geochemists have always recognized this in a limited way. But now, it seems that this chemical reactor, with its attendant flowing fluids, extends to much greater depths than generally supposed.

ESC1 Chemical Anomalies in the Stratigraphic Record

Description. Enhanced concentrations or "spikes" of specific chemical elements, their isotopes, and chemical compounds appearing in the stratigraphic record, including the ice in the polar regions.

Of special interest here are those "spikes" of high amplitude (relative to concentrations in rocks directly above and below), pronounced sharpness (suggestive of very short periods of deposition), and wide geographical distribution (signifying a major terrestrial event of some sort).

Chemical anomalies may be correlated stratigraphically with geological phenomena (unconformities), biological events (extinctions and/or explosions of life forms), other kinds of chemical spikes, and the presence of spherules, shocked quartz, microtektites, etc.

List of entries:

X1. Iridium
X2. Osmium
X3. Carbon isotopes
X4. Uranium isotopes
X5. Oxygen isotopes
X6. Sulphur isotopes
X7. Lead-210
X8. NO_3^-
X9. Beryllium-10
X10. Carbonate ($CaCO_3$)
X11. Methane
X12. Oxides
X13. Gold
X14. Anoxic intervals
X15. Carbon dioxide
X16. Calcite dissolution
X17. Amino acids
X18. Strontium isotopes
X19. Rhodium
X20. Helium isotopes

Background. The value of chemical anomalies as indicators of important events in the earth's history was highlighted in the late 1970s by the discovery of the now-famous, worldwide iridium spike at the Cretaceous-Tertiary boundary. Most of the literature on chemical anomalies, in fact, appeared after this date. While there is no doubt that geochemical anomalies record past catastrophic events, such as asteroid impacts or great climatic changes, there is still considerable controversy as to just which events caused which anomalies and just what, if any, effect they had on the earth's biosphere. Despite the great certainty with which some hypotheses are advanced and the finality claimed for some explanations, an objective student of the subject almost always finds controversy and a lack of consensus. Much research must be carried out in this field before all parties concur.

Although the organization of this section is a bit cumbersome, due to the great variety of chemical spikes and their diverse interpretations, I thought it would be more revealing to treat all aspects of this type of geological phenomenon in one place.

Data Evaluation. Substantial data bases are at hand for the siderophile elements (iridium, osmium, gold, etc.) and the isotope ratios of carbon, oxygen, and sulphur. Elsewhere the data are scanty. Nevertheless, even where data are abundant, the stratigraphic record has only been sampled vertically and horizontally. Rating: 2.

Anomaly Evaluation. The chemical anomalies cataloged here mostly represent major geological and, often, biological events. Thus, they are potentially highly anomalous. Since, in most cases, consensus does not exist throughout the entire scientific community and controversy reigns, we must admit that this potential is realized. The existing data simply do not convince scientists from a wide spectrum of disciplines that they should join a consensus, say, for the asteroid-impact origin of the iridium spike. Rating: 1.

Possible Explanations. Explanations for chemical anomalies fall into various categories:

- -Terrestrial causes: Volcanism leading to acid rain, falls of dust and ash, temperature changes, etc.
- -Extraterrestrial causes: Asteroid/comet impacts with falls of iridium and other siderophile elements; Cosmic radiation leading to the formation of NO_3^-, and other species in the atmosphere.
- -Physical processes: Selection of ^{16}O over ^{18}O in seawater evaporation as a function of temperature.
- -Biological processes: Selection of ^{12}C over ^{13}C in photosynthesis.
- -Climatic changes: Variations in CH_4, CO_2, and O_2.

Similar and Related Phenomena. Other chemical anomalies: in igneous and metamorphic rocks (ESC2); combustion metamorphism (ESC8); chemical anomalies in oceans, lakes, and groundwater (ESC12); in gases (ESC15-16). Physical phenomena: magnetic particles in sediments (ESP7); crushed and shocked structures (ESP11); discordant radiometric dates(ESP12); natural nuclear reactors (ESP13). Biological phenomena: extinctions and explosions in the fossil record (ESB1, ESB2); biological evidence for recent, catastrophic climate changes (ESB4).

Examples

X1. Iridium. Of all the geochemical anomalies, the worldwide iridium concentration "spike" at the Cretaceous-Tertiary boundary (frequently called the K-T boundary) has generated the most scientific excitement. The reason for this is clear: the favored explanation of this iridium layer invokes the terrestrial impact of a large asteroid or comet some 65 million years ago---a period when widespread biological extinctions also occurred. While such catastrophic mechanisms are no longer shunned as completely as they were a decade or two ago, considerable heated debate has swirled around the asteroid/comet hypothesis. To illustrate, paleontologists see the K-T extinctions as a gradual, complex process instead of a sharp, sudden event. Some geologists also favor a gradualistic scenario, say, an extended episode of severe volcanism and basalt flows rather than something of extraterrestrial origin.

Our treatment of the iridium anomaly is divided into five parts:

- X1A. The story behind the discovery of the iridium spike.
- X1B. The nature and extent of the spike at the K-T boundary.
- X1C. Discoveries of iridium spikes elsewhere in the stratigraphic record.
- X1D. Correlations of iridium anomalies with other phenomena, such as the presence of soot, spherules, biological extinctions, etc.
- X1E. Theories that have been proposed to explain the iridium anomalies.

....

X1A. The discovery of the iridium spike. Serendipity played a role in the discovery of the K-T boundary iridium spike; no one was looking for it specifically. W. Alvarez, who was a key figure in the discovery, reminisced about the history of the iridium research in the September 2, 1986, issue of Eos. (R102)

It seems that W. Alvarez and some of his colleagues were studying the geomagnetic polarity-reversal record in the limestones of the Upper Cretaceous and Lower Tertiary in the early 1970s. A very complete section of these limestones exists in the Bottaccione Gorge, near Gubbio, Italy; and field work was carried out there. It was noted that the Cretaceous and Tertiary limestones at Gubbio were separated by a few centimeters of distinctive clay. Alvarez began wondering how long it had taken for the clay layer to be deposited and whether it was in any way connected with the widescale biological extinctions that concluded the Cretaceous period. Alvarez consulted with his father, L. Alvarez, a physicist at the University of California at Berkeley, who suggested testing the iridium content of the clay. Since the earth's crust contains little iridium, any increased concentration in the Gubbio clay layer would probably come from the steady influx of micrometeorites, which are much richer in iridium. In effect, the concentration of iridium might be a measure of the time taken for the clay layer to accumulate, since the influx rate and iridium content of micrometeoroids is known.

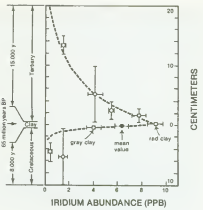
To everyone's great surprise, the iridium concentration was about 25 times that of the normal terrestrial background. This abnormal concentration of an element common in meteoric matter but rare in terrestrial sediments, when added to the fact of massive biological extinctions, led naturally to the hypothesis that a large asteroid, or possibly a comet, impacted the earth at the end of the Cretaceous---in fact, it might have been the cause of the end of the Cretaceous period. (R102; R7)

....

X1B. The nature and extent of the iridium anomaly at the K-T boundary.

Italy. Following the startling results from the analysis of the Gubbio clay samples, it was only natural for the Alvarez team to test more samples from Gubbio and also from other exposures of Cretaceous-Tertiary limestones in Italy, including a site 30 kilometers away from Gubbio. The results from 29 iridium samples confirmed the presence of an iridium spike at all the Italian sites that were investigated. In an attempt to eliminate the possibility that the iridium might somehow be terrestrial iridium that was somehow concentrated by geological mechanisms, samples from clay and limestone above and below the K-T boundary were analyzed. The result: "...neither clay layers from below the C-T boundary nor clay components in the limestone show evidence of Ir above the background level." (R17) Note that C-T is occasionally used instead of K-T to designate the Cretaceous-Tertiary boundary! (WRC)

In contrast to the strong belief of the Alvarez group that the K-T boundary iridium spike is the product of astronomical catastrophism, other scientists studying the clay remark that, except for the iridium spike, its character is terrestrial in nature. For example,



The iridium spike. Iridium levels increase sharply when the clay layer separating Cretaceous and Tertiary formations is reached. (X1) (Adapted from R27)

M.R. Rampino and R.C. Reynolds state, "This material could represent a minor volcanogenic component that has been converted to smectite-illite by diagenesis, or it could be a terrigenous weathering product." As for the iridium spike, it might be derived from volcanic ash. (R46)

Those scientists who doubt the asteroid-hypothesis have proposed several purely terrestrial scenarios for the formation of the K-T boundary clay layer and its iridium spike, as evidenced in the forgoing paragraph. (WRC)

The iridium profile at Gubbio's K-T boundary, however, has turned out to be quite complex, as revealed in the two abstracts that follow.

"Abstract. Iridium, Pd, Pt, and Au were determined in sections from the Bottaccione Gorge and Contessa Valley, Gubbio, Italy, by radiochemical neutron activation. Shales and limestones were sampled from 2.85 m above to 219 m below the Cretaceous/Tertiary (K/T) boundary. Metal enrichment was evaluated by comparing the boundary shale region with the lower part of the section (background). Iridium is concentrated by 63 times in the boundary shales in comparison with the background, whereas other metals are enriched by no more than 2.2 times. The enrichment of Ir is not confined to the boundary shales but extends approximately 2 m above and below this horizon. Within this Ir-rich region there are four distinct Ir maxima in addition to the major Ir enrichment in the K/T boundary shales. Iridium maxima are stratigraphically coincident with maxima in abundances of shocked minerals characteristic of explosive volcanism. Limestones are much lower in noble metals than shales, and their Ir contents in the K/T boundary region are largely accounted for by their minor clay mineral contents. The time represented by the 4 m of Ir-rich section is at least 3 x 10^5 yr, if published sedimentation rates are used. To sustain an increased Ir flux over this period and to account for the Ir distribution near the K/T boundary, intense volcanic activity is a preferred alternative to impact of extraterrestrial material."(R161)

Abstract. "A geochemical study has been made of nearly 50 meters of limestone covering over 5 million years of deposition near the Cretaceous-Tertiary (K-T) boundary in the Bottaccione Gorge near Gubbio, Italy. Except in 2.6 meters of rock directly adjacent to the huge K-T Ir spike, no Ir anomalies were observed, and the average Ir background was 12.6 x 10^{-12} gram of Ir per gram of rock (ppt). Close to the spike, however, are about a dozen Ir peaks ranging from 20 to 80 ppt above background.

"In a study with H.R. Bowman, the Tertiary peaks disappear when ratios were taken to abundances of elements in clay, eg. Fe, Si and Al. The continuous nearly exponential nature of the resulting curve suggests that the deposition of Ir was not episodic, and so the Ir is not due to volcanism or impacts of comet clusters. Washing of the continents following the K-T impact is a possible Ir source.

"The Cretaceous Ir peaks, on the other hand, do not disappear when ratios are taken to the abundance of clay elements, and they may be due to diffusion." (R164) Quite obviously, the two abstracts differ in several respects.

Denmark. Strong confirmation of the asteroid hypothesis came when an iridium spike similar to that in Italy was detected in Denmark ---a location far enough from Italy to suggest a "non-local" origin for the iridium.

At Stevnsklint, Denmark, a thin marl layer marks the K-T boundary. It is known as the "fish clay." R. Ganapathy described the geochemical situation: "Evidence for a major meteorite impact on the earth 65 million years ago is shown by the presence of meteoritic debris in the 'fish clay' from Denmark representing the Cretaceous-Tertiary boundary. Noble metals (iridium, osmium, gold, platinum, rhenium, ruthenium, palladium, nickel, and cobalt), which are sensitive indicators of meteorites and are normally depleted on the terrestrial surface by factors of 10^4 to 10^2 relative to cosmic abundances, are enriched in this boundary clay by factors of 5 to 100 over the expected abundances." (R20)

As with the Italian K-T clay, geological opinion was divided. M.R. Rampino and R.C. Reynolds saw a different picture: "Diffractograms of clays from the boundary sequence at Nye Kløv, Denmark, show that the boundary layer is pure smectite. The absence of discrete illite, normally a ubiquitous detrital phase in mudstones and limestones, suggests that the boundary layer here is a bentonite (altered volcanic ash)." (R46)

Spain. At Caravaca, in southeastern Spain, the K-T iridium anomaly is associated with an extremely sharp paleontological event.

"Abstract. Closely spaced samples from an uninterrupted calcareous sequence across the Cretaceous-Tertiary boundary reveal that the extinction of planktonic Foraminifera and nannofossils was abrupt without any previous warning in the sedimentary record, and that the moment of extinction was coupled with anomalous trace element enrichments, especially of iridium and osmium. The rarity of these two elements in the crust of the Earth indicates that an extraterrestrial source, such as the impact of a large meteorite may have provided the required amounts of iridium and osmium." The authors of this paper from Nature, open by stating that the Cretaceous-Tertiary boundary seems to be the only one of any consequence in the stratigraphic record that does not become diffuse when examined in detail. For example, the rich biological record of the Cretaceous disappears within 0-5 millimeters of rock, representing a transition (extinction) within perhaps only 200 years. (R18)

New Mexico. The first reports on the iridium spike came from rocks that had been deposited under marine conditions. Since the marine environment could conceivably modify and even concentrate the deposition of iridium, it became important to the asteroid hypothesis to find iridium spikes in non-marine situations. Such locations were soon discovered in the American west.

"Abstract. An iridium abundance anomaly, with concentrations up to 5000 parts per trillion over a background level of 4 to 20 parts per trillion, has been located in sedimentary rocks laid down under freshwater swamp cohditions in the Raton Basin of northeastern New Mexico. The anomaly occurs at the base of a coal bed, at the same stratigraphic position ~~as~~ which several well-known species of Cretaceous-age pollen became extinct." (R26) The Raton Basin findings greatly weakened arguments that noncatastrophic marine processes could account for the iridium anomaly. (R25)

Montana. An iridium spike was also discovered at Hell Creek in northeastern Montana. Here, as in New Mexico, there was an abrupt disappearance of certain pollen species and a sudden shift in the ratio of fern spore to angiosperm pollen. (R53). However, the paleontological events were not as sharp as asteroid hypothesizers might like, particularly as concerns the demise of the dinosaurs.

R. A. Kerr, reviewing the Montana iridium spike situation, noted: "At Hell Creek the youngest dinosaur fossil, the femur of a Tyrannosaurus rex, was found at a level about 3 meters below the iridium layer, which is at the base of a coal layer. Not only did the dinosaurs of the Cretaceous period seem to have disappeared before the dust from the asteroid impact settled to the earth, ... but fossils of vertebrates typical of the next geological epoch, the Paleocene, were found at a level about 2 meters below the iridium layer." Even the pollen 1.5 meters under the iridium anomaly was in a transitional state. (R39) According to this evidence, some sort of biological event was in progress long before the iridium layer was deposited.

To confuse the situation even more, in 1985 K. Rigby and colleagues, at the University of Notre Dame, found dinosaur bones at the Hell Creek site, which were in a streambed, covered by sediments containing Paleocene pollen. Further, the stream had cut through the iridium layer itself. The researchers concluded that at least some of the dinosaurs lived at least 40,000 to 200,000 years into the Paleocene. The possibility exists, of course, that the dinosaur bones were "reworked"; that is, they were eroded from Cretaceous sediments by a later Paleocene stream. (R78)

New Zealand. The pro-impact forces were strengthened when a strong iridium spike was found in shale at the K-T boundary at Woodside Creek, New Zealand. Not only was the spike sharp, but: "The boundary material showed striking compositional similarities with the Stevns Klint Danish boundary shale. Elemental concentrations were in general much higher in the New Zealand material than in nonboundary shales from elsewhere in the world." (R59) Later, in 1986, three new iridium anomaly sites in New Zealand were recorded. This negated the suggestion that the Woodside Creek iridium had been deposited under unusual weathering conditions. (R104) The well-defined iridium anomaly sites in New Zealand helped convince everyone that the iridium layer was essentially a worldwide phenomenon.

Other sites of iridium anomalies. By 1984, some 50 locations from all parts of the globe had been found to have iridium spikes at the K-T boundary. W. Alvarez et al published a most convincing map of the known sites in the March 16, 1984, issue of Science. In addition, scores of additional scientific reports on specific sites, beyond those discussed above, may be found in the literature. Whatever its genesis, the iridium layer at the Cretaceous-Tertiary boundary was now seen to be a global situation; in actuality, it had become one of the best global markers of the K-T boundary.

The "sharpness" of the iridium spike. Some of the investigations mentioned above question the assertion of the proponents of the impact hypothesis that the iridium layer was deposited very quickly; that is, within a few months or years or, geologically speaking, "instantaneously".

In the fore of the critics of the extraterrestrial connection were C. B. Officer and C. L. Drake. The essence of their reservations can be found in this excerpt from their 1983 paper: "The fossil sequences from cores across the Cretaceous-Tertiary boundary show a range of transition times and transition time intervals depending on the fossil indicators and the location of the site. These variations, together with the pattern of iridium distribution with depth at some sites, differences in total amounts of iridium, variations in noble metal abundances normalized to extraterrestrial concentrations, the depositional effects that might be expected in a reducing environment, and the clay mineralogy of the boundary layer clays, put into question the interpretation that an extraterrestrial event was the cause of the faunal changes and the iridium anomaly in the vicinity of the Cretaceous-Tertiary transition." These authors favored purely terrestrial mechanisms for the production and concentration of the iridium. (R50)

In 1984, Alvarez et al answered criticisms such as those of Officer and Drake. These champions of the impact theory complained that Officer and Drake based their case on a few sites where stratigraphic complications made the interpretations "ambiguous."

Discussion of one oceanic site is termed "seriously misleading." Some iridium analyses cited by Officer and Drake are said to have originated with a group known to have published other results that suffered from chemical contamination. Alvarez et al pointed to the extensive body of evidence that supported the sharpness of the iridium spike and the hypothesis of extraterrestrial impact. In short, Alvarez et al maintained that all criticisms can be shown to be "invalid." (R57)

In 1985, after further study, C.B. Officer and C.L. Drake reasserted their criticisms and their belief that the evidence supported a terrestrial source of the iridium spike and its associated extinctions. Examining in detail the record at several K-T sites they conclude: "The geologic record of terminal Cretaceous environmental events indicates that iridium and other associated elements were not deposited instantaneously but during a time interval spanning some 10,000 to 100,000 years." According to these researchers, the geological evidence favors a scenario consisting of a series of intense eruptive events. (R86)

Alabama. Not only is the sharpness of the iridium spike questioned, but some evidence indicates that it is multiple in some places. "...scientists at Exxon Production Research Co. in Houston concluded that the K/T iridium spikes may have nothing to do with extinctions. Art Donovan and his coworkers have studied what they say is one of the most complete K/T sections known. They have found three iridium spikes created in a time span of about 1 million years at a site in the Clayton formation in central Alabama. Most significantly, each of these spikes corresponds to a period when sedimentation rates were very low." Conclusion: the iridium spikes are likely depositional phenomena; that is, a sedimentation effect. The iridium could have originated either during impact events or volcanic eruptions. (R93) At the beginning of this section, X1B, the Ir profile at Gubbio, Italy, was shown to be similarly complex and controversial.

The intensity of the iridium spike. Early in the history of the controversy, some scientists ventured that the terrestrial iridium spikes were too intense; that is, the concentrations of iridium were too high to be explained by the asteroid-impact theory. At most iridium-anomaly sites, the concentrations of meteoric material amounts to several percent; at the Denmark site, the clay is about 10% meteoric. Lunar soils, by way of comparison, contain less than 4% meteoric material; and these soils have been accumulating ejecta from impacts for billions of years. Some specialists in impact cratering maintained that in a terrestrial impact: "Even hundreds of trillions of tons of asteroid would be so diluted...by terrestrial rock churned up on impact that the chemical traces of the asteroid should be faint if recognizable at all." (R21) If this criticism has been laid to rest, we have not yet seen the appropriate article. (WRC)

....

X1C. Claims of iridium spikes elsewhere in the stratigraphic record. Several investigators have analyzed portions of the stratigraphic column, particularly in the regions of major biological extinctions, to check for the presence of iridium layers. The purpose, of course, is to determine whether other biological extinctions might be blamed upon asteroid/comet impacts.

Some negative results. F.T. Kyte and J.T. Wasson measured 149 samples from a 9-meter section of Pacific abyssal clay for iridium anomalies. The time span covered the range 33-67 million years before the present. Except for the famous K-T spike at 65 million years ago, no other iridium enhancements were found. (R95)

Negative results were also reported by C.J. Orth et al for Late Cambrian limestone deposits in western Utah. (R56) Orth et al have also investigated the Ordovician-Silurian boundary on Anticosti Island, Quebec, and conclude that the Ir profile there does not indicate the impact of a large asteroid/comet at this juncture in geological history. (R149)

The Late Devonian Frasnian-Famennian extinction horizon in New York State was analyzed by G.R. McGhee, Jr., et al, with negative results. (R64) However, an iridium spike at this horizon has been reported from Australia, as described below.

Although we will report on several iridium spikes found outside the K-T boundary below, there exists a general tendency to discount such claims. In a 1985 overview in Science, R.A. Kerr put it this way: "Geochemical searches around the times of other major extinctions besides the one 65 million years ago have thus far failed to produce any clear-cut evidence of large impacts. Reported iridium anomalies have not yet been confirmed by a laboratory having a good track record, have been contradicted by independent analyses, or are associated with fossil bacteria that could have concentrated the iridium from their surroundings." (R87)

The Precambrian-Cambrian boundary. At Ulakhan-Sulugur, Siberia, a portion of the Pestrotsvet Formation contains a six-fold iridium enrichment. (R97)

The Lower Cambrian. At the Meishucun and Yangtze Gorge sites in China, an anomalous iridium peak appears in the Lower Cambrian, at the base of a black-shale sequence that overlies a series of phosphatic limestone and dolomite. ((R84, R110)

P. Wilde et al have studied the Ordovician-Silurian boundary, using the shales at Dob's Linn, Scotland. Although a major biological extinction occurred here, no spike of iridium was present. Rather, the iridium concentration was high at every horizon sampled, over a 20-million-year section. This iridium is thought to have been concentrated by terrestrial processes. (R103, R114) If terrestrial mechanisms can concentrate iridium in a thick section, why not a narrow section? A reasonable question. (WRC)

The Upper Devonian. In 1984, P. E. Playford et al announced that they had found an iridium anomaly in Australia in an extremely condensed limestone sequence in the Upper Devonian. These rocks, in the Canning Basin, contained an anomaly about 20 times the local background. The iridium spike occurred at or near the Frasnian-Famennian boundary, which is correlated with a worldwide biological extinction of major proportions. (R62)

The Australian Upper Devonian spike, however, may be local in extent, because G. R. McGhee, Jr., et al have unsuccessfully tried to find iridium spikes at the Frasnian-Famennian boundary in New York and Belgium. Thus, it is quite possible that the Australian spike is the consequence of local chemical, physical, or biological processes, or possibly a "small" asteroid impact or volcanic event. (R85, R117, R143)

The Permian-Triassic boundary. In 1984, a report came out of China that scientists had discovered a strong iridium anomaly at the Permian-Triassic boundary, which is generally dated at 248 million years before the present. Mass extinctions also occurred at this period of time. The sites of the Chinese iridium spikes are the Baoqing Quarry, in Zhejiang Province, and the Shangsi section, Sichuan Province. (R66, R146)

However, further investigation of this boundary in China, reported by D. L. Clark et al, revealed a rather low concentration of iridium (0.002 part per billion), and close-spaced sampling showed only a drop in conodont abundance in response to the extinction event. (R99, R114) Thus, at this boundary, too, we see nothing like what is found at the K-T boundary.

The Middle-Lower Jurassic. In the Venetian Region of northern Italy, R. Rocchia et al have found a strong iridium anomaly: "Abstract. A significant iridium enrichment has been found in a Jurassic marine sequence, about 180 million years old, outcropping in the Alps of the Venetian region. The maximum iridium concentration of $3.2 \pm 0.2 ng \cdot g^{-1}$ occurs in a brown crust 2-3 mm thick, containing essentially iron hydroxide. This crust characterized by a nearly total absence of detritic components, lies on top of upper Lias limestones, and is overlaid with Bajocian-Bathonian limestones. The origin of the Ir anomaly is not clearly understood yet but could be explained by either a drop in the sedimentation rate resulting in the concentration within a thin sediment layer of the normally infalling cosmic dust and/or by an increase of cosmic material infall following an asteroid or comet impact(s)." (R100)

Middle Cretaceous. "Abstract. Two abundance peaks, both 0.11 ppb (whole-rock basis) over local background of 0.017 ppb, have been found in Middle Cretaceous marine rocks near Pueblo, Colorado. They occur just below the 92-million-year-old Cenomanian-Turonian (C-T) stage boundary. No other peaks were found in 45 meters of strata (~ 2.5 million years of deposition) above and below the boundary the boundary interval. The broad lower peak straddles the first in a series of extinctions of benthic and nektonic macro biota which comprise the C-T extinction event. The sharp upper peak occurs stratigraphically about 1.2 meters above the lower peak. The excess Ir might be from meteoroid impacts although no microspherules or shocked-mineral grains have yet been found and several elements not normally associated with meteorites (Sc, Ti, and Mn) are enriched at the Ir peaks. Alternatively, several terrestrial Ir enrichment processes are suggested." (R166)

The Eocene. "Abstract. A deep-sea core from the Caribbean contains a layer of sediment highly enriched in meteoritic iridium. This layer underlies a layer of North American microtektites dated at 34.4 million years ago and coincides with the extinction of five major species of Radiolaria. It is suggested that a massive, chemically undifferentiated meteorite collided with the earth, producing the tektites and leading to the extinctions 34 million years ago." (R40)

To the above, W. Alvarez et al added the information that the tektites involved are considered part of the North American strewn field, and that mass extinctions of terrestrial mammals also occurred within 4 million years of the iridium spike. (R41)

The Late Pliocene. Abstract. "A 2.3-Myr-old layer in a sediment from the Antarctic Ocean contains Ir and Au at levels comparable with those at the Cretaceous-Tertiary boundary. A sizable fraction of the noble metals is contained in vesicular, millimetre-sized poly-mineralic grains that closely resemble ablation debris from chrondritic meteorites, and there is little doubt that the noble metals resulted from the accretion of a large extra-terrestrial object. No massive extinctions or other evidence of environmental stress seem to be associated with this accretionary event." (R24) This report was submitted by F. Kyte et al, who did the research aboard the vessel Eltanin. The cores were taken in the South Pacific at about 90°W, 57°S, west of the tip of South America. Six years later, Kyte and his colleagues reported on another core, extracted about 75 miles southwest of the earlier site. Here, there was a much higher concentration of iridium, and the impact debris constitutes about 10% of the total sedimentary layer, which was probably about 1 centimeter thick initially. The researchers associated this debris with drastic climate changes that transpired 2.2 to 2.5 million years ago. (R112)

In 1988, Kyte et al updated their work on the Late Pliocene iridium spike. Abstract. "Debris from a late Pliocene asteroid impact is spread across at least 600 kilometers of the ocean floor in the southeast Pacific. On the basis of iridium concentrations in sediments from six deep-sea cores, the asteroid diameter was at least 0.5 kilometer; the impacting projectile may have been one of the largest in the last few million years. The stratigraphic age of this impact is the same as that inferred for the onset on the Northern Hemisphere glaciation." (R153)

The late Pliocene meteoric debris, however, seems local rather than worldwide, because R. A. F. Grieve has examined late Pliocene sediments from the North Pacific and has failed to find any iridium spike. (R77)

June 30, 1908. Russian scientists, led by M.I. Korina, have found excess iridium in a peat layer 17-18 inches below the surface at the site of the famous Tunguska Event---often called the Siberian Meteor, even though no significant crater was excavated. Peat at the indicated level probably formed at about the time of the cataclysm. Antarctic ice of that period also shows a similar concentration of iridium. The Soviets suggest that this wide distribution of iridium-rich material might be explained if the celestial object, whatever it was, was accompanied by a dust cloud. It seems that bright sky glows were widely observed around Europe around the June 30 date. (R113) See GLA15 for descriptions of the Tunguska sky glows, and ETC3 for the Tunguska "craters".

Miscellaneous-and-undetailed reports of other iridium spikes. Summarizing the iridium-anomaly situation in 1987, R. A. Kerr mentioned several very recent and not fully documented discoveries: Two small anomalies just below the Cenomanian-Turonian boundary (91 million years old) near Pueblo, Colorado; and a small iridium anomaly in a deep-sea core taken between New Zealand and Australia, with an age of about 11.7 million years. (R120)

....

X1D. Correlations of iridium spikes with other phenomena. Iridium spikes, especially those at the Cretaceous-Tertiary boundary, have been correlated stratigraphically with several other geological phenomena. In the forgoing treatment, we have dwelt mainly on associations with biological extinctions. Here, we will mention these again, briefly, and then proceed in the following order:

- Biological extinctions (see also ESB1 and ESB2)
- Spherules (see also ESI11, ESP7)
- Tektites and microtektites (see ESM3)
- Other meteoric debris
- Shocked quartz (see ESP11)
- Soot (see also ESD9, ESC1-X3)
- Other siderophiles/noble metal spikes (see also ESC1-X2, X13)

Biological extinctions. At some K-T boundary sites, the iridium spikes are closely correlated with the disappearance of some species, as mentioned in several of the entries under X1B. In other cases, though, the extinctions are not sharply delineated in time; occasionally, there will be scant evidence of any paleontological changes. Here, since the asteroid/comet-impact hypothesis is now the reigning theory, and since this Catalog's purpose is the underscoring of purported challenges to mainstream theories, we now offer some reservations expressed by critics of the impact hypothesis relative to correlations between iridium spikes and extinctions.

The extinction of the dinosaurs is a popular topic in any discussion of catastrophism. The complexity of this particular extinction has already been mentioned, and some scientists are not yet ready to agree that an asteroid or comet did these beasts in. To illustrate, R. E. Stone et al maintain that the dinosaur extinction in Montana, Wyoming, and Alberta was a gradual process that commenced 7 million years before the K-T boundary was created. Some dinosaurs in that region seem to have survived beyond the end of the Cretaceous. (R101) In light of such paleontological data, R. Kollgaard, as late as January 1988, was comfortable in stating in a letter to <u>Physics Today</u>:

> "As is always the case in science, the interpretation of data can change, and many of the points that I have outlined may eventually be found compatible with an asteroid impact. I have no desire to get into a debate on the details of mass extinctions, but only want to illustrate that although there is a great deal of evidence for an asteroid impact 65 million years ago, whether this impact was the primary cause for the extinction of the dinosaurs is still an open question." (R128)

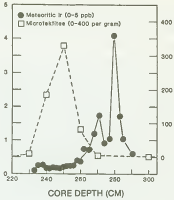
Of course, W. Alvarez and other proponents of the asteroid hypothesis are convinced otherwise. In replying to Kollgaard, Alvarez maintains, "I believe that question has been thoroughly closed off in the past several years." (R128)

We have already recorded the reservations of C. B. Officer and C. L. Drake concerning the impact hypothesis and W. Alvarez's responses. Basically, Officer and Drake believe that the correlation of the iridium spike and biological extinctions at the K-T boundary is poor. (R50, R82) Officer and Drake are not alone in voicing such thoughts, as the following quotations will demonstrate.

> "...careful study of extinctions at the K-T boundary, at the Eocene-Oligocene boundary about 36 million years ago and at the Cenomanian-Turonian boundary 90 million years ago show that these extinctions were neither purely catastrophic <u>nor</u> entirely gradual, report Erle Kauffman at University of Colorado in Boulder, Gerta Keller at Princeton (N. J.) University and Thor Hansen at Western Washington University in Bellingham. Instead, they say, these extinctions were 'step-wise', with some species dying out thousands to hundreds of thousands of years before and after the main extinction boundary and the entire extinction sequence lasting about 3 million years."
>
> Kauffman admits there is good evidence for impacts at the K-T and late Eocene extinction boundaries. "But in few cases, he said, do these impact events coincide in the stratigraphic record with major extinctions. And the Cenomanian-Turonian extinction record contains no direct evidence of impacts at the boundary at all. Rather, Kauffman's group found that the steps of large extinctions are usually associated with changes in ocean chemistry and with large and rapid drops in temperature of 2 to 5°C ---as measured by the ratios of oxygen isotopes in deep-sea sediments." (R98)

A. A. Ekdale and R. G. Bromley also see a lack of impact/extinction correlations: "The hypothesis that high iridium concentrations in some Cretaceous-Tertiary boundary layers reflects a catastrophic meteorite impact, which in turn caused the terminal Cretaceous extinction event, does not appear to explain several empirical facts: 1) the permanent draining of epicontinental seas at the end of the Mesozoic Era, 2) the selectivity of the biotic extinctions, 3) the pulse of calcite dissolution in shallow marine waters, and 4) the widely disparate geochemical signals of iridium and other trace elements in sites which are only a few hundred kilometers apart. All four of these facts are supported by observations in the Danish boundary strata as well as by observations in boundary sections from numerous other localities all over the world." (R67)

After commenting on the skepticism of the paleontological community concerning the impact hypothesis, Tony Hallam elaborates: "For many groups, such as tropical plants, mammals, crocodiles, birds and benthic invertebrates the change across the Cretaceous-Tertiary boundary was less than catastrophic, in a way not easy to reconcile with the original Alvarez scenario. Furthermore it could be shown that many groups were in decline well before the end of the Cretaceous, suggesting that a more gradual environmental deterioration was responsible. There have also been difficulties in establishing whether the dinosaurs died out at exactly the same time, geologically speaking, as the plankton which are used to fix the Cretaceous-Tertiary boundary in the marine realm. Some geologists have argued, on the basis of magnetic reversal stratigraphy, which is the only means of correlating marine and terrestrial strata, that the two sets of extinctions could have been out of phase by several hundred thousand years." Hallam goes on to say that, if an impact event did occur, it probably did no more than deliver the coup-de-grace to already declining species. (R60)



Concentration of iridium and clear-glass microtektites in a deepsea core from the Caribbean, suggesting an extinction event in the Eocene. (X1) (Adapted from R40)

Spherules. At some---not all---K-T sites, geologists have found sand-sized, microtektite-like spherules. "There are three types: sanidine-, glauconite- and magnetite-bearing. Although the chemistry and texture of much of the spherule mass have changed over geological time, the magnetite grains in the spherules are believed to have retained their original characteristics. They are enriched in iridium and have approximately chondritic abundances of other siderophiles. In texture, they resemble rapidly-crystallized high-temperature liquids. (R61)

Some researchers feel that these spherules are the consequence either of shock-melting of crustal material (probably of marine origin) or the atmospheric melting of an extraterrestrial object. Although the spherules have some features of microtektites, they are not as "glassy", and they may have a different origin. (WRC)

Spherules occur in the K-T boundary materials at sites in Italy, Spain, and two Pacific-floor sites. (R61)

B. F. Bohor et al have found spherules at a Wyoming K-T boundary: "The boundary clay consists of a basal kaolinitic claystone layer as much as 3 cm thick containing hollow goyazite spherules, overlain by a 2-3 mm smectitic layer (the 'magic' layer) containing both shock-metamorphosed minerals and an iridium anomaly of 21 ppb. A palynological break coincides with the base of the claystone layer; numerous Late Cretaceous palynomorph species terminate at this boundary." (R123) Here, the coexistence of spherules, shock-altered material, and iridium constitutes strong evidence for the impact origin of the spherules. (WRC)

Microtektites. Microtektites appear at the Eocene (34.4 million years ago) iridium/extinction boundary layer in the Caribbean. The physical similarity of these microtektites and their apparent age have led to the assertion that they are part of the North American tektite strewn field. (R40) However, the extinction-associated iridium layer appears to predate the microtektite horizon. (R76)

Meteoric debris. The late Pliocene (2.3 million years ago) iridium spike found in Antarctic sediments is correlated with what is termed "meteoritic debris." This material consists of vesicular glasses, brecciated and shocked basalt, and iron-nickel metal. (R77)

Shocked minerals. Shocked minerals, particularly quartz, are widely correlated with iridium anomalies. Some examples: the Gosau Basin, Austria (quartz and plagioclase) (R105); Denmark, Italy, Spain, Colorado, New Mexico (quartz) (R72); Wyoming (various minerals) (R123); off Antarctica (basalt) (R77); and Montana (quartz) (R61, R70).

Proponents of the volcanism hypothesis for the origin of the iridium-anomaly phenomena are hard put to explain the presence of shocked quartz through volcanic action. Shocked minerals can be generated in volcanic eruptions, but these minerals seem quite different from those shocked minerals at K-T coundaries. (R120)

It is also favorable to the asteroid theory that shocked quartz grains found in North America are considerably larger---0.5 as opposed to 0.1-0.2 millimeters---than those found elsewhere. Such differences suggest a size-effect in grain dispersal; one that indicates that the impact crater is in or near North America. (R120) See also ESP11.

Possible tsunami deposits. Sites near the Brazos River, Texas, display an iridium anomaly in conjunction with paleontological evidence of extinctions overlying a bed of coarse-grained sandstone. The bed contains large clasts of mudstones and reworked carbonate nodules. The sandstone becomes finer-grained near its top. Other strata below and above are characteristic of quiet-water deposition. This sandstone bed, however, is consistent with the occurrence of a tsunami 50-100 meters high, such as might be produced by the water impact of an asteroid/comet. (R154)

Soot. In the K-T boundary clays from Denmark, New Zealand, and Spain, analysis has revealed the presence of elemental carbon in particle form similar to that of soot. This carbon is concentrated in the K-T clays at levels 4-25 times greater than in modern marine sediments and 4-5 higher than in the marls above and below the Danish boundary layer. One interpretation is that the assumed asteroid/comet impact started widespread wildfires that deposited soot over much of the globe. (R102, R152, R157) Certainly this must be considered a plus for the impact theory. (WRC)

Other siderophiles. Iridium anomalies are often stratigraphically coincident with anomalous concentrations of gold, platinum, osmium, and other noble metals. Like iridium, most of these elements are rare on earth and much more common in asteroids and meteorites. Of these, only osmium and gold have been explored as stratigraphic markers, and then only cursorily when compared with the work done with iridium. (See X2 and X13.)

. . . .

X1E. Theories about the origin of the iridium anomaly.

Supernovas. An early explanation suggested for the iridium anomaly at the Cretaceous-Tertiary boundary involved the existence of a nearby supernova 65 million years ago. Such an astronomical explosion would have emitted an expanding shell of newly-created heavy elements, including iridium and plutonium-244. According to supernova theory, the abundance ratio of these two atoms would have been 10^3; that is, 1000 iridium atoms for every plutonium-244 atom. The half life of plutonium-244 is known (80.5 millions of years), and the age of the event is also available (65 million years). If a supernova were the cause of the iridium spike, there should be enough undecayed plutonium-244 mixed with the iridium for scientists to detect it. They cannot, so the supernova theory was jettisoned. (R17)

Comets. Comets are composed mostly of ices, but siderophile elements, like iridium, are probably present, in very low abundances, in both the cometary nucleus and the cloud of gases and particulate matter accompanying the nucleus. A comet, being readily friable, would probably break up during atmospheric reentry, spreading its materials over a wide area, while leaving no appreciable crater. Since the iridium anomaly is worldwide and no K-T crater has been positively identified as yet, the impact of a comet or a swarm of comets remains a possible cause for the iridium anomaly. A strong negative fact, however, is the frequent presence of shock-metamorphized quartz at K-T boundary sites. (R81)

The asteroid-volcanism debate. This controversy still flares. It is appropriate at this time to reproduce summary statements from both sides of the argument:

F. T. Kyte. Abstract. "Since the initial discovery in 1979 of anomalous concentrations of Ir in Cretaceous-Tertiary boundary sediments, several lines of physical evidence have supported predictions which can be inferred from the impact hypothesis. These include: 1) Worldwide occurrence of anomalous Ir at every locality (and in any environment) at which sedimentation was continuous. 2) Relative abundances of siderophile elements roughly similar to chondritic (solar) abundances. 3) Osmium isotopic abundances consistent with only a meteoritic or mantle source. 4) Widespread occurrence of high pressure (shocked quartz) and high temperature (skeletal spinel) minerals. 5) Presence of an exotic boundary clay (probably terrestrial ejecta) which is isotopically distinct from normal detrital sediments. These data are easily reconcilable only with a major impact event. The only alternative hypothesis, an extremely unusual volcanic event, must be considered a very low probability alternative." (R80)

C. B. Officer and C. L. Drake. Abstract. "The character of the variety of geologic signatures at Cretaceous-Tertiary time including iridium and other associated elements, microspherules, and shock deformation features suggests that the transition was marked by a period of intense volcanism. The volatile emissions from this volcanism would lead to intense acid rain and a reduction in the alkalinity and pH of the surface oceans, global atmospheric cooling, and ozone layer depletion with consequent increased ultraviolet radiation. These effects with the associated sea level regression can explain the selective nature of the extinctions, viz., extinction of the carbonate dependent phytoplankton and zooplankton of the surficial ocean waters as well as the survival of the dinoflagellates and benthic foraminifera; selectivity in extinction of the shallow water macrofauna and freshwater fish; extinction of the dinosaurs as well as survival of the mammals, birds and crocodiles; and selectivity in the floral changes." (R82)

It is apparent from the two abstracts above that the authors are concentrating on different aspects of the K-T boundary event. Kyte dwells on the physical, chemical, and geographical facets; while Officer and Drake are concerned more about the paleontological features.

Volcanic sources of iridium. Those scientists who prefer a terrestrial cause for the Cretaceous-Tertiary boundary events attempt to account for the iridium spike by postulating volcanic sources. Originally, volcanologists maintained that volcanos emitted little if any iridium but, in 1983, Kilauea, in Hawaii, released surprisingly large amounts of iridium. (R142, R148) But, since Kilauea appears to be unique in this respect, the elation of the anti-asteroid camp was short-lived.

In this same vein, the immense basalt flows constituting the Deccan Traps, in India, were looked at as another possible iridium source. The Traps are approximately the same age as the Cretaceous-Tertiary boundary, and they are impressively large. However the analysis of samples from the Deccan Traps revealed only minor amounts of iridium. This finding, though, does not end the debate, for the French scientists who did the research remarked: "This does not help to constrain the debate on the internal vs external origin of KTB boundary events, since for instance Ir could have been outgassed from the magma, and original concentrations of only 0.05 $ng.g^{-1}$ prior to outgassing are sufficient to account for the worldwide Ir excess mass at the KTB." (R168)

Without question the asteroid/comet hypothesis is now dominant, but it has difficulty in explaining such phenomena as:

- The apparent lack of a suitable K-T crater
- The multiple and dispersed character of some iridium anomalies
- The extremely high concentration of iridium at some sites
- The selective nature of the K-T biological extinctions
- The claimed poor correspondence in time of the iridium anomaly and the various species involved in the K-T extinctions. (WRC)

X2. Osmium. This element, one of the siderophiles, often exhibits a concentration spike synchronously with iridium at the Cretaceous-Tertiary boundary. The literature examined does not reveal if osmium spikes occur at all K-T boundary sites, or whether osmium anomalies have been found above or below the K-T boundary.

Osmium-spike data have been published for the K-T site in Spain, where the enhancement is great (R48), and for Denmark (R20). Many reports on the iridium anomaly mention coexisting osmium. (R11, R45)

The ratio of osmium-184 to osmium-190 was measured for the Danish fish clay using neutron activation analysis. This ratio was found to be essentially identical to that in terrestrial and meteoric samples. (R20)

However, osmium has many isotopes. J.-M. Luck and K. Turekian found that the ratio of osmium-187 to osmium 186 in the Danish fish clay was closer to that in meteoric sources than terrestrial sources. The same was found for the osmium ratio from the K-T site in the Raton Basin, Colorado. Curiously, though, the ratios from the Danish osmium (1.660 and 1.654) were substantially higher than a Colorado sample (1.29). Luck and Turekian wondered if this signified that there were two separate asteroids involved. (R48, R86, R139)

To complicate matters still further, A. Hallam has pointed out that the Danish osmium ratios are almost identical to that in a sample from the mantle-derived Bushveld Complex in South Africa. (R119) This contradiction can be traced beck to the assumption of Luck and Turekian that the ratio should be about 1 for meteoric material and about 10 for mantle material. (R86) It is apparent that some terrestrial osmium ratios may be close to those measured in extraterrestrial samples. (WRC)

X3. Carbon isotopes. The significance of the carbon isotopes ^{12}C and ^{13}C in geology is found in the tendency of biological systems---life, that is---to preferentially use the lighter isotope, ^{12}C, in frabricating biological materials. Such isotopic separation means that sediments rich in the lighter isotope probably contain considerable biogenetic carbon. Thus, carbon-isotope anomalies or excursions may signify important biological events, such as explosions and extinctions of life.

In the literature, the carbon-isotope ratio $\delta^{13}C$ is usually employed and is given by:

$$\delta^{13}C = \frac{^{13}C/^{12}C(\text{sample}) - {^{13}C}/^{12}C(\text{standard})}{^{13}C/^{12}C(\text{standard})}$$

$\delta^{13}C$ is commonly expressed as a percentage and, as the equation indicates, is determined by reference to a standard (CO_2 standard PDB). 'Light' carbon from biological materials is usually negative in sign.

In specifying $\delta^{13}C$ values, one must stipulate the source of the carbon as "organic" or "carbonate". Organic carbon, as its name implies, is biogenetic. Negative $\delta^{13}C$ excursions in organic carbon usually reflect increased biological productivity. Carbonate carbon (sometimes called "marine" carbon) is that carbon extracted from seawater by carbonate-manufacturing organisms. Positive $\delta^{13}C$ excursions in carbonate carbon may also be the result of increased biological productivity. The reasoning is that if biogenetic activity fixes large amounts of ^{12}C in organic material, which is then buried in sediments and removed from the environment, the isotope ^{13}C becomes more common in the environment. Carbonate carbon thus becomes heavier, as reflected in positive excursions of $\delta^{13}C$.

Our treatment of carbon-isotope anomalies proceeds, as usual in this section, upward through the stratigraphic column.

Precambrian. It is hypothesized that terrestrial life originated early in this period, but its precise course is a matter of much speculation. The carbon-isotope record turns out to be rather confusing.

In 1972, D. Z. Oehler et al found wide variations in the carbon-isotope ratio in South African rocks: "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 (Threespruit 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." (R3; R1)

K. M. Towe pointed out that carbon in the Precambrian and early Phanerozoic sediments is not "normal". When it is compared to the carbon of the algal biota thought to have employed it, it is anomalously depleted in ^{13}C. In this context, the anomalous graphite carbons reported by Schoell and Wellmer are merely more anomalous.

The normal $\delta^{13}C$ values for Precambrian sediments range from -24 to -28%. "Such values appear quite normal when compared with the reduced carbon of modern C_3 terrestrial plants. However, a substantial land plant community did not develop until the Silurian, so that when compared with the reduced carbon from modern marine algae and algal mats, these 'normal' Precambrian isotopic ratios become disturbingly anomalous, and are especially so for the carbonate stromatolites. Present-day marine algal organic carbon is significantly heavier isotopically, with mean values ranging from -18 to -20%. Modern marine algal mats are even heavier, with values ranging from -8 to -19%. This difference between the average terrestrial isotopic values and the average marine values of reduced carbon is so striking that it has been used to evaluate the impact of land-derived organic matter in modern marine sediments." So, with no terrestrial plant community of any significance in the Precambrian, the low values of $\delta^{13}C$ (-24 to -28%) are exceedingly difficult-to-explain. (R33)

A letter from Schoell and Wellmer in response to Towe's letter reveals that some scientists have now concluded that the Precambrian $\delta^{13}C$ data demonstrate that marine algae could not have produced the Precambrian reduced carbon. Marine phytoplankton, however, display $\delta^{13}C$ values more in agreement with Precambrian $\delta^{13}C$ measurements. (R33)

It has long been held that marine algae were an important early form of life, but the $\delta^{13}C$ data seem to deny this assertion that is so common in the textbooks. (WRC)

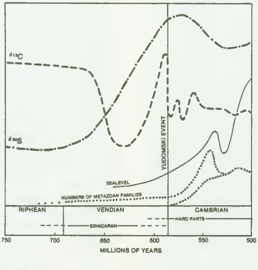
Early development of life. A remarkable implication derived from Precambrian carbon-isotope data is that prolific microbial life was fully established when the oldest sediments were formed some 4 billion years ago. This unexpectedly early appearance of photosynthesizing life forms is signaled by a marked increase in the $^{12}C/^{13}C$ ratio in these sediments. (R169) Apparently life either develops more rapidly than theory contemplates or, possibly, earth was "seeded" extraterrestrially. (WRC)

The Precambrian-Cambrian boundary. $\delta^{13}C$ anomalies have been detected in the vicinity of the Precambrian-Cambrian boundary by several investigators. The amounts of the shift vary, and their significance relative to biological explosions and extinctions is still being debated. Something of a biological nature happened during this transitions, but what?

The first data came from southwest China and were reported by K. J. Hsu et al: "We have undertaken a search for geochemical anomalies at the Precambrian-Cambrian contact. We report here the discovery of a sharp negative carbon-isotope shift in the carbonate of a clay immediately above a marker in the Precambrian-Cambrian boundary, the China C marker, and interpret this signal as evidence of sudden decrease in fertility before the Cambrian explosion of invertebrate evolution. The discovery suggests that the Precambrian-Cambrian boundary might be defined by an event-marker at a palaeontologically correlative horizon." See accompanying graph. An iridium anomaly (X1) also exists at this site and boundary. (R84)

S. M. Awramik, commenting on the above results, questions the correlation between the geochemical and biological anomalies. "Regardless of the precise position of the geochemical changes with respect to the China C marker, these data do not coincide with any measurable mass extinction or phytoplankton mass mortality, and do not precede the Cambrian explosion. They occur during the explosion, when Metazoa are undergoing the most magnificent radiation in their history." (R97) In his response to Awramik, Hsu states that the definition of the base of the Cambrian is still a matter of contention.

Interestingly enough, positive $\delta^{13}C$ excursions also may be found at the Precambrian-Cambrian boundary; and the explanation of these is also in terms of increased biological activity. M. E. Tucker has found such anomalies in Morocco. Quoting from his Abstract: "I present here a carbon isotope profile, from the Precambrian/Cambrian boundary beds in Morocco, where two distinctive positive $\delta^{13}C$ excursions are revealed. These are interpreted as records of increased organic productivity as part of the Precambrian/Cambrian explosion of life. $\delta^{13}C$ excursions could be useful points for correlation between boundary sections." The difference between the carbon in the Morocco rocks and that at the other sites mentioned above is that it is oceanic carbon and not carbon fixed by photosynthesis or some other biological process. The Morocco carbon was taken directly from seawater by the organisms that formed the dolomites and limestones that were sampled. And if a biological explosion had been in progress at the time the dolomites and limestones were laid down, the organisms involved would be fixing large quantities of light carbon (^{12}C), thus depleting the oceans. In this way, the seawater carbon going into calcareous deposits would contain more ^{13}C than before the explosion. A positive $\delta^{13}C$ excursion is therefore indicated. (R109) In contrast, sediments containing carbon involved in organic synthesis would show a negative anomaly! (WRC)



Data on several biological, geological, and chemical trends across the Precambrian-Cambrian boundary. (X3, X6)

Such a negative anomaly has been recorded across the Precambrian-Cambrian boundary on the Siberian Platform by M. Magaritz et al: "We present here an initial survey of carbon isotope ratios in a section on the Siberian Platform that spans the Proterozoic/Palaeozoic boundary. After a high of $\delta^{13}C = +3.4\%$, 15 m below the boundary, $\delta^{13}C$ drops sharply in two cycles across the boundary, to $\delta^{13}C = -2\%$ near the end of the Tommotian Stage. These variations suggest an initial bloom of biomass in late Vendian time corresponding to the dramatic diversification that must have preceeded the widespread appearance of new taxa in the Cambrian fossil record." (R107) But like the rocks analyzed in Morocco, those studied on the Siberian Platform were dolomites, some of which have been called limestones. So, we have an apparent conflict: positive and negative anomalies for the same types of rocks at the same spot in the stratigraphic column. (WRC)

The conflict just noted may be due to carelessness in specifying the source of the carbon being analyzed. Some authors state clearly that they are working with "organic" carbon or "carbonate" carbon. The latter carbon is identical to the "marine" carbon mentioned earlier in connection with the Morocco limestones and dolomites. (WRC)

Late Middle Ordovician. Oils generated by Middle Ordovician rocks are found widely in the central United States. J.R. Hatch et al have reported that these oils possess a wide range of carbon isotope composition. The range for saturated hydrocarbons is $\delta^{13}C = -24.9$ to -33.9%. The range for aromatic hydrocarbons is similar. The authors comment on the implications in their Abstract: "The wide ranges in $\delta^{13}C$ for oils and rock extracts reflect a major, positive excursion(s) (6-9%) in organic matter $\delta^{13}C$ in late Middle Ordovician rocks. This excursion has at least a regional significance in that it can be documented in sections 480 mi (770 km) apart in south-central Kansas and eastern Iowa. The distance may be as much as 930 mi (1,500 km) if the carbon isotope variations observed in Michigan basin Ordovician oils and in organic matter from late Middle Ordovician rocks in southwestern Ontario are related to the same carbon isotope excursion. Organic-matter $\delta^{13}C$ in core samples from south-central Kansas and eastern Iowa is not directly related to variations in quantity or quality of organic matter, or maceral composition. The positive excursion in organic matter $\delta^{13}C$ is a possible result of increased organic matter productivity and/or preservation." Hatch et al also mention that core samples from an Iowa well show parallel shifts in both organic and carbonate $\delta^{13}C$. The magnitudes of the positive shifts differ, being 8.8 and 4.2% respectively. This might be due to a decrease in available dissolved CO_2. (R127)

Permian. "Abstract. Samples of dolomite and limestone from the Permian Irati Formation collected in the Parana Basin, southern Brazil, have been analyzed for δC^{13} and O^{18}. The δC^{13} ranges from +18.3% to -17.4%, while the δO^{18} ranges from -2.6% to -12.5% PDB. In some quarries where the exposures are especially good, a large variation in δC^{13} can be found. The lower, dense gray dolomite has light carbon (-17 to +2.6 %), whereas the overlying intermediate zone of interbedded organic-rich shale and black dolomite has dolomite containing heavy carbon (+4.8 to +14.9% PDB).

"We believe that the dolomite represents diagenetically altered limestone, and that the light CO_2 produced by decomposing organic matter was involved in the diagenesis of the lower units, while the heavy CO_2 produced by the isotopic exchange between CO_2 and methane was involved in the alteration of the upper, organic-rich layers." (R4) "Diagenesis" is a term referring to the geochemical changes in sediments before consolidation. The chemical changes that may be introduced by diagenesis cloud the picture drawn by geochemical anomalies, as we shall see in the next entry. (WRC)

In 1983, M. Magaritz et al published their analysis of striking carbon-isotope shifts in the Late Permian. Abstract. "Closely spaced samples (285 in number) of varved sediments from the Upper Permian in Delaware Basin, Texas, have been analyzed for $\delta^{13}C_{carb}$, $\delta^{13}C_{org}$, $\delta^{18}O_{carb}$, C_{org}, C_{carb}, and calcite/dolomite. $\delta^{13}C$ records a dramatic rise from -2.8 to +5.7% in only 4400 years, detected in three sections across the basin, extrapolating smoothly through a 600-year interruption by a local (west side of the basin) freshwater inflow evidenced by $\delta^{18}O$. This continuity and low C_{org} within the basin, both indicate that the excess net deposition of C_{org}, necessary to generate the rise in $\delta^{13}C$, took place in the ocean external to the Delaware Basin. Correlation with similar records from the Zechstein Basin suggest that the event was world-wide, although this poses obvious difficulties for the carbon cycle. The rate of rise of $\delta^{13}C$, and its sustained high level, must imply conversions of oxidized carbon to reduced carbon that are very large depending on which reservoirs were involved." (R140) A subsequent paper from the Magaritz group extended this carbon-isotope anomaly geographically to Greenland, Europe, China, and elsewhere. (R147) Obviously, great chemical changes were occurring in the Late Permian.

In commenting on the very large $\delta^{13}C$ shifts found by Margaritz et al, M. A. Arthur was inclined to blame diagenesis rather than environmental changes. He stated, "The implications of such an event for organic carbon burial rates and for changes in atmospheric ocean chemistry are staggering." Further, "A critical problem in extracting primary geochemical signals from ancient sedimentary rocks is the ubiquitous spectre of diagenetic overprints." Arthur goes on to relate various ways in which the sediments Margaritz et al studied, which were rich in organic carbon, might have been altered diagenetically to create spurious geochemical signals. (R74)

Permian-Triassic boundary. "Abstract. Carbon isotope ratios in marine carbonate rocks have been shown to shift at some of the time boundaries associated with extinction events; for example, Cretaceous/Teriary and Ordovician/Silurian. The Permian/Triassic boundary, the greatest extinction event of the Phanerozoic, is also marked by a large $\delta^{13}C$ depletion. New carbon isotope results from sections in the southern Alps show that this depletion did not actually represent a single event, but was a complex change that spanned perhaps a million years during the late Permian and early Triassic. These results suggest that the Permian/Triassic (P/Tr) extinction may have been in part gradual and in part 'stepwise', but was not in any case a single catastrophic event." (R132) Such "smearing" of phenomena accompanying extinction events tends to undercut single-impact astronomical catastrophism. (WRC)

Cretaceous-Tertiary boundary. Once again we come to the K-T boundary, where there is considerable dispute about whether its genesis was extraterrestrial or purely terrestrial. The complexity of this subject is once more apparent below.

K. J. Hsu et al have analyzed the carbonate $\delta^{13}C$ anomalies in a K-T core extracted from the ocean bottom off the west coast of southern Africa. The carbonate in a deep-sea species and, also, in larger surface-dwelling organisms was studied.

"For the isotope carbon 13 in the bulk samples (surface-dwellers) there were again two anomalies, one at the CT boundary and one about one metre above. Both anomalies represent depletions of ^{13}C relative to the more plentiful ^{12}C. But the selected samples of G. beccariiformis show no fluctuations in the ratio of the two isotopes. So the anomaly was confined to surface waters and was spread over a period of about 50 000 years." (R44; R42)

A. Hallam elaborated on this phenomenon: "One of the most striking chemical signatures at the K/T boundary is a strong and short-term negative excursion of the carbon isotope ratio in coccoliths and planktonic forams in deep-sea cores, which is best explained in terms of a reduction in the $\delta^{13}C$ gradient between surface and deep ocean waters, such as would result from a drop in the global rate of photosynthesis over the ocean surface; this is of course what one could predict from a mass extinction event in the phytoplankton. The calcareous plankton oxygen isotope record reveals no such dramatic change, with several oscillations in oxygen isotope ratio directly above and below the boundary being almost as marked as the small rise of 0.5 per mil immediately at the boundary. Whether such short-term oscillations represent environmental signals as opposed to diagenetic noise has not yet been clearly established." (R119)

Chemically speaking, the K-T boundary is most complex. Just how complex is stated nicely by A. A. Bray: "It is now quite clear that the K-T boundary is marked by a major geochemical event, which is of world-wide nature, and affects both marine and non-marine environments. However, this geochemical perturbation exhibits a good deal of variation with regard to intensity and timing. For instance, at El Kef, Tunisia, whilst C^{12} values show a change at the boundary, O^{18} values only alter above the boundary, the K-T boundary geochemical perturbations in Israel appear to be gradual, with C^{12} values starting to decline 1.50 m below the boundary, and the minimum occurring 0.80 m above the boundary. Apart from such differences, the magnitude of anomalies at different sites shows great variability." It seems that most scientists write off such variations as "diagenetic modification", without really trying to explain them. (R89)

It is interesting to observe that in none of the above is the asteroid/comet hypothesis mentioned! It is as if all of the biological and geochemical changes at the K-T boundary took place without the impact of an extraterrestial object. This, of course, is exactly what many paleontologists and geochemists maintain. (WRC)

In the asteroid/comet context, K. J. Hsu estimated in 1980 what the geochemical effect of a large asteroid/comet might be, irrespective of other effects. "A large input of cometary carbon should also significantly alter the isotopic composition of calcareous sediments in the ocean. The isotopic composition of carbon for meteorites and for the Earth's mantle has about the same composition of -6 to -7% $\delta^{13}C$. However, the carbonate in meteorites and the carbon in chondrites have very heavy ^{13}C, with values up to more than +50%. As the CO_2 in the nucleus of a comet may have represented a distilled fraction, it should have an isotopic composition much lighter than that of the average meteorite. Assuming a cometary $\delta^{13}C$ of -25%, a -1.5% carbon-excursion in dissolved carbonate can be caused by the fall of a 10^{18} g comet of which carbon atoms constitute a quarter of its mass." (R19)

Recent (last 400,000 years. Using a long sediment core taken from Lake Biwa, in Japan, M.R. Rampino has constructed a 400,000-year history of geomagnetic excursions, changes in the earth's ice volume, eccentricity of the earth's orbit, oxygen-isotope excursions and, of importance here, the percent organic carbon present in the core. Three prominent changes in magnetic inclination; the Blake, Biwa 1, and Biwa 2; correlate well with sharp minima in the percent of organic carbon. and, by inference, with climatic changes. (R10) Note that $\delta^{13}C$ is not involved here, only the percentage of organic carbon. Nevertheless, the correlation is most interesting. Are any $\delta^{13}C$ excursions in the stratigraphic record correlated with magnetic reversals? (WRC)

X4. Uranium isotopes. In ESP13, we presented examples where the isotope uranium-235 has been found depleted in various geological settings. At the Oklo site, in Gabon, especially, such depletion of uranium-235 seems to be the consequence of natural fission reactors preferentially removing that isotope.

In this Catalog entry, the emphasis shifts to the uranium isotope-ratio $^{234}U/^{238}U$. The normal value of this ratio in seawater is well-defined, 1.15. However, marked excursions of this ratio have appeared in recent deep-sea hydrothermal deposits and, possibly, in recent volcanic rocks.

East Pacific Rise. "An iron deposit (sample AMPH D-2) dredged from the flank of a sea mount at the crest of the East Pacific Rise has a $^{234}U/^{238}U$ ratio which is significantly higher than that of sea water. This result was unexpected and is somewhat puzzling. The iron deposit in question has been described as a product of submarine volcanism, probably formed by interaction between hydrothermal solutions and sea water. It is worth noting that the U/Fe ratio in this deposit is much lower than in the sediments nearby, but very similar to the U/Fe ratio of 0.6×10^{-5} in a sample of geothermal brine from the Red Sea." Explanations proposed include magmatic fractionation and the preferential leaching of ^{234}U from rock walls by ascending hydrothermal solutions. The isotope ratio in the sample AMPH D-2 was 1.22. (R2)

Sanghihe Island Arc. "Abstract. Although hydrothermal ferromanganese deposits often display variable $^{234}U/^{238}U$ ratios, published values generally do not differ by more than 20% from the seawater value of their hydrogenous counterparts. Here we report very high $^{234}U/^{238}U$ ratios in hydrothermal manganese crusts recovered from the Sanghihe island arc system in the West Pacific. Such ratios, about twice that of normal seawater, confirm a low-temperature hydrothermal supply of uranium, which is best explained by leaching of the underlying rocks by the hydrothermal fluids and deposition together with the manganese oxides before mixing with seawater. This suggests that the $^{234}U/^{238}U$ in seafloor deposits may be used as a tracer of low-temperature hydrothermal reactions in the ocean crust." (R126)

The Caucasus. "(V. V.) Cherdyntsev et al. report significant departures from radioactive equilibrium between ^{234}U and ^{238}U in recent volcanic rocks from the Caucasus, with $^{234}U/^{238}U$ ratios ranging from 0.55 to 2.12. However, no such disequilibrium could be detected in historic lavas from Hawaii, nor in recent volcanic rocks from Iceland, Mt. Pelee or Mt. Katmai." (R2)

X5. Oxygen isotopes. Oxygen-isotope ratios are commonly employed in the study of past climatic conditions or "paleoclimates." The most common stable oxygen isotope is oxygen-16 (^{16}O) (99.759%). A heavier stable isotope, ^{18}O (0.204%) is used in isotope studies. The isotope ratio, $\delta^{18}O$, is calculated in the same manner as $\delta^{13}C$, as described in X3.

The basic reason why $\delta^{18}O$ can indicate climatic conditions is that the evaporation process at ocean surfaces preferentially selects lighter water molecules---those containing oxygen-16---leaving behind seawater enriched in heavier oxygen-18. Foraminifera in the surface waters secrete this heavier oxygen in their shells, which upon the death of the organisms, settle to the ocean bottom. Thus, cores taken from the ocean bottom contain a historical record, as read from the oxygen-isotope ratios of foraminifera shells, of the temperature of surface waters. Or so a superficial analysis would suggest.

Actually, under equilibrium conditions, the evaporated seawater (enriched in ^{16}O) is quickly returned to the ocean via precipitation. However, if climatic conditions turn colder, and the preciptiation falls as snow, the evaporated water will remain locked up in ice and snow. Under these conditions, the foraminifera in ocean-bottom cores will reveal a positive swing in $\delta^{18}O$, representative of more ^{18}O relative to ^{16}O. The ratio $\delta^{18}O$ is now generally considered to be an indicator of the planet's ice volume. And, of course, a climate change conducive to the formation of more terrestrial ice will also be reflected in lower ocean surface temperatures.

With this background, we present below some of the $\delta^{18}O$ anomalies found so far in the literature.

Precambrian-Cambrian boundary. The research of K. J. Hsu et al at the Precambrian-Cambrian boundary in China revealed an iridium anomaly (X1) and a carbon-isotope anomaly (X3); their graphs for $\delta^{18}O$ across the China C marker at their Yangtze site also showed a strong negative swing in $\delta^{18}O$. (R84)

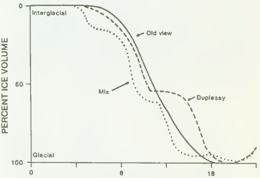
Permian. Samples of dolomite and limestone from the Permian Irati Formation, in Brazil, show $\delta^{18}O$ swings from -2.6 to -12.5%. (R4) In X3, wide swings in $\delta^{13}C$ were noted for this unusual formation. It is difficult to interpret such wild variations.

The K-T boundary. In a study of the $\delta^{18}O$ variations across the K-T boundary, R. Wright chose the deep-sea species G. beccariiformis, while other members of the team led by K. J. Hsu analyzed a bulk collection of larger, surface-dwelling species, as already described in X3. Their results: "Oxygen 18 shows fluctuations similar to carbon 13, but they are less clear-cut. There is a peak in oxygen 18 at the boundary, which possibly indicates a drop in temperature at that time, but in general there is a decrease that parallels the ^{13}C decrease and probably reflects a general warming of the water. G. beccariiformis shows the same ^{18}O pattern as the bulk samples; this suggests that the warming affected deep and surface waters, while only the surface waters showed a change in bicarbonate content." (R44; R42) See X3 for $\delta^{13}C$ changes discovered in this research.

Oxygen isotopes in Weddell Sea sediments imply that some 200,000 years before the K-T boundary event, the earth's climate cooled suddenly. (R160) This precursory development, with its effect on biological extinction, further complicates deciphering of the K-T boundary scenario. (WRC)

Recent (last 400,000 years). Oxygen-isotope ratios are commonly used to elucidate the changing climate during and following the Ice Ages.

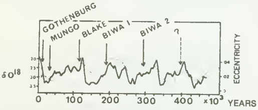
Today, scientists generally believe that the Ice Ages were caused by changes in insolation which were the consequence of orbital variations---the Milankovitch hypothesis. Several lines of geological evidence support the Milankovitch hypothesis. Insolation peaked about 11,000 years ago, and geolog-



Recent studies by Mix and Duplessy suggest that deglaciation occurred in steps, contrary to the mainstream theory. Oxygen-isotope data from deepsea sediments were used. (X5) (Adapted from R52) ical considerations generally pointed toward rapid disintegration of the ice sheets at that time. However, $\delta^{18}O$ research seems to show a glitch occurred. J-C. Duplessy and his colleagues "have concluded from their oxygen-isotope study of deep-sea sediments from the Bay of Biscay, south of the English Channel, that at least one-third of the ice melted between 16,000 and 13,000 years ago. That was long before increasing insolation could have melted much ice. Further complicating matters, melting of the ice sheets appeared to pause between 13,000 and 10,000 years ago, just when the fastest melting had been deduced from earlier studies. A second episode of melting apparently led to the present volume of ice by about 6000 years ago." (R52) Thus, the $\delta^{18}O$ data are at variance with accepted theory.

Studies of cores off Antarctica highlight additional glitches. This work was carried out by L.D. Labeyrie et al, who concluded: "There is a definite indication that the Southern Ocean led by 2 kyr the North Atlantic warming and Northern Hemisphere deglaciation. A more important result of our study is that there have been several periods during the last glacial of large isotopic anomalies in the surface waters of the Antarctic polar front, particularly between 35 and 17 kyr BP. These anomalies are due to a large input of melt water during periods when the periphery of the Antarctic ice sheet was rapidly eroded." (R106) The Milankovitch hypothesis doesn't provide any insight here. (WRC)

Oxygen-isotope research, on the other hand, does provide some support for the Milankovitch theory when one brings in geomagnetic excursions, which are believed to be linked to orbital parameters. First, the analysis of Antarctic deep-sea cores for $\delta^{18}O$ reveals peaks that can be correlated with specific magnetic excursions <u>and</u> the earth's orbital eccentricity. See the accompanying graph adapted from the work of M.R. Rampino. (R10) Note the rather regular spacing of the peaks.



Record of oxygen-isotope variations during the past 475,000 years in sub-Antarctic deepsea cores. Low δO^{18} levels indicate small ice volumes. Dotted line is eccenticity of the earth's orbit. (X5)

It is becoming more acceptable these days to correlate orbital variations with geomagnetic excursions and climatic variations. Some deep-sea core records of $\delta^{18}O$ variations go back more than a million years. The Milankovitch hypothesis predicts periodic cycles in global temperature with lengths of 19,000, 23,000, and 41,000 years. Some of this periodicity can be seen in the oxygen-isotope records. (R92)

<u>Correlation with $\delta^{18}O$ in ice cores</u>. Very long ice cores, representing perhaps one hundred thousand years of precipitation in the north polar regions, have been obtained in Greenland and elsewhere in the Arctic. The oxygen in these cores is in gaseous form, having been trapped as bubbles during the millennia of deposition. With proper adjustments for thinning of the annual ice layers, a fairly good correlation can be obtained between these ice cores and ocean-bottom cores for $\delta^{18}O$. (R31)

<u>A $\delta^{18}O$ caveat</u>. The analysis of deep-sea cores for $\delta^{18}O$ is difficult, and the possibilities for error manifold. In a very long, well-documented paper, written from an admittedly antiestablishment point of view, M.J. Oard questions the accuracy of $\delta^{18}O$ data: "This part has shown in detail that the interpretation of oxygen isotope fluctuations in deep-sea cores is practically impossible, and therefore cannot be related to the astronomical theory of the ice ages. Very small changes in ^{18}O can result in large changes in $\delta^{18}O$, leaving much room for error. The laboratory procedure for measuring the isotopes in foraminifera is very complex. The equation relating the measurements to paleotemperature and the oxygen isotopic composition of the sea water cannot be solved. In addition, there are many other unknown or poorly understood variables related to $\delta^{18}O$ of the sample. Some of these are paleodepth of the foraminifera, seasonal differences in oceanic parameters and species abundance, and biological variables of foraminifera. There are additional complicating factors introduced by possible secular changes of $\delta^{18}O$ of sea water percolating through the crust, by cold or warm core eddies caused by rapid currents, by shell dissolution with depth, by bioturbation of the sediments and by the reworking of the sediments from common geophysical processes." (R73) This is a very scholarly study based upon some 185 references, mostly from scientifically impeccable sources. (WRC)

X6. Sulphur isotopes. The sulphur-isotope ratio $\delta^{34}S$ is calculated in the same way as $\delta^{13}C$, as described in X3. The predominant stable sulphur isotope is sulphur-32 (95.1%) Sulphur-34 is much rarer (4.2%). The ratio $\delta^{34}S$ has geological significance because it displays several excursions in marine sulphates, as found in some evaporite deposits. Such excursions probably denote catastrophic events in the history of the oceans and, perhaps, the history of life, too.

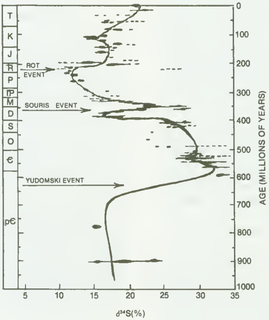
In 1977, W.T. Holser published an overview of oceanic chemical events that focussed on $\delta^{34}S$. We quote the first few sentences of his Abstract: "Catastrophic chemical events are characterised by sharp rises in $\delta^{34}S$ in the surface of the whole world ocean, and by greater overshoots locally. Three events are recognized and named for the formation in which they are most sharply displayed. The sharpness of the rise in $\delta^{34}S$ suggests that the sulphide deposition necessary to explain it must have been accumulating residual high-$\delta^{34}S$ seawater for some tens of millions of years out of contact with the surface ocean." Holser next detailed the three events. (R5)

Upper Precambrian-Lower Cambrian. The Yudomski event, represented by a sharp positive swing from 15 to 35% in $\delta^{34}S$.

Upper Devonian. The Souris event. A sharp peak at 35%, which followed a broad minimum of about 15% in the Lower Devonian.

Lower Triassic. The Rot event, which consisted of a sharp excursion from about 12 to 25%. (R5)

S.C. Morris speculated about the nature of $\delta^{34}S$ events in a 1987 number of American Scientist: "Values of $\delta^{34}S$ depend on the balance between bacterially controlled precipitation of sulfides (pyrite) in anoxic sediments, increasing $\delta^{34}S$ in the overlying seawater, and oxidation of sulfides elsewhere. The Yudomski event must in some way reflect sulfide accumulation. While its duration is rather uncertain, the time available indicates that rates of accumulation would have to be impossibly rapid to generate the $\delta^{34}S$ excursion during the event's actual



Curve showing the best estimate for δ S^{34} in equilibrium with the oceans' surfaces. Catastrophic chemical changes are indicated by the named events. (X6) interval. Thus, the isotope anomalies in evaporites deposited close to the (K-T) boundary record only the end result of a more protracted process." (R110)

Recognizing the constraints suggested by Morris, models constructed to explain the three large $\delta^{34}S$ events usually invoke the accumulation of large quantities of brine in isolated marine basins (perhaps like the Mediterranean Basin has been at times). The sudden surges in $\delta^{34}S$ are thought to have been initiated when geological events (continental drift?) allowed these brine reservoirs to mix with the main oceans.

A further note: the three primary $\delta^{34}S$ events took place during times of mass extinctions. Yet, the released brines probably carried substantial nutrients as well as phosphorus that would eventually enhance biological productivity.

The strong, sharp $\delta^{34}S$ spikes must be considered anomalous until we have more than speculations about their origins. (WRC)

X7. Lead-210. Lead-210 is a radioisotope with a half life of about 20 years. It exists in the earth's atmosphere as a product of the decay of radon. Some of the lead-210 falls out in Antarctica along with snow. By taking samples from the snow and firn (snow in the process of being changed to glacier ice), one can construct a history of this radioisotope's deposition. The lead-210 record, however, possesses anomalies.

"Abstract. The ^{210}Pb concentration has been measured in 92 adjacent firn samples collected at the South Pole along a 18 m depth profile. The decay analysis shows that significant changes happened around 1920 and and 1954 either in the accumulation rate or in the ^{210}Pb content of the new fallen snow." (R6) The nature of these events is unknown.

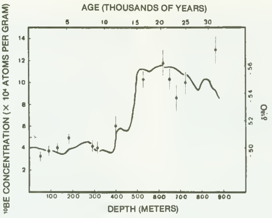
X8. NO_3^-. "Rood et al. have discovered four prominent 'spikes' in a long time record (circa 1150 to the present) of the NO_3^- concentration inside an Antarctic ice core. These four spikes rise 2-3 times higher than the upper envelope of a fluctuating background level of 0-20 $\mu g l^{-1}$ that has been plausibly attributed to the action of high-energy solar radiation (photons and particles) impinging on the Earth's upper atmosphere and ionizing N_2, thereby leading to various chains of chemical reactions that culminate in the formation of NO_3^-, some of which is transported within a few weeks or months, to Antarctica." The dates of the largest maxima are: 1130-1160, 1300-1340, 1590-1600, and 1610-1620. One theory is that these spikes were created not by solar radiation but rather by galactic supernovas. Three suspect supernovas occurred in 1604, 1572, and 1181. However, R. Stothers maintains that the total energy requirements for the creation of the NO_3^- spikes are very difficult to meet for distant supernovas. Further, the dates of the recognized supernovas do not coincide with the spikes precisely. Stothers suggests instead that the necessary ionizing radiation came from unusually powerful solar flares. (R14; R13; R136) Obviously we do not have a uniformity of opinion as to the origin of the NO_3^- spikes, and we must consider them mildly anomalous. (WRC)

To further complicate matters, a Danish group has not been able to confirm the presence of the NO_3^- spikes in Arctic ice cores. Annual variations in the level of NO_3^- are obvious, but there seem to be no excursions around the four dates specified for the Antarctic ice cores. (R38)

X9. Beryllium-10. Beryllium-10 is a component of cosmic radiation. Antarctic ice cores preserve a depositional record of the influx of this isotope. The concentration of beryllium-10 in ice cores is a function of several factors: (1) the annual amount of snowfall; (2) the global atmospheric circulation patterns that carry beryllium-10 to the Antarctic troposphere; (3) the level of solar activity, which modulates the cosmic-ray flux; and (4) the strength of the geomagnetic field.

G. M. Raisbeck et al reported in 1981 their analysis of an Antarctic ice core acquired at Dome C. Here is an excerpt from their Abstract; "We report here the first significant measurements in our programme to determine the ^{10}Be concentration profile over the entire length of a 906-m Antarctic ice core. The results suggest an increased production of ^{10}Be during the Maunder minimum, a period of apparently low solar activity lasting from 1645 to 1715. More surprisingly, we have also found a substantially increased ^{10}Be concentration in snow deposited during the last ice age." (R30)

Since the Maunder minimum was apparently



Beryllium-10 concentrations (data points) and δ O^{18} data (solid line) for an Antarctic ice core from Dome C. (X9)

a time of reduced solar activity, the increase in beryllium-10 has been attributed to the weakening of the solar wind and its modulation of the cosmic-ray flux. On the other hand, the increased beryllium-10 concentration during the Ice Ages is probably the result of reduced precipitation. (R30)

Later, in 1987, Raisbeck et al presented additional beryllium-10 data from Dome C and also from Vostok ice cores. These data confirmed the facts of increased beryllium-10 concentrations during the Maunder minimum and Ice Ages, but they also introduced two previously undetected anomalies: "In the Vostok profile there was one sample, corresponding to ~60,000 yr BP, which gave an unusually large ^{10}Be concentration, not correlated with any obvious climatic event. We suggested that this sample might be reflecting increased ^{10}Be production, as for example during a period of reduced solar modulation. We have now measured a much more detailed concentration profile for ^{10}Be in the Vostok core. The results confirm a ^{10}Be 'peak', lasting ~1,000-2,000 years, at ~60,000 yr BP, and show another similar peak at ~35,000 yr BP. We have also observed the latter peak in the Dome C core." (R124) If these excursions were due to reduced solar activity, we have no explanation for sudden reductions in solar activity.

X10. Carbonate ($CaCO_3$). Since marine organisms use the bicarbonate ions in seawater to construct their chalky shells, the carbonate content of deep-sea sediments can reveal much about what has transpired in the oceans across geological time. It is the carbon and oxygen in this marine carbonate that are employed in measuring δ^{13}C and δ^{18}O anomalies. (X3 and X5)

Cretaceous-Tertiary boundary. Analysis of a sediment core retrieved from the ocean floor off the west coast of southern Africa, by. K.J. Hsu et al, displayed two carbonate anomalies in the vicinity of the K-T boundary. A report in the New Scientist summarized the situation succinctly: "There were also anomalies in the amount of calcium carbonate---chalk---in the core. Below the CT boundary there is the usual 40 per cent chalk, and well above it the level is again 40 per cent. But between these points there are two distinct minima, one in the clay boundary itself and one about 2.5 meters above the boundary." (R44; R42) Changes in carbonate percentage can mean either a change in carbonate production by organisms or a change in the deposition rates of other kinds of sediments. The existence of two carbonate excursions in the vicinity of the boundary certainly point to a complex event, as do many of the other geochemical indicators. (WRC)

Pleistocene. Cores of recent deep-sea sediments show very striking correlations of maxima and minima in the following four parameters: (1) carbonate percentage; (2) δ^{18}O; (3) sediment natural remanent magnetism or NRM; and (4) magnetic susceptibility. However, the authors of the referenced study (R34) point out that their results do not really support a causal connection between the earth's magnetic field and climatic conditions. For example, the decreased carbonate contents of sediments during glacial periods result in increased concentrations of magnetic materials, which in turn contribute to higher NRM intensities. (R34) In reality, these correlations do not seem anomalous, since explanations come readily. Although any demonstrable causal link between geomagnetism and climate would represent a marked modification in current thinking. (WRC)

X11. Methane. The gas bubbles trapped in ice cores contain a bit of methane. The source of atmospheric methane is primarily biogenetic, with additional quantities coming from volcanos and other abiogenetic sources. It would be helpful in assessing the composition of the earth's atmosphere over the past few thousand years, if we could be sure that the methane in these bubbles had not changed. Unfortunately, we cannot be sure, because the ice may contain methane-consuming bacteria. What scientists do know is that the methane level in bubbles trapped only a few hundred years ago is only half that in today's atmosphere. The level began increasing about 400 years ago. Naturally, human activities are suspected. (R36, R138)

Later measurements of ice cores from both Greenland and Antarctica confirm these dramatic changes in methane levels in the atmosphere. During the last glaciation, the methane level was only 350 parts per 10^9 by volume; the mean pre-industrial level was about 650; today's value is put at 1,650. (R151, R159) The cause of the pre-industrial increase is not obvious. One thought is that rising temperatures enhanced the activities of bacteria in fresh-water wetlands. (R155) See also ESC16.

X12. Oxides. The presence of oxygen in ancient rocks, in the form of oxides, tells us that perhaps the earth's primordial atmosphere was not devoid of oxygen, as many scientists have maintained.

Precambrian. J. S. Levine has commented as follows about the evolution of the earth's primordial atmosphere: "In the case of our calculated oxygen levels, one bit of evidence from the early geological record supports our conclusion. It is puzzling, but geologists know from their analyses of the oldest known rocks that the oxygen level of the early atmosphere had to be much higher than previously calculated. Analyses of these rocks, estimated to be more than 3.5 billion years old, found oxidized iron in amounts that called for atmospheric oxygen to be at least 110 times greater and perhaps up to one billion times greater than otherwise accepted." (R43) See ESC9-X20.

X13. Gold. Gold spikes in the stratigraphic record usually parallel those of iridium (X1), osmium (X2), and other noble metals. All of these siderophile elements are present in the spikes in cosmic abundances; that is, the same abundances we find in meteoric matter.

Cretaceous-Tertiary boundary. A number of the studies cited in X1 present data for gold as well as iridium. By way of illustration, the iridium and gold abundances, as plotted by M. Kastner et al, for the Stevns Klint, Denmark, site, show striking similarities. (R54)

On the other hand, at some K-T sites the profiles are not identical, as described by F. T. Kyte and J. T. Wasson: "Recent analyses of 2 KT boundaries suggest that the ETC (Extraterrestrial Component) may be much greater than 20%. These locations, Caravaca, Spain and DSDP Hole 465A from the central North Pacific both contain similar thin (~2 mm-thick) basal layers. The Ir concentrations in these basal layers are 40 and 15 ng g^{-1}, yielding ETC's of 7 and 3%, respectively. However, in both of these locations, the siderophiles Au, Co, Ni, and Cr are strongly concentrated in the basal layers whereas the Ir is largely outside this layer. In 465A, Ir has even been measured (~1.5 ng g^{-1}) in sediments a few mm below the basal layer and increases in concentration upwards through the first cm. A reasonable interpretation for this observation is that the Ir has somehow mobilized and diffused through pore waters in both of these sections and the basal layer concentrations are not representative of the original compositions." (R47) Of course, opponents of the asteroid/comet impact theory think that this smearing out of the iridium spike weakens the thesis. In general, though, the presence of these siderophile elements in cosmic abundances over a wide variety of K-T boundary sites constitutes good evidence in favor of the asteroid/comet hypothesis. (WRC)

X14. Anoxic intervals. Localized anoxic intervals, usually recognized by the presence of carbon-rich black shales, are not uncommon in geology. The lack of oxygen seems to indicate biologically traumatic conditions. On a very small scale, such anoxic intervals are not surprising, but when spread over very large areas of the earth, we have a geochemical event worth cataloging.

Mid-Cretaceous. Recently, in 1984, P. C. de Graciansky et al described an extremely widespread anoxic interval, which they called the Cenomanian-Turonian Black Shale Horizon (CTBSH): "The occurrence of laminated carbonaceous shales with marine organic matter in an unoxidized state implies deposition and early diagenesis in anaerobic environments. The stratigraphic record above and below the CTBSH in environments as different as the deep North Atlantic Ocean and marginal and epicontinental seas over enormous areas in North America, North Africa and northwestern Europe is characterised by a stratigraphic gap, a disconformity or a continuous but strongly condensed stratigraphic section." This anoxic layer coincided timewise with the maximum extension of a marine transgression. As the authors say, there is no easy explanation for the occurrence of this interval over such wide ranges of depth and environmental conditions. (R58)

X15. Carbon dioxide. Carbon dioxide is present in today's atmosphere at a level of about 350 parts per million. It is also present in air bubbles trapped in polar ice in varying quantities that reveal much about past climates. Carbon dioxide, being a "greenhouse" gas, is usually directly related to the earth's temperature.

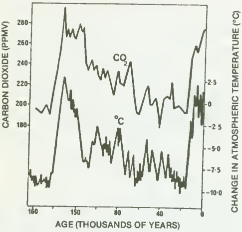
Cretaceous-Tertiary boundary. Before becoming involved with the ice-core carbon dioxide measurements, let us pause again at the K-T boundary. R. M. Macintyre has speculated that a strong carbon dioxide spike probably occurred at this time (65 million years ago), drastically affecting the climate and biosphere. The evidence for Macintyre's supposition lies in the large number of carbonatites found around the world which are dated at 65 million years. Carbon dioxide derived from these carbonatites could have created a carbon dioxide spike. (R75)

Another possible source of extra carbon dioxide in the vicinity of the K-T boundary is the degassing of the Deccan Traps, in India. Approximately coincident with the K-T boundary event, a great flood of basaltic lava covered some 2.6 million square kilometers of India. Carbon dioxide released from the lava probably elevated the rate of mantle CO_2 release by 10-25%. (R144)

Pleistocene. In a 1984 review of ice-core data P. Campbell described how early surprises were subsequently explained: "A year or two ago, ice cores yielded the surprising result that at the end of the ice age, between 15,000 and 10,000 yr ago, the atmospheric CO_2 abundance climbed from about 210 to 280 parts per million by volume (p.p.m.v.) in only a few thousand years. W. S. Broecker pointed out that over time scales shorter than the 180,000-yr residence time of CO_2 in the atmosphere and oceans, atmospheric CO_2 is controlled by the physical, biological and chemical state of the oceans. Thus such a 'rapid' increase of 70 p.p.m.v. would seem to have required an unusual perturbation to this system." To explain this, Broecker suggested that debris from surface organisms containing organic carbon and phosphate was deposited on the continental shelves as they were being submerged by water from the melting ice sheets. The submergence reduced the phosphate/carbon ratio in the oceans and, since phosphate was the limiting nutrient, the rate at which carbon was fixed by marine photosynthesis was reduced. Hence, the CO_2 in the ocean would have increased, as would that in the atmosphere. (R65)

Campbell's article continues with a description of carbon-dioxide anomalies found in the so-called Dye 3 ice core extracted from Greenland ice, as presented by B. Stauffer et al: "Four sharp peaks in CO_2, reaching levels of 250 p.p.m.v. from a 'background' of 200 p.p.m.v., occurred during the last ice age (see the figure). The magnitude of the changes are of the order which the phosphate-extraction model seeks to explain, but the excursions appear to have occurred within a hundred years or so---ten times faster than can possibly be explained by shelf deposition. The excursions are well correlated with oxygen isotope changes, as are accompanying variations in trace chemicals Cl, NO_3^-, and SO_4^{2-}."

Recent. We quote here a paragraph from R. Fifield's review of a workshop sponsored by the Dahlem Konferenzen in March 1988: "Ulrich Siegenthaler of the University of Bern startled the Dahlem scientists by revealing measurements on an ice core from Antarctica showing that the concentration of carbon dioxide between AD 1200 and 1300 increased dramatically by 10 parts per million.



Vostok ice-core data from Antarctica, showing CO_2 concentration and temperature versus age. (X15)

This was, of course, long before any major industrialisation. Could a natural disaster have vented carbon dioxide into the atmosphere setting up a climatic 'cloche', if not a complete greenhouse?" (R134) Under GWD1, we have cataloged three instances of dark days and/or solar obscurations during the period 1206-1241. (WRC)

X16. Calcite dissolution.

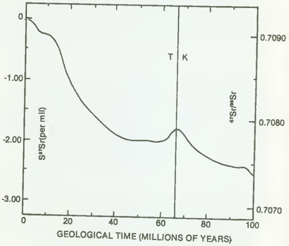
Cretaceous-Tertiary boundary. "Evidence from Cretaceous-Tertiary boundary sequences in Denmark and elsewhere suggests that no single catastrophe can account for the major biotic extinctions that occurred at the end of the Cretaceous Period. The primary causal factors of the terminal Cretaceous extinction event appear to be drastic global sea-level regression occurring simultaneously with extensive volcanism on land and a strong pulse of calcite dissolution in ocean surface waters." (R67)

X17. Amino acids. Some of the amino acids found in carbonaceous meteorites and possibly comets are extremely rare on earth. If they were found at the K-T boundary, or any other geological boundary, we would have good evidence that an impact was involved.

Cretaceous-Tertiary boundary. J. L. Bada and N. C. Lee have been searching for extraterrestrial amino acids in deep-sea samples. "So far, the researchers have tested for alpha-amino isobutyric acid (AIBA) and have indeed discovered evidence for it in a K-T deep-sea sample. Unfortunately, this sample appears to have been contaminated by terrestrial organic matter, so it is premature to say that it clearly contains AIBA, observes Bada." (R91)

X18. Strontium isotopes. The ratio of strontium-87 to strontium-86, as it has changed with geological time, can be determined for seawater by analyzing the foraminifera found in deep-sea cores. The origin of $^{87}Sr/^{86}Sr$ excursions is still controversial, as the following excerpts will demonstrate.

Cretaceous-Tertiary boundary. "The strontium isotope ratio ($^{87}Sr/^{86}Sr$) in seawater increased from the late Cretaceous to the Recent in a regular way, but with a major interruption at the end of the Cretaceous, signified by a small but distinctive sharp rise followed by an equally sharp restoration to the original level. By far the likeliest reason for the increase in the ratio in the Cenozoic is the correlative fall of sea level, thereby increasing continental area and runoff. Applying the same reasoning to the end-Cretaceous event leads to the inference of a sealevel fall of a magnitude greater than for many millions of years previously, followed by a rapid rise to the earlier level." (R119) The major



Strontium isotope changes in seawater from the mid-Cretaceous to the present. (X18) source of strontium in seawater is continental runoff. Theories explaining the strontium-ratio spike usually depend upon somehow increasing continental weathering. (WRC)

J. D. Macdougall has a different interpretation from that of A. Hallam (above): A large bolide impact at the end of the Cretaceous, in Macdougall's view, would have produced large quantities of nitrogen oxides, which would have led to an episode of strong acid rain. The acid rain would have greatly increased continental weathering and, thus, the runoff of strontium-containing waters into the oceans. (R133; R129)

X19. Rhodium. This element is another siderophile, like iridium, osmium, etc.; and sharp increases in its abundance are generally thought to indicate asteroid/comet impacts.

Cretaceous-Tertiary boundary. A group of Soviet scientists, headed by G.I. Bekov, has reported the discovery of a rhodium spike at the K-T boundary: "Here we present the first data on rhodium concentrations at the K-T boundary in the Sumbar-SM-4 section (Turkmen SSR) obtained by the ultrasensitive laser photoionization spectroscopy (LAPIS) technique. The maximum Rh concentration in the samples studied is 24.2 ng g^{-1}. The Rh/Ir ratio is 0.34 ± 0.06, which is close to the cosmic ratio of these elements." The plots of iridium and rhodium concentrations provided are very similar, both showing the typical sharp spikes at the K-T boundary. (R130)

X20. Helium isotopes. Helium possesses two stable isotopes, helium-3 and helium-4. In the earth, helium-4 is continually created through the alpha-decay of heavy elements, such as uranium; but there are no consequential sources of helium-3. Essentially all helium-3 found in terrestrial minerals and gases is believed to be primordial; that is, an original constituent of the material that formed the earth. The normal value of the $^3He/^4He$ ratio is a very low 1.4×10^{-6}. An enhancement of this value may signify the influx of extraterrestrial material.

Marine ferromanganese nodules. Y. Sano et al have measured the helium-isotope ratios of ten sea-floor manganese nodules. "The observed $^3He/^4He$ ratios are extraordinarily high, with values up to 59.3×10^{-6}. Considering that the direct supply of materials from the deep mantle is an insignificant factor in the area studied, the negligible contribution of ragiogenic ^3He, and the improbability of artificial nuclear fallout debris, the most likely explanation appears to be conglomeration of extraterrestrial matter." (R145)

References

R1. Oehler, Dorothy Z., and Schopf, J. William; "Carbon Isotopic Studies of Organic Matter in the Oldest Known Sedimentary Rocks," American Journal of Botany, 58:471, 1971. (X3)
R2. Veeh, H. Herbert, and Bostrom, Kurt; "Anomalous $^{234}U/^{238}U$ on the East Pacific Rise," Earth and Planetary Sciences Letters, 10:372, 1971. (X4)
R3. Oehler, Dorothy Z., et al; "Carbon Isotopic Studies of Organic Matter in Precambrian Rocks," Science, 175:1246, 1972. (X3)
R4. De Giovani, Wagner Ferraresi, et al; "Unusual Isotopic Composition of Carbonates from the Irati Formation, Brazil," Geological Society of America, Bulletin, 85:41, 1974. (X3, X5)
R5. Holser, William T.; "Catastrophic Chemical Events in the History of the Ocean," Nature, 267:403, 1977. (X6)
R6. Sanak, J., and Lambert, G.; "Lead 210 or Climate Changes at South Pole?" Geophysical Research Letters, 4:357, 1977. (X7)
R7. "Dinosaur Demise: Extraterrestrial Source?" Science News, 115:356, 1979. (X1)
R8. "An Iridium Clue to the Dinosaur's Demise," New Scientist, 82:798, 1979. (X1)
R9. Hallam, A.; "The End of the Cretaceous," Nature, 281:430, 1979. (X5)
R10. Rampino, Michael R.; "Possible Relationships between Changes in Global Ice Volume, Geomagnetic Excursions, and the Eccentricity of the Earth's Orbit," Geology, 7:584, 1979. (X3, X5)
R11. O'Keefe, John D.; "Impact Mechanics of the Cretaceous-Tertiary Extinction Bolide," Eos, 61:1021, 1980. (X1, X2)
R12. "Now---Asteroid-Caused Extinctions," Science News, 117:22, 1980. (X1)
R13. Ruderman, M., and Truran, J. W.; "Possible Transfer of Lunar Matter to Earth Due to a Nearby Supernova," Nature, 284:328, 1980. (X1, X8)
R14. Stothers, Richard; "Giant Solar Flares in Antarctic Ice;" Nature, 287:365, 1980. (X8)

R15. Kyte, Frank T., et al; "Siderophile-Enriched Sediments from the Cretaceous-Tertiary Boundary," Nature, 288:651, 1980. (X1)
R16. Garmon, Linda; "The Empyrean Strikes Back," Science News, 117:381, 1980. (X1)
R17. Alvarez, Luis W., et al; "Extraterrestrial Cause for the Cretaceous-Tertiary Extinction," Science, 208:1095, 1980. (X1)
R18. Smit, J., and Hertogen, J.; "An Extraterrestrial Event at the Cretaceous-Tertiary Boundary," Nature, 285:198, 1980. (X1, X2)
R19. Hsu, Kenneth J.; "Terrestrial Catastrophe Caused by Cometary Impact at the End of the Cretaceous," Nature, 285:201, 1980. (X1, X3)
R20. Ganapathy, R.; "A Major Meteorite Impact on the Earth 65 Million Years Ago: Evidence from the Cretaceous-Tertiary Boundary Clay," Science, 209:921, 1980. (X1, X2)
R21. Kerr, Richard A.; "Asteroid Theory of Extinctions Strengthened," Science, 210: 514, 1980. (X1)
R22. Surlyk, Finn; "The Cretaceous-Tertiary Boundary Event," Nature, 285:187, 1980. (X1)
R23. Kent, Dennis V., et al; "Asteroid Extinction Hypothesis," Science, 211:648, 1981. (X1)
R24. Kyte, Frank T., et al; "High Noble Metal Concentrations in a Late Pliocene Sediment," Nature, 292:417, 1981. (X1, X13)
R25. "Nonmarine Iridium Anomaly Linked to Extinctions," Science, 212:1376, 1981. (X1)
R26. Orth, Charles J., et al; "An Iridium Abundance Anomaly at the Palynological Cretaceous-Tertiary Boundary in Northern New Mexico," Science, 214:1341, 1981. (X1)
R27. Fisher, Arthur; "The World's Great Dyings," Mosaic, 12:2, March/April 1981. (X1)
R28. Ganapathy, R., et al; "Iridium Anomaly at the Cretaceous-Tertiary Boundary in Texas," Earth and Planetary Science Letters, 54:393, 1981. (X1)
R29. Emiliani, Cesare, et al; "Sudden Death at the End of the Mesozoic," Earth and Planetary Science Letters, 55:317, 1981. (X1)
R30. Raisbeck, G. M., et al; "Cosmogenic ^{10}Be Concentrations in Antarctic Ice during the Past 30,000 Years," Nature, 292:825, 1981. (X9)
R31. Dansgaard, W., et al; "A New Greenland Deep Ice Core," Science, 218:1273, 1982. (X5)
R32. Long, Austin; "100 to 200 Year Solar Periodicities," Nature, 298:223, 1982. (X3)
R33. Towe, Kenneth M.; "Anomalous ^{13}C Depletion in Precambrian Organic Carbon," Nature, 295:171, 1982. (X3)
R34. Kent, D. V.; "Apparent Correlation of Palaeomagnetic Intensity and Climatic Records in Deep-Sea Sediments," Nature, 299:538, 1982. (X10)
R35. "Dinosaur Extinction Due to Asteroid?" Physics Today, 35:19, May 1982. (X1)
R36. "Record of Methane Rise Frozen in Polar Ice," Science News, 122:375, 1982. (X11)
R37. Russell, Dale A.; "The Mass Extinctions of the Late Mesozoic," Scientific American, 246:58, January 1982. (X1)
R38. "Puzzle of Nitrate in Arctic Ice," New Scientist, 93:156, 1982. (X8)
R39. Kerr, Richard A.; "Extinctions: Iridium and Who Went When," Science, 215:389, 1982. (X1)
R40. Ganapathy, R.; "Evidence for a Major Meteorite Impact on the Earth 34 Million Years Ago: Implication for Eocene Extinctions," Science, 216:885, 1982. (X1)
R41. Alvarez, Walter, et al; "Iridium Anomaly Approximately Synchronous with Terminal Eocene Extinctions," Science, 216: 886, 1982. (X1)
R42. Hsu, Kenneth J., et al; "Mass Mortality and Its Environmental and Evolutionary Consequences," Science, 216:249, 1982. (X1, X3, X5, X10)
R43. "New Evidence on Evolution of Early Atmosphere and Life," American Meteorological Society, Bulletin, 63:1328, 1982. (X5, X12)
R44. "Extraterrestrial Body Hits Earth---Millions Die," New Scientist, 94:210, 1982. (X1, X3, X5, X10)
R45. O'Keefe, John D., and Ahrens, Thomas J.; "Impact Mechanics of the Cretaceous-Tertiary Extinction Bolide," Nature, 298: 123, 1982. (X1, X2)
R46. Rampino, Michael R., and Reynolds, Robert C.; "Clay Mineralogy of the Cretaceous-Tertiary Boundary Clay," Science, 219:495, 1983. (X1)
R47. Kyte, Frank T., and Wasson, John T.; "On the Nature of the Materials Accreted at the End of the Cretaceous," Meteoritics, 18:332, 1983. (X1, X13)
R48. "Osmium Ratios Boost Impact Hypothesis," Science News, 124:329, 1983. (X1, X2)
R49. Jastrow, Robert; "The Dinosaur Massacre: A Double-Barreled Mystery," Science Digest, 91:51, September 1983. (X1)

R50. Officer, Charles B., and Drake, Charles L.; "The Cretaceous-Tertiary Transition," Science, 219:1383, 1983. (X1)
R51. Sandberg, Philip A.; "An Oscillating Trend in Phanerozoic Non-Skeletal Carbonate Mineralogy," Nature, 305:19, 1983. (X10)
R52. Kerr, Richard A.; "An Early Glacial Two-Step?" Science, 221:143, 1983. (X5)
R53. Tschudy, R.H., et al; "Disruption of the Terrestrial Plant Ecosystem at the Cretaceous-Tertiary Boundary, Western Interior," Science, 225:1030, 1984. (X1)
R54. Kastner, M., et al; "The Precursor of the Cretaceous-Tertiary Boundary Clays at Stevns Klint, Denmark, and DSDP Hole 465A," Science, 226:137, 1984. (X1, X13)
R55. Gilmore, J.S., et al; "Trace Element Patterns at a Non-Marine Cretaceous-Tertiary Boundary, Nature, 307:224, 1984. (X1)
R56. Orth, Charles J., et al; "A Search for Iridium Abundance Anomalies at Two Late Cambrian Biomere Boundaries in Western Utah," Science, 223:163, 1984. (X1)
R57. Alvarez, W., et al; "The End of the Cretaceous: Sharp Boundary or Gradual Transition?" Science, 223:1183, 1984. (X1)
R58. de Graciansky, P.C., et al; "Ocean-Wide Stagnation Episode in the Late Cretaceous," Nature, 308:346, 1984. (X14)
R59. Brooks, Robert R., et al; "Elemental Anomalies at the Cretaceous-Tertiary Boundary, Woodside Creek, New Zealand," Science, 226:539, 1984. (X1)
R60. Hallam, Tony; "Asteroids---and Extinction---No Cause for Concern," New Scientist, p. 30, November 8, 1984. (X1)
R61. Grieve, Richard A. F.; "Physical Evidence of Impact," Nature, 310:370, 1984. (X1)
R62. Playford, Phillip E., et al; "Iridium Anomaly in the Upper Devonian of the Canning Basin, Western Australia," Science, 226:437, 1984. (X1, X3)
R63. Davis, Marc, et al; "Extinction of Species by Periodic Comet Showers," Nature, 208:715, 1984. (X1)
R64. McGhee, George R., Jr., et al; "No Geochemical Evidence for an Asteroidal Impact at Late Devonian Mass Extinction Horizon," Nature, 308:629, 1984. (X1)
R65. Campbell, Philip; "New Data Upset Ice Age Theories," Nature, 307:688, 1984. (X15)
R66. Simon, C.; "Abundant Ir Marks a Third Boundary," Science News, 125: 213, 1984. (X1)
R67. Ekdale, A.A., and Bromley, Richard G.; "Sedimentology and Ichnology of the Cretaceous-Tertiary Boundary in Denmark: Implications for the Causes of the Terminal Cretaceous Extinction," Journal of Sedimentary Petrology, 54:681, 1984. (X1, X16)
R68. Kyte, Frank T.; "Iridium Sedimentation in the Cenozoic: No Evidence for a Death Star," Meteoritics, 19:257, 1984. (X1)
R69. Fenner, F.D., and Presley, B.J.; "Iridium in Mississippi River Suspended Matter and Gulf of Mexico Sediment," Nature, 312:260, 1984. (X1)
R70. Bohor, B.F., et al; "Mineralogic Evidence for an Impact Event at the Cretaceous-Tertiary Boundary," Science, 224:867, 1984. (X1)
R71. Simon, C.; "New Findings Establish Impact Occurred," Science News, 125: 197, 1984. (X1)
R72. Kerr, Richard A.; "An Impact But No Volcano," Science, 224:858, 1984. (X1)
R73. Oard, Michael J.; "Ice Ages: The Mystery Solved? Part II. The Manipulation of Deep-Sea Cores," Creation Research Society Quarterly, 21:125, 1984. (X5)
R74. Arthur, Michael A.; "Carbon Isotope Anomalies," Nature, 310:450, 1984. (X3, X6)
R75. Macintyre, R.M.; "The Cosmic Connection of Catastrophism?" Nature, 318: 606, 1985. (X15)
R76. Sanfilippo, Annika, et al; "Late Eocene Microtektites and Radiolarian Extinctions on Barbados," Nature, 314:614, 1985. (X1)
R77. Grieve, Richard A. F.; "Siderophile-Enriched Sediments and Meteoritic Debris," Nature, 318:411, 1985. (X1)
R78. Weisburd, S.; "Could Dinosaurs Have Survived Asteroid?" Science News, 128: 151, 1985. (X1)
R79. Smit, Jan, et al; "Cretaceous-Tertiary Extinction: Alternative Models," Science, 230:1292, 1985. (X1)
R80. Kyte, Frank T.; "Physical Evidence Indicates a Major Impact at the Cretaceous-Tertiary Boundary," Eos, 66:813, 1985. (X1)
R81. Hut, Piet, et al; "Comet Showers as Possible Causes of Stepwise Mass Extinctions," Eos, 66:813, 1985. (X1)
R82. Officer, Charles B., et al; "Volcanism and Cretaceous/Tertiary Extinctions," Eos, 66:813, 1985. (X1)
R83. Van Valen, Leigh M.; "Iridium, Impacts and Para-Volcanism," Nature, 316: 396, 1985. (X1)
R84. Hsu, Kenneth J., et al; "'Strangelove Ocean' before the Cambrian Explosion," Nature, 316:809, 1985. (X1, X3, X5)
R85. McLaren, Digby J.; "Mass Extinction

and Iridium Anomaly in the Upper Devonian of Western Australia: A Commentary," Geology, 13:170, 1985. (X1)
R86. Officer, Charles B., and Drake, Charles L.; "Terminal Cretaceous Environmental Events," Science, 227:1161, 1985. (X1, X2)
R87. Kerr, Richard A.; "Periodic Extinctions and Impacts Challenged," Science, 227: 1451, 1985. (X1)
R88. Goldsmith, Donald; "The Birth of the Impact Theory," Nemesis, New York, 1985, p. 15. (X1)
R89. Bray, A.A.; "Will Impacts Become Extinct?" Modern Geology, 9:397, 1985. (X1)
R90. Weisburd, Stefi; "Volcanos and Extinctions: Erupting of the Impact Idea?" Science News, 127:172, 1985. (X1)
R91. Weisburd, Stefi; "Search for Impact Clues: Amino Acids and Shocked Mineral Grains," Science News, 128:300, 1985. (X17)
R92. Gribbin, John; "New Statistics Tie Climate Theories Together," New Scientist, p. 20, February 7, 1985. (X5)
R93. Weisburd, Stefi; "Iridium Spike Not a Comet Strike?" Science News, 130:361, 1986. (X1)
R94. Muller, Richard A., et al; "Comet Showers, Periodic Extinctions, and Iridium," Science, 234:1484, 1986. (X1)
R95. Kyte, Frank T., and Wasson, John T.; "Accretion Rate of Extraterrestrial Matter: Iridium Deposited 33 to 67 Million Years Ago," Science, 232:1225, 1986. (X1)
R96. Nichols, D.J., et al; "Palynological and Iridium Anomalies at Cretaceous-Tertiary Boundary, South-Central Saskatchewan," Science, 231:714, 1986. (X1)
R97. Awramik, Stanley M., et al; "The Precambrian-Cambrian Boundary and Geochemical Perturbations," Nature, 319: 696, 1986. (X1, X3)
R98. Weisburd, Stefi; "Extinction Wars," Science News, 129:75, 1986. (X1)
R99. Clark, David L., et al; "Conodont Survival and Low Iridium Abundances across the Permian-Triassic Boundary in South China," Science, 233:984, 1986. (X1)
R100. Rocchia, Robert, et al; "An Iridium Anomaly in the Middle-Lower Jurassic of the Venetian Region, Northern Italy," Journal of Geophysical Research, 91:E259, 1986. (X1)
R101. Sloan, Robert E., et al; "Gradual Dinosaur Extinction and Simultaneous Ungulate Radiation in the Hell Creek Formation," Science, 232:629, 1986. (X1)
R102. Alvarez, Walter; "Toward a Theory of Impact Crises," Eos, 67:649, 1986. (X1)
R103. Wilde, Pat, et al; "Iridium Abundances across the Ordovician-Silurian Stratotype," Science, 233:339, 1986. (X1)
R104. Brooks, Robert R., et al; "Stratigraphic Occurrences of Iridium Anomalies at Four Cretaceous/Tertiary Boundary Sites in New Zealand," Geology, 14:727, 1986. (X1)
R105. Preisinger, A., et al; "The Cretaceous/Tertiary Boundary in the Gosau Basin, Austria," Nature, 322:794, 1986. (X1)
R106. Labeyrie, L.D., et al; "Melting History of Antarctica during the Past 60,000 Years," Nature, 322:701, 1986. (X5)
R107. Magaritz, Mordeckai, et al; "Carbon-Isotope Events across the Precambrian/Cambrian Boundary on the Siberian Platform," Nature, 320:258, 1986. (X3)
R108. Knoll, A.H., et al; "Secular Variation in Carbon Isotope Ratios from Upper Proterozoic Successions of Svalbard and East Greenland," Nature, 321:832, 1986. (X3)
R109. Tucker, Maurice E.; "Carbon Isotope Excursions in Precambrian/Cambrian Boundary Beds, Morocco," Nature, 319: 48, 1986. (X3, X6)
R110. Morris, Simon Conway; "The Search for the Precambrian-Cambrian Boundary," American Scientist, 75:157, 1987. (X1, X3, X6)
R111. Officer, Charles B., et al; "Late Cretaceous and Paroxysmal Cretaceous/Tertiary Extinctions," Nature, 326:143, 1987. (X1)
R112. "A Big Splash in the Pacific," Sky and Telescope, 74:12, 1987. (X1)
R113. "New Evidence Unearthed at Tunguska Site," Sky and Telescope, 74:459, 1987. (X1)
R114. Donovan, Stephen K.; "Iridium Anomalous No Longer?" Nature, 326:331, 1987. (X1)
R115. Courtillot, Vincent E., and Cisowski, Stanley; "The Cretaceous-Tertiary Boundary Events: External or Internal Causes?" Eos, 68:193, 1987. (X1, X3)
R116. Shaw, Herbert R.; "The Periodic Structure of the Natural Record, and Nonlinear Dynamics," Eos, 68:1651, 1987. (X1)
R117. McGhee, George R., Jr., et al; "Late Devonian 'Kellwasser Event' Mass Extinction Horizon in Germany: No Geochemical Evidence for a Large-Body Impact," Geology, 14:776, 1987. (X1)
R118. Alvarez, Luis W.; "Mass Extinctions Caused by Large Bolide Impacts," Physics Today, 40:24, July 1987. (X1)
R119. Hallam, Anthony; "End-Cretaceous Mass Extinction Event: Argument for Terrestrial Causation," Science, 238:

1237, 1987. (X1, X2, X3, X18)
R120. Kerr, Richard A.; "Asteroid Impact Gets More Support," Science, 236:666, 1987. (X1)
R121. Weisburd, Stefi; "Volcanoes and Extinctions: Round Two," Science News, 131:248, 1987. (X1)
R122. Lerbekmo, John F., et al; "The Relationship between the Iridium Anomaly and Palynological Floral Events at Three Cretaceous-Tertiary Boundary Localities in Western Canada," Geological Society of America, Bulletin, 99:325, 1987. (X1)
R123. Bohor, Bruce F., et al; "Dinosaurs, Spherules, and the 'Magic' Layer: A New K-T Boundary Clay Site in Wyoming," Geology, 15:896, 1987. (X1)
R124. Raisbeck, G. M., et al; "Evidence for Two Intervals of Enhanced ^{10}Be Deposition in Antarctic Ice during the Last Glacial Period," Nature, 326:273, 1987. (X9)
R125. Jouzel, J., et al; "Vostok Ice Core: A Continuous Isotope Temperature Record over the Last Climatic Cycle (160,000 Years)," Nature, 329:403, 1987. (X5)
R126. Reyss, Jean Louis, et al; "Anomalous $^{234}U/^{238}U$ Ratios in Deep-Sea Hydrothermal Deposits," Nature, 325:798, 1987. (X4)
R127. Hatch, Joseph R., et al; "Possible Late Middle Ordovician Organic Carbon Isotope Excursion: Evidence from Ordovician Oils and Hydrocarbon Source Rocks, Mid-Continent and East-Central United States," American Association of Petroleum Geologists, Bulletin, 71:1342, 1987. (X3)
R128. Kollgaard, Ronald, et al; "Bolide Extinction Theory Makes an Impact," Physics Today, 41:13, January 1988. (X1)
R129. Waldrop, M. Mitchell; "After the Fall," Science, 239:977, 1988. (X18)
R130. Bekov, G.I., et al; "Rhodium Distribution at the Cretaceous/Tertiary Boundary Analysed by Ultrasensitive Laser Photoionization," Nature, 332:146, 1988. (X1, X19)
R131. Rampino, Michael R., and Volk, Tyler; "Mass Extinctions, Atmospheric Sulphur and Climatic Warming at the K/T Boundary," Nature, 332:63, 1988. (X5)
R132. Magaritz, Mordeckai, et al; "The Carbon-Isotope Shift at the Permian/Triassic Boundary in the Southern Alps is Gradual," Nature, 331:337, 1988. (X3)
R133. Macdougall, J.D.; "Seawater Strontium Isotopes, Acid Rain, and the Cretaceous-Tertiary Boundary," Science, 239:485, 1988. (X18)
R134. Fifield, Richard; "Frozen Assets of the Ice Cores," New Scientist, p. 28, April 14, 1988. (X11, X15)
R135. MacAyeal, Douglas Reed; "A Catastrophe Model of the Paleoclimate," Journal of Glaciology," 24:245, 1979. (X5)
R136. Rood, Robert T., et al; "X- or γ-Rays from Supernovae in Glacial Ice," Nature, 282:701, 1979. (X8)
R137. Risbo, T.; "Supernovae and Nitrate in the Greenland Ice Sheet," Nature, 294: 637, 1981. (X8)
R138. Craig, H., and Chou, C.C.; "Methane: The Record in Polar Ice Cores," Geophysical Research Letters, 9:1221, 1982. (X11)
R139. Luck, J.M., and Turekian, K.K.; "Osmium-187/Osmium-186 in Manganese Nodules and the Cretaceous-Tertiary Boundary," Science, 222:613, 1983. (X2)
R140. Magaritz, Mordeckai, et al; "Isotope Shifts in the Late Permian of the Delaware Basin, Texas, Precisely Timed by Varved Sediments," Earth and Planetary Science Letters, 66:111, 1983. (X3)
R141. Shackleton, N.J., et al; "Oxygen and Carbon Isotope Record of East Pacific Core V19-30: Implications for the Formation of Deep Water in the Late Pleistocene North Atlantic," Earth and Planetary Science Letters, 65:233, 1983. (X3, X5)
R142. Zoller, William H., et al; "Iridium Enrichment in Airborne Particles from Kilauea Volcano: January 1983," Science, 222:1118, 1983. (X1)
R143. McGhee, George R., Jr., et al; "No Geochemical Evidence for an Asteroid Impact at Late Devonian Mass Extinction Horizon," Nature, 308:629, 1984. (X1)
R144. McLean, Dewey M.; "Deccan Traps Mantle Degassing in the Terminal Cretaceous Marine Extinctions," Cretaceous Research, 6:235, 1985. (X15)
R145. Sano, Yuji, et al; "$^{3}He/^{4}He$ Ratios of Marine Ferromanganese Nodules," Nature, 317:518, 1985. (X20)
R146. Dao-Yi, Xu, et al; "Abundance Variation of Iridium and Trace Elements at the Permian/Triassic Boundary at Shangsi in China," Nature, 314:154, 1985. (X1)
R147. Holser, William T., et al; "Carbon-Isotope Stratigraphic Correlations in the Late Permian," American Journal of Science, 286:390, 1986. (X3)
R148. Olmez, I., et al; "Iridium Emissions from Kilauea Volcano," Journal of Geophysical Research, 91:653, 1986. (X1)
R149. Orth, C.J., et al; "Terminal Ordovician Extinction: Geochemical Analysis of the Ordovician/Silurian Boundary,

Anticosti Island, Quebec," Geology, 14: 433, 1986. (X1)
R150. Patrusky, Ben; "Mass Extinctions: The Biological Side," Mosaic, 17:2, Winter 1986/1987. (X1)
R151. Stauffer, B., et al; "Methane Concentration in the Glacial Atmosphere Was Only Half That of the Preindustrial Holocene," Nature, 332:812, 1988. (X11)
R152. Wolbach, Wendy S., et al; "Global Fire at the Cretaceous-Tertiary Boundary," Nature, 334:665, 1988. (X1)
R153 Kyte, Frank T., et al; "New Evidence on the Size and Possible Effects of a Late Pliocene Oceanic Asteroid Impact," Science, 241:63, 1988. (X1)
R154. Bourgeois, Joanne, et al; "A Tsunami Deposit at the Cretaceous-Tertiary Boundary in Texas," Science, 241:567, 1988. (X1)
R155. "Early Warning," New Scientist, p. 45, June 30, 1988. (X11)
R156. Pearson, Jerome; "The Lonely Life of a Double Planet," New Scientist, p. 38, August 25, 1988. (X3, X5)
R157. Henbest, Nigel; "How Astronomers Scored a Knockout Cometary Blow," New Scientist, p. 32, September 15, 1988. (X1)
R158. Monastersky, R.; "C-T Extinctions without the Impact," Science News, 133: 278, 1988. (X1)
R159. Monastersky, R.; "Ice Age Air Reveals Greenhouse Gas Story," Science News, 133:295, 1988. (X11)
R160. Monastersky, R.; "New Signs of World Upheaval at K-T," Science News, 134:309, 1988. (X5)
R161. Crocket, James H., et al; "Distribution of Noble Metals across the Cretaceous/Tertiary Boundary at Gubbio, Italy: Iridium Variation as a Constraint on the Duration and Nature of Cretaceous/Tertiary Boundary Events," Geology, 16:77, 1988. (X1, X13)
R162. Wilde, P., and Berry, W.B.N.; "Comment and Reply on 'Sulfur-Isotope Anomaly Associated with the Frasnian-Famennian Extinction, Medicine Lake, Alberta, Canada,'" Geology, 16:86, 1988. (X6, X14)
R163. Orth, C.J., and Attrep, M., Jr.; "Elemental Abundance Patterns across Bio-Event Horizons," Eos, 69:301, 1988. (X1, X13)
R164. Asaro, F., et al; "Impacts and Multiple Iridium Anomalies," Eos, 69:301, 1988. (X1)
R165. Loper, D.E., and McCartney, K.; "Catastrophic Volcanism as a Cause of Iridium and Shocked Quartz Found at the K/T Boundary," Eos, 69:302, 1988. (X1)
R166. Orth, C.J., et al; "Iridium Abundance Maxima in the Upper Cenomanian Extinction Interval," Geophysical Research Letters, 15:346, 1988. (X1)
R167. Derry, Louis A., and Jacobsen, Stein B.; "The Nd and Sr Evolution of Proterozoic Seawater," Geophysical Research Letters, 15:397, 1988. (X18)
R168. Rocchia, R., et al; "A Search for Iridium in the Deccan Traps and Inter-Traps," Geophysical Research Letters, 15:812, 1988. (X1)
R169. Schidlowski, Manfred; "A 3,800-Million-Year Isotopic Record of Life from Carbon in Sedimentary Rocks," Nature, 333:313, 1988. (X3)

ESC2 Chemical Anomalies in Igneous and Metamorphic Rocks

Description. Enhanced concentrations of specific chemical elements, their isotopes, and chemical compounds appearing in igneous and metamorphic rocks. In contrast to the chemical "spikes" found in the stratigraphic record (ESC1), which often signify event-type phenomena, the chemical anomalies in this section usually betoken the past presence of such processes as mixing, migration, and diffusion.

Data Evaluation. Considerable research has been carried out on lead, helium, argon, and strontium anomalies, especially in connection with isotopic abundances. The literature is quite impressive here. Rating: 1.

Anomaly Evaluation. The usual explanations of chemical anomalies in igneous and metamorphic rocks involve the processes of mixing, migration, and diffusion. In other words, the unexpected concentrations of chemical species are attributed to invading fluids and/or the outright assimilation of "foreign" material by magmas. Such processes are reasonable and well within mainstream geology, although they are so general in character that they reveal little insight. When such geochemical phenomena can be legitimately invoked, a high level of anomalousness is obviously not assignable. Nevertheless, the anomalies described below do impact upon the reliability of radiometric dating and, in other cases, seem to reveal the presence of unexpected structures in the earth's crust. Rating: 3.

Possible Explanations. See above discussion.

Similar and Related Phenomena. Radiometric dating (ESP12); natural nuclear reactors (ESP13); chemical anomalies in the stratigraphic record (ESC1).

Examples

X1. Lead isotopes. Lead, as found in nature, is composed of a mixture of stable isotopes. Only one of these, lead-204, is non-radiogenic; that is, not derived from the radioactive decay of uranium and thorium. Lead-isotope anomalies are to be found in the wildly varying ratios of the different radiogenic isotopes when compared to the concentrations of other radiogenic isotopes and lead-204. The origins of these anomalies are not well-understood, being generally attributed to such factors as "mixing" and "migration."

Our treatment here is divided into two parts which reflect the two basic types of lead-isotope anomalies:

X1A. Lead associated with uranium and thorium ores.
X1B. Lead in eruptive basalts.

....

X1A. Lead in uranium/thorium ores. Lead-isotope "fingerprints" are often used in geochemical prospecting for uranium/thorium deposits. R. W. Boyle has provided a good introduction to the puzzles encountered with lead isotopes in nature:

"...lead minerals in uranium deposits tend to have a high proportion of (radiogenic) uranium-lead, that is, they are enriched in Pb^{206} and Pb^{207}, the derivatives of U^{238} and U^{235}; in thorium-rich deposits, a high enrichment of (radiogenic) thorium-lead, Pb^{208}, can be expected in the lead minerals. In ordinary lead-bearing deposits, the lead minerals have a component of original (primal) lead isotopes (Pb^{204}, Pb^{206}, Pb^{207}, Pb^{208}), depending, among other factors, on the age of the deposit. Furthermore, there are deposits in which the lead minerals have isotopic ratios that are unusual or anomalous (the J-lead of the Mississippi Valley deposits and also of such deposits as Keno Hill, Yukon). The reasons for the various isotopic composition of lead in deposits are extremely complex, to say the least, and certainly not understood as yet. Scientists need to understand the processes involved in the migration and concentration of lead isotopes before their theories can be placed on a firm basis." (R30) So far, we have found no additional information on the J-lead and the Keno Hill lead mentioned by Boyle. (WRC)

Some other specific lead isotope anomalies will be be described.

Central Africa. In 1924, T. W. Richards and P. Putzeys reported that lead associated with uranium ores mined in the Congo had an average atomic weight of only 206.20, a full unit less than 207.20, the then-accepted atomic weight for "normal" lead. (R1)

Others have commented on the anomalies of the Congo leads. M. A. Cook remarked: "The uranium ore at Shinkolobwe, Katanga, contains no Pb-204 (thus no common lead) and no Th-232, but it contains 0.08% Pb-208. The observed ratio Pb-206/Pb-207 is 94.2/5.72 $\pm$16.5 from which the ore has been assigned the age 640 million years. The questions are: where did the Pb-208 come from, and what does it mean concerning age?" (R7)

Colorado. "Isotopic analysis of the lead from the galena and pyrite associated with the uranium ore from the Colorado Plateau and the Blind River districts shows that: (1) lead is substantially enriched in radiogenic Pb^{206} and Pb^{207} compared to common leads, and (2) the Pb^{207}/Pb^{206} ages of this radiogenic component are appreciably older than the Pb^{207}/Pb^{206} ages of the uranium ores or the enclosing rocks." (R2) Obviously, lead-isotope anomalies complicate radiometric dating immensely. (WRC)

Canada. M. A. Cook has noted that uranium ore at Martin Lake, Canada, contains no Pb^{204} at all, and only 0.02% as much thorium as uranium; i.e., all the lead is radiogenic. Nevertheless, the lead contains 0.53% Pb^{208} (thorium lead), despite the very tiny amount of thorium present. (R7)

Lead ores in the Sudbury, Ontario, region are highly variable, as described by R. M. Farquhar and R. D. Russell: "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 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." (R3)

. . . .

X1B. Lead in eruptive basalts. Lead-isotope ratios in basalts, as with those in uranium ores, exhibit wide variations. Once again, mixing is blamed; but there are some interesting global trends.

Terceira, one of the Azores. Three basalt flows of different ages are found on this island. B. Dupre et al have determined that the lead isotope ratios, Pb^{207}/Pb^{204} and Pb^{206}/Pb^{204}, vary substantially, but generally in accord with the estimated emplacement ages of the three flows and in consonance with the hypothesis of mixing of various basalt components in the mantle. (R21) The "mixing" hypothesis can "explain" almost anything! (WRC)

Italy. A similar situation occurs in Italian volcanics: "In southern Italy, there are several active volcanoes which occur in diverse geotectonic settings. Isotope determinations on coexisting minerals and whole-rocks from zero-age lavas from Vesuvius, Etna and Stromboli reveal an isotope equilibrium for Sr isotopes but not for Th. Analyses for Pb in the same samples also reveal differences in isotope composition, and in all cases the phenocrysts are less radiogenic than the whole rocks. We argue here that the Pb and Th isotope composition of the magmas changed during and after fractional crystallization, possibly by crustal assimilation or by addition of mantle-derived fluids and that whole-rock Pb isotope data are not representative of the magma sources." (R26)

East Africa. And again in Africa! R. Vollmer and M. J. Norry have found that the Pb^{206}/Pb^{204} variations in Nyiragongo nephelinites are the largest ever observed for young volcanic rocks. (R22)

Indian Ocean islands. Another possible source of variation in lead-isotope ratios comes from the injection of sediments into the mantle. After studying basalts collected from islands in the Indian Ocean, B. Dupre and C. J. Allegre conclude: "Some Pb-Sr isotopic results obtained on islands of the Indian Ocean are similar to those of the North Atlantic Ocean (Comores, for example) and others are similar to those of the South Atlantic (Kerguelen, for example). These Pb-Sr-Nd isotopic similarities on a large geographical scale suggest a broad cartography of large domains with specific characteristics: North Atlantic and West Pacific on one hand, and South Atlantic and Indian Ocean on the other.

"The Pb, Nd, Sr and He characteristics of the endmembers represented by Gough, Tristan da Cunha and Kerguelen are interpreted by the mixing of lower mantle material with subducted sediments.

"The isotopic peculiarity of the Indian Ocean islands is also found, with less intensity, in the Indian Ridge tholeites. This confirms the hypothesis of mixing between the oceanic islands source and the ridges theoleites source." (R23)

A Southern Hemisphere anomaly. Although these basalt isotope data are difficult-to-interpret, S. R. Hart sees an interesting global trend which, in effect, heightens the anomalousness of the situation: Abstract. "Basalts from many Southern Hemisphere regions have anomalous Sr and Pb isotopic characteristics. This article shows that the isotopic mantle anomaly is globe-circling in extent, centred on latitude 30°S. Arguments suggesting that this mantle anomaly has been in existence for billions of years place severe constraints on mantle convection models." (R25)

X2. Helium. Helium anomalies, in the context of igneous and metamorphic rocks, are of two varieties: (1) the very large excess of helium in some beryl crystals and, to a lesser extent, in a few other kinds of crystals; (2) excess helium in volcanics. By "excess" one means over and above the amount of helium that one expects from radioactive decay.

Beryl crystals. As early as 1908, Lord Rayleigh recognized that beryl contained more helium than could have been produced by the decay of uranium and thorium in the mineral after its formation. P. E. Damon and J. L. Kulp researched this phenomenon, summarizing their results as follows: "Abstract. All beryl crystals appear to contain a quantity of helium and argon in great excess over that which can be accounted for from radioactive decay. Other magmatic minerals which have structural sites suitable for large non-essential atoms such as cordierite and tourmaline also show this excess in variable amount. It seems that this excess inert gas must represent a sample of the magmatic gases in the immediate environment of the forming crystal and as such can provide useful information on magmatic conditions. Although there are considerable differences in the helium and argon concentration even in the same beryl crystal, these are small compared to the one hundred-fold difference between crystals formed in the early Precambrian (~ 3.0 b.y.) and Paleozoic eras. This strong age effect is interpreted as suggesting more extensive outgassing of the mantle in the earlier phases of earth history." (R4) The suppositions that the excess helium comes from the magma and that there was more outgassing of the earth in earlier times are both quite reasonable; in fact, no other interpretations seem possible. (WRC)

Volcanics. Basalts and other volcanics frequently contain so much excess helium that radiometric dating is compromised. For a more thorough discussion of this problem, see ESP12 and ESC3. Here, it is sufficient to quote from the conclusions of a study of Hawaiian basalts by J. G. Funkhouser and J. J. Naughton: "We have shown by crushing and decrepitation experiments that radiogenic helium and argon reside in the secondary fluid and gaseous inclusions so prevalent in the minerals of Hawaiian ultramafic xenoliths. The anomalously great K-Ar and U-He ages of these nodules are ascribed to excess radiogenic gases contained in such sites. It is believed that the potassium and uranium-thorium concentrated in the inclusions during recrystallization are insufficient to generate the observed quantities of inert gases; therefore, such gases represent a portion of the environment in the magma chamber. The relatively low ratios of radiogenic helium to argon that were measured indicate derivation from a chondritic-like source or are the result of preferential loss of helium through a mechanism involving diffusion." (R8) As in the case of beryllium crystals, the excess helium is (and apparently must be) attributed to the magmatic environment. (WRC)

X3. Argon. Many minerals contain "too much" radiogenic argon. As with the excess helium (X2), one can account rather easily for the presence of excess argon; i. e., it comes from the surrounding magma. The implications, however, are serious, because these excess gases seriously impact on radiometric dating. Below are presented the results of just a few studies which show just how widespread anomalous argon is among the different minerals, and how much radiometric dating by the potassium-argon method is compromised.

Beryl. Beryl crystals almost always contain considerable excess argon. See X2 for the Abstract of a 1958 study. (R4)

Pyroxenes. Initially pyroxenes were thought to be unlikely hosts of excess argon, but S. R. Hart and R. T. Dodd, Jr., showed this was not the case: "An anomalously high pyroxene age from Mont Royal, Quebec, was reported by Hart, and was ascribed to either excess initial radiogenic argon or sample contamination. Since then, two more pyroxenes have been analyzed, and the results given here clearly indicate the presence of excess radiogenic argon in these samples. Very high K-Ar ages have also been found by Baadsgaard for several pyroxenes from the Precambrian shield in Canada." (R5)

Basalts. Many very young basalts have old potassium-argon dates, with some recent deep-ocean basalts appearing to be up to 22 million years old. (R6)

The quandry created for radiometric dating is well-summarized by J. G. Funkhouser et al: Abstract. "Excess radiogenic argon and helium were found in fresh, geologically young submarine basalts dredged from the crest of the East Pacific Rise and from several seamounts at varying distances from the crest. The presence of the excess gases is related to the glass content of the samples: the glassy outer rim retaining the greatest amount, the more crystalline interior of the flow showing less or no excess radiogenic gases. No definite criteria, other than glass content, could be established to judge the validity of measured K-Ar ages, although fission-track measurements on a limited number of samples provided reasonable upper limits." (R9)

Micas. Abstract. "Potassium-argon determinations on 23 muscovite-biotite pairs from the Upper East Alpine Altkristallin of the Eastern Alps yield apparent ages ranging between 79 and 107 m.y. for the muscovite and between 78 and 430 m.y. for the coexisting biotite. The micas appear to be of the same generation and neither differential leaching of potassium nor abnormal blocking temperature relationships are able to explain this discordance. It is concluded that excess radiogenic ^{40}Ar entered the micas in a zone at least 1 1/2 km thick and 200 km^2 in area." (R11)

Pegmatites. Variable quantities of excess radiogenic argon has also been found in plagioclase and spodumene. (R13)

X4. Strontium isotopes. Strontium is still another element employed in radiometric dating, specifically in the rubidium-strontium method. Variations in the Sr-87/Sr-86 ratio have been found in several localities, which again suggest using caution in interpreting radiometric dates. In addition, geographical changes in the Sr-87/Sr-86 ratio have been utilized to infer otherwise unobserved crustal and mantle structural features.

Strontium-isotope variations with geographical scale. In 1982, B. Dupre et al reported that three basalt flows on one of the Azores, Terceira, display distinctly different strontium-isotope ratios. They interpret these anomalies in terms of the mixing to two different mantle components. (R21)

On an even finer scale, A. W. Laughlin et al have found that the strontium-isotope ratio is variable over the dimensions of a single basalt flow---the McCartys basalt flow, in New Mexico and of recent age. Here, the ratio varies over the range 0.7040-0.7084. Geologists have generally assumed isotopic homogeneity within single flows. This is obviously not the case here. The authors opine that such small-scale variations must be the consequence of near-surface crustal contamination. (R17)

Moving to a much larger scale, "continental volcanics commonly possess higher and more variable $^{87}Sr/^{86}Sr$ ratios than oceanic volcanics." C. Brooks et al explain this as a consequence of magma contamination as it rises through the old subcontinental lithosphere. Oceanic basalts, in contrast, do not have to pass through such a layer. (R19)

Generally, then, the smaller the geographical scale of the strontium-isotope ratio variations, the nearer the surface is the source of the contamination. This is all quite reasonable and leads us to conclude that these variations are not very anomalous. (WRC)

Hints at large-scale discontinuities in the earth's structure. The nature and heterogeneity of the lower continental crust may be explored by analyzing the strontium-isotope ratios occurring in inclusions in volcanic rocks. R.I. Kalamarides et al made such a study of volcanics in the McMurdo Sound region of Antarctica, encompassing an area of 12,000 square kilometers. "Along with results from analyses of major and trace elements, the isotopic data reveal a profound discontinuity in the composition and probably the age of the lower crust that coincides with the boundary between the Transantarctic Mountains and the Ross Embayment. Although this topographic boundary between East and West Antarctica is largely a Cenozoic development, which apparently reflects a simple subvertical faulting relationship due to crustal rifting, the isotopic differences in the lower crust across the boundary suggest that the current faulting and rifting may coincide with an older crustal suture, the age of which is uncertain." (R27)

In X1, it was mentioned that lead-isotope data suggested the presence of a globe-circling mantle anomaly centered on latitude 30° S. The distribution of strontium-isotope variations underscore the existence of this global anomaly. (R25)

X5. Plutonium-244. Plutonium-244, one of the transuranic elements, does occur naturally in minute quantities: "Dr. Darleane Hoffmann and Francine Lawrence at the Los Alamos Scientific Laboratory have chemically isolated about 8×10^{-15} grams of plutonium-224 from 85 kg. of bastnasite ore from the Mountain Pass, Calif., mine of Molybdenum Corp. of America. Jack Mewherter and Frank Rourke at the Knolls

Atomic Power Laboratory, Schenectady, N.Y., identified the isotope by mass spectrometry. Detection of this relatively short-lived isotope (80 million years) may indicate that synthesis of heavy elements was still occurring at the time of formation of the solar system." (R5) Working backwards in time and assuming an age for the earth of 4.6 billion years, we see that about 57 half lives of plutonium-244 have elapsed. At the time of the earth's formation, then, the 8×10^{-15} grams of Pu-244 of today was roughly 10^{17} times larger, or about 800 grams, a not inconsiderable amount. We insert this item here to emphasize that the early earth may have played host to many transuranic elements, some in large quantities. Plutonium-238, for example, has a half life of only 89 years; there could have been immense amounts of this isotope around early in the earth's history, leaving no record at all in today's geological formations. (WRC)

X6. Neodymium isotopes. "Gerald Wesserburg at Caltech and Donald dePaolo at 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 which might be expected from ancient rocks." (R20)

X7. Uranium isotopes. The extraordinary low concentrations of uranium-235 in the uranium ores at sites in Gabon, West Africa, have already been treated in ESP13. At some locations at the Oklo site, the U-235 concentration was found to be only 0.44% instead of the nominal 0.7202%. This depletion of fissionable U-235, along with other evidence of thermal activity, led to the supposition that natural nuclear reactors had formed, which led to the "burning" of some of the uranium-235. (R18) See ESP13 for more information.

X8. Carbon isotopes. "In Archaean (older than 2.5 billion years) gold lode deposits, such as those in Canada and Australia, gold mineralization occurs with sulphides, often in quartz veins, which are enveloped by or associated with rocks rich in carbonate. The gold may have been carried into place by reduced sulphur complexes in low salinity H_2O-CO_2 fluids. Where did these fluids come from? One hypothesis is that the fluids were derived by metamorphic degassing of crustal rocks; alternatively, they may have magmatic sources." (R28)

The parameter employed in comparing carbonates in this area of geochemistry is $\delta\,^{13}C$, which is computed using a seawater-derived standard (not an atmospheric standard as in ESC1-X3). Gold-mine carbonates generally have $\delta\,^{13}C$ values between -2 and -4%. If seawater had been the only source of these carbonates, their $\delta\,^{13}C$ values would have been slightly positive. Other sources of carbonates are: the crust ($-6 \pm 1\%$), magmas (about -5%), and the mantle (about -2 to -5%). From these data, it is obvious that one cannot decide the source(s) of gold-mine carbonates; one can only say that it was not solely seawater.

E.G. Nisbet and T.K. Kyser, the authors of the introductory paragraph, introduce the thought that some of these very old carbonates might be biogenic: "It is also possible that biological effects alter the $\delta\,^{13}C$ value of the 'mantle' carbon. Biological carbon is very light ($\delta\,^{13}C = -30\%$) and work in Archaean high-grade terrains has shown that rocks originally formed on the surface within the biosphere often constitute part of the deep continental crust. Perhaps this may be a source of carbon with low $\delta\,^{13}C$ values in the gold mines, especially as bacteria may have lived and died in the hydrothermal systems that eventually degassed during metamorphism to give rise to auriferous fluids. Yet the discussions of carbon in carbonate from Archaean gold lode deposits usually ignore and biological effects." (R28)

References

R1. "The Atomic Weight of Lead from the Belgian Congo," American Journal of Science, 208:81, 1924. (X1)
R2. Stieff, L.R.; "Original Radiogenic Lead in Pb-U Dating," Geological Society of America, Bulletin, 67:1825, 1956. (X1)
R3. Farquahar, R.M., and Russell, R.D.; "Anomalous Leads from the Upper Great Lakes Region of Ontario," American Geophysical Union, Transactions, 38:552, 1957. (X1)
R4. Damon, Paul E., and Kulp, J. Laurence; "Excess Helium and Argon in Beryl and Other Minerals," American Mineralogist, 43:433, 1958. (X2, X3)
R5. Hart, S.R., and Dodd, R.T., Jr.; "Excess Radiogenic Argon in Pyroxenes," Journal of Geophysical Research, 67:2998, 1962. (X3)
R6. Noble, C.S., and Naughton, J.J.; "Deep-Ocean Basalts: Inert Gas Content and Uncertainties in Age Dating," Science, 162: 265, 1968. (X2, X3)
R7. Cook, Melvin A.; "Do Radiological 'Clocks' Need Repair?" Creation Research Society Quarterly, 5:69, 1968. (X1, X3)
R8. Funkhouser, John G., and Naughton, John J.; "Radiogenic Helium and Argon in Ultramafic Inclusions from Hawaii," Journal of Geophysical Research, 73:4601, 1968. (X2, X3)
R9. Funkhouser, John G., et al; "Excess Argon in Deep-Sea Rocks," Earth and Planetary Science Letters, 5:95, 1968. (X2, X3)
R10. Pushkar, Paul; "Strontium Isotope Ratios in Volcanic Rocks of Three Island Arc Areas," Journal of Geophysical Research, 73:2701, 1968. (X4)
R11. Brewer, M.S.; "Excess Radiogenic Argon in Metamorphic Micas from the Eastern Alps, Austria," Earth and Planetary Science Letters, 6:321, 1969. (X3)
R12. Wanless, R.K., et al; "Excess Radiogenic Argon in Biotites," Earth and Planetary Science Letters, 7:167, 1969. (X3)
R13. Laughlin, A. William; "Excess Radiogenic Argon in Pegmatite Minerals," Journal of Geophysical Research, 74:6684, 1969. (X3)
R14. Dalrymple, G.B.; "$^{40}Ar/^{36}Ar$ Analyses of Historic Lava Flows," Earth and Planetary Science Letters, 6:47, 1969. (X3)
R15. "Natural Plutonium," Chemical & Engineering News, 49:29, September 20, 1971. (X5)
R16. Giletti, Bruno J.; "Discordant Isotopic Ages and Excess Argon in Biotites," Earth and Planetary Science Letters, 10: 157, 1971. (X3)
R17. Laughlin, A.W., et al; "Variations in the Initial Strontium Ratios of a Single Basalt Flow,: Earth and Planetary Science Letters, 14:79, 1972. (X4)
R18. Cowan, George A.; "A Natural Fission Reactor," Scientific American, 235:36, July 1976. (X7)
R19. Brooks, C., et al; "Ancient Lithosphere: Its Role in Young Continental Volcanism," Science, 193:1086, 1976. (X4)
R20. "Underground Sites of Ancient Earth," New Scientist, 83:886, 1979. (X6)
R21. Dupre, Bernard, et al; "Isotopic Variations within a Single Oceanic Island: the Terceira Case," Nature, 299:620, 1982. (X1, X4)
R22. Vollmer, R., and Norry, M.J.; "Unusual Isotopic Variations in Nyiragongo Nephelinites," Nature, 301:140, 1983. (X1, X4, X6)
R23. Dupre, Bernard, and Allegre, Claude J.; "Pb-Sr Isotope Variation in Indian Ocean Basalts and Mixing Phenomena," Nature, 303:142, 1983. (X1)
R24. Sheng, Z.Z., and Kuroda, P.K.; "The α-Recoil Effects of Uranium in the Oklo Reactor," Nature, 312:535, 1984. (X7)
R25. Hart, Stanley R.; "A Large-Scale Isotope Anomaly in the Southern Hemisphere Mantle," Nature, 309:753, 1984. (X1, X4)
R26. Cortini, M., and van Calsteren, P.W.C.; "Lead Isotope Differences between Whole-Rock and Phenocrysts in Recent Lavas from Southern Italy," Nature, 314:343, 1985. (X1)
R27. Kalamarides, Ruth I., et al; "Lateral Isotopic Discontinuity in the Lower Crust: An Example from Antarctica," Science, 237:1192, 1987. (X4)
R28. Nisbet, E.G., and Kyser, T.K.; "Archaean Carbon and Gold," Nature, 331: 210, 1988. (X8)
R29. Groves, D.I., et al; "Archaean Carbon Reservoirs and Their Relevance to the Fluid Source for Gold Deposits," Nature, 331:254, 1988. (X8)
R30. Boyle, R.W.; "Geochemical Prospecting," McGraw-Hill Encyclopedia of Science and Technology, 6:128B, 1977. (X1)

ESC3 Unusual Surface Films on Rocks

Description. Films, varnishes, coatings, and glazes observed on rocks in various environments.

Data Evaluation. Field observations predominate the scanty literature located to date; there has been little laboratory analysis of these films or the processes that cause them. Rating: 2.

Anomaly Evaluation. All types of films recorded seem to have at least one element in common: the episodic wetting of exposed surfaces. The precise chemistry involved has not been in the literture examined. Indeed, there may be more than one process. Nevertheless, we catalog these curious films, not because we expect that strange chemistries are involved, but rather because so little seems to be known about them. Rating: 3.

Possible Explanation. Yet undetermined chemical reactions between rocks and transitory coatings of moisture on the surfaces.

Similar and Related Phenomena. None.

Examples

X1. Black surface films on cataract rocks.

"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. As is well known, such rocks occur, not only in 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, as 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 had 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 constitutents 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 exides. 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, and also in the Nile Water (both in suspension and solution). (R1)

X2. Desert varnish. Although the above item on rock films in cataracts asserts that the river films are identical to films on desert rocks, the following comments about desert "varnish" are appropriate.

"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 Rock Mountains are commonly 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 grading 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 the 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 of the product of past pluvial climates." (R2) As the reader will readily discern, we have many generalities and few specifics. (WRC)

X3. Desert glaze. This phenomenon is said to be distinct from desert varnish (X2).

"This rare phenomenon consists of a very thin, colorless, transparent, highly lustrous coating upon the exposed upper surfaces of siliceous pebbles and cobbles of the desert. Although perhaps related in origin, it is easily distinguished from the dark-colored oxide concentration known as desert varnish, desert lacquer or desert patina. Also, it is readily distinguished from polished rock surfaces caused by wind-blown sand and dust abrasion, known as desert polish, that are almost universally present in the great Sahara. Rather, it has the appearance of a thin, clear ceramic glaze and, hence, the name 'desert glaze' is herewith proposed for this natural phenomenon. As with clear ceramic glaze, the siliceous coating seems to intensify or deepen the natural color of the stones which it partially covers without adding any color of its own.

"The geological process which produces desert glaze appears to be highly selective in that perhaps only one or two pebbles out of millions in the same vicinity may exhibit it. Desert glaze generally occurs in areas where little or no sand abrasion is presently in progress and always appears upon the most dense of siliceous or quartzitic rocks, notably chalcedony. It was found principally upon pebbles of flint, agate, petrified wood and quartzite. Glaze was noted on larger sized pieces of petrified wood and seemingly developed more extensively on such material."

Desert glaze is thought by the author of the above paragraphs to be a thin film of silica dissolved from the rock by dew and subsequently deposited after evaporation. (R3) If such were so, one would expect the phenomenon to be more general rather than so highly selective. (WRC)

References

R1. "The Blackened Rocks of the Nile Cataracts," Geographical Journal, 27:197, 1906. (X1)

R2. Hunt, Charles B.; "Desert Varnish," Science, 120:183, 1954. (X2)

R3. Fisk, E. P.; "Desert Glaze," Journal of Sedimentary Petrology, 41:1136, 1971. (X3)

R4. "Discoloration of the Rocks at the Nile Cataracts," Geographical Journal, 20: 655, 1902. (X1)

ESC4 Spontaneous, Rapid, Exothermic Reactions in Nature

Description. Natural, spontaneous conflagrating, heating, and exploding phenomena caused by energetic exothermic reactions.

Data Evaluation. The data file for natural heating and burning associated with the oxidation of pyrite (X1 below) is quite good and spans nearly two centuries. However, we have found little on natural detonation phenomena. Rating: 2.

Anomaly Evaluation. The oxidation of pyrite, an exothermic chemical reaction, represents an adequate explanation for most natural heating of rocks and spontaneous "fires". (X1) A mystery, though, hovers around the nature of the spontaneous ignition of natural gases (X3), especially in cases where the phenomenon occurs repeatedly in the same location, although sparks generated by rock movements may suffice. Despite the intriguing character of these phenomena, a low level of anomalousness prevails. Rating: 3.

Possible Explanations. See above.

Similar and Related Phenomena. Natural explosive sounds (GSD1 and GSD2), some of which may be due to the spontaneous ignition of natural gases. Nocturnal lights (GLN1) and earthquake lights (GSD8). Combustion metamorphism (ESC8); explosive slickensides and rockbursts (ESP16).

Examples

X1. Natural combustion. Here we catalog a selection of naturally occurring exothermic reactions, which have been energetic enough to attract the attention of scientists and laymen alike.

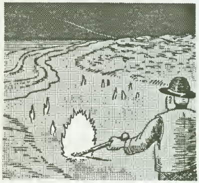
Ringstead Bay, England. "A very remarkable appearance of nature, well deserving the attention of the curious or the philosophic, may now be seen at a place called Ringstead, situate on the shore opposite to Weymouth; it is a volcano in miniature, and has appeared for more than a week, the rocks on the cliff, to the extent of some feet, exhibiting a smoking appearance, and on being stirred with a stick, which became charred, flames issued forth of sufficient magnitude to allow of the toasting of a piece of bread. So unusual a sight has attracted a great number of persons to the spot, though some of the neighbours state that the smoking appearance has been partially visible at intervals, for the last three years." (R2)

From a later letter to the same journal: "One of our correspondents informs us that this extraordinary phenomenon now presents the appearance of an immense building in flames. Exhalations of vapour or smoke have continued to issue, in greater or less quantitites, from different parts of the cliff, now upwards of seven months uninteruptedly. The increased and still increasing number of apertures since the first discovery of fire, prove how vast a space this subtle element occupies in the interior of the cliff. The original surface exhibiting fire did not cover a larger portion than six feet square, increased shortly afterwards to ten, ultimately extending at this spot upwards of thirty." (R4) coal?

Some 80 years later the Ringstead Bay phenomenon was mentioned again in the Geological Magazine: "In September, 1826, spontaneous combustion took place in the Kimeridge Clay near the east extremity of Ringstead Bay, at Holworth Cliff, adjacent to the promontory of White Nore. This combustion continued until 1829, although the extent of the surface of the clay that was burnt did not exceed 50 feet square." The phenomenon was attributed to the decomposition of iron pyrites. (R15) Ringstead Bay, in 1876, was also the site of a strange display of luminous spheres. See GLD7-X3. (WRC)

Lyme Regis, England. A similar phenomenon, also attributed to the decomposition of iron pyrites, developed along a cliff near Lyme Regis in January 1908. C. Grover reported to the readers of the English Mechanic: "I went over yesterday, February 6, to see the spot. This is about a mile east of Lyme Regis, where landslips and cliff movements have been going on for ages. But there is no denying that of late years these movements have become much larger and more rapid than formerly, a large area of the land is moving bodily seaward, and it is in a large mound of shale and iron pyrites which has been pushed forward near the sea, that combustion is now going on. Outwardly there is not much to see. Light clouds of whitish vapour, or steam, issue from various parts of the cliff, and very soon it feels uncomfortably hot to the feet; but when a crowbar is applied, and a hole dug in the side, then it is seen that the interior of the cliff is a bright, red-hot body of fire, and heat is intense. Stones can be taken out red-hot, and the first appears to extend a long way into the cliff, and will, no doubt, go on burning for some time to come." (R17)

Blundellsands, England. In GLN1, we catalog rather extensively the spontaneous ignition of gases escaping from marshy tracts. One of these accounts is reproduced here for comparative purposes: June 5, 1902. "The evening was dull and grey, a strong northwesterly wind was blowing in from the sea and the tide was flowing in. In the distance we first saw smoke with frequent jets of fire bursting forth from the mud of a shallow canal. Drawing near, we perceived a strong sulphurous odour, and saw little flames of fire and heard a hissing sound as though a large quantity of phosphorous was being ignited. It was impossible to detect anything which caused the fire, only the water where the flames appeared had particles of a bluish hue floating on the surface. The area over which the tiny flames kept bursting forth was about 40 yards. A gentleman present stirred up the mud with his walking stick, and immediately large yellow flames nearly 2 feet in length and breadth burst forth. The phenomenon lasted some time, until the tide covered the part and quenched the fire." (R11)



Flames erupting from an English mud flat in 1902. (X1)

Idria (or Idrija), Yugoslavia. A conflagration in a mercury mine. "In 1803, on the night between the 15th and 16th of March, the workmen observed a thick smoke issuing from some of the lower galleries. It ascended, and spread itself through the higher. No fire was seen, no sound of flames was heard, but it was too evident that the mine was on fire, below. Some of the workmen, with great intrepidity, endeavoured to reach the scene of the conflagration. It was in vain; they were forced to retreat from one gallery to another, flying before an enemy whom they could not discover; for the smoke, which continued to make its way upwards to the open air, was not merely so dense and suffocating, but so loaded with noxious fumes, and particles let loose from the fossils among which the flames were raging in the bowels of the earth, that no living creature could safely meet it, much less penetrate it." Sealing the mine, to exclude air, proved to no avail. A river was finally diverted into the mine, and this extinguished the fire. (R5) From the information at hand, it is impossible to determine the nature of the chemical reaction(s) involved. It is presumed here that some violent exothermic chemical reactions took place; that is, something beyond the simple burning of mine timbers, etc. (WRC)

Nebraska. "The seat of the 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." (R8; R6)

Colorado. It is not clear from the following brief description whether we have here only a burning coal seam or something more interesting: "Internal fires of Carbon Mountain, near Durango, Colo., are the cause of the 'moving mountain' phenomenon now attracting attention, scientists of the Colorado Museum of Natural History of Denver explain. The explosion under this mountain producing additional avalanches of rock, heavy smoke and fumes, indicates fire in the underlying deposits. The original movements are doubtless traceable, in the opinion of the scientists, to expansion and pressure imposed through the heat of underlying fires." (R20)

Maine. Kittery Point; September 1, 1905. "On the evening of Friday, September 1, the guests at the Hotel Parkfield were startled by the appearance of flames rising from the beach and from the surface of the water, an event of so remarkable and unusual a character as to excite great curiosity and some alarm. The conflagration occurred between seven and eight o'clock in the evening, and lasted for upwards of forty-five minutes. The flames were about one foot in height. They were accompanied by a loud and continuous crackling noise which could be distinctly heard one hundred yards away, while at the same time there was a very strong liberation of sulphurous acid fumes which penetrated the hotel, drove the proprietor and his staff from the office and filled the other rooms to such an extent as to cause great inconvenience to the guests. One guest of an investigating turn of mind secured some of the sand in his hand, but was obliged to drop it on account of the heat. When some of the sand was taken into the hotel and stirred with water, bubbles of gas were liberated and produced flame as they broke at the surface in contact with the air." (R13) See also GLN1.

Canada. The so-called "Smoking Hills" of the Canadian Arctic were mentioned as early as 1851 by Sir John Richardson: "On the Mackenzie a shaly formation makes the chief part of the banks and also much of the undulated valleys between the elevated spurs. It is based on horizontal beds of limestone and in some places of sandstone. Covering the shaly beds, there exists in many places a deposit of sand, sometimes cohering as a friable sandstone... The shale crumbles readily and often takes fire spontaneously, occasioning the ruin of the bank; it is only by the encroachments of the river carrying away the debris that the true structure is revealed.

"When exposed for even a short time to the atmosphere, the coal, which is probably all or mostly of Tertiary age, splits into rhomboidal fragments, which again separate into thin layers, so that it is difficult to preserve a piece large enough to show the woody structure in perfection. Much of it falls eventually into a coarse powder; and if exposed to the action of moist air in the mass it takes fire and burns with a fetid smell and little smoke or flame, leaving a brownish-red ash, not one-tenth of the original bulk of coal taken from the purer beds, for some contain much earthy matter."

.....

"From the readiness with which the coal takes fire spontaneously, the beds are destroyed as they become exposed to the atmosphere; and the bank is constantly tumbling down, so that it is only when the debris has been washed away by the river that good sections are exposed. The beds were on fire near Bear River when Sir Alexander Mackenzie discovered them in 1785, and the smoke, with flames visible by night, has been present in some part or other of the formation ever since." (R16)

M. Havas and T. C. Hutchinson have provided a more recent and more technical description: "Such an ecosystem occurs in the western Canadian Arctic at the Smoking Hills area of Cape Bathurst, North-West Territories (70° 14' N, 127° 10'W). Here, along 30 km of sea cliffs, exposed bituminous shales are spontaneously burning. Dense clouds of white smoke are emitted from several fumaroles. The smoke, which consists of sulphur dioxide, sulphuric acid aerosol, and steam, is carried inland across the tundra and occasionally out over the sea-ice and open waters of Franklin Bay. New fumigations arise from time to time, especially in the spring, as cliffs are eroded and slide into the sea, exposing fresh shale deposits.

"The deposits are of Upper Cretaceous age, and are comprised of black shales interbedded with yellow bands of jarosite ($KFe_3(SO_4)_2(OH)_6$). Spontaneous combustion occurs as a result of finely divided sulphur coming into contact with bitumen and producing an exothermic reaction, much as it does in colliery spoil heaps. The burned material lies in huge brick-red and white mounds on the beaches. The jarosite and the shales emit sulphur dioxide when heated.

"The burns at the Smoking Hills were first reported by nineteenth century explorers seeking the North-West Passage. Sir John Franklin's expedition examined the phenomenon and the physician-naturalist Richardson described the sulphurous nature of the emissions. He suggested the sulphur-bitumen exothermic reaction, and noted the 'sour' taste of pools and ponds in the vicinity. The enormous quantity of burnt material in the cliffs and on the shore, in relation to the slow rate of burning observed over the period 1975-1981, together with widespread areas of dead vegetation and burnt sea cliffs in regions where burns no longer occur, strongly suggest an antiquity of several hundred to several thousand years." (R22; R23)

In their 1984 survey of the Smoking Hills and adjacent areas, W. H. Mathews and R. M. Bustin introduce the word "bocanne" to designate active areas of fire-burned rock. Besides the bocannes of the Smoking Hills Formation, the Horton Valley contains at least 17 more; and more are found on the sea cliffs of Franklin Bay. (R24)

Panama Canal Zone. "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."

.....

"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 sulphur-dioxide, 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 due mainly to the vaporization of ground water." The heating of these rocks was ascertained to be the result of oxidization of pyrites, accentuated by the hot, moist atmosphere and the finely divided nature of the pyrites. (R18; R19)

General observations. Worldwide, many cases of spontaneous ignition in coal beds have been noted. In general, the oxidization of pyrite, an exothermic reaction, has been blamed. (R10) Lightning and human activities probably account for a few cases. (WRC)

X2. Detonating mud. The data here are obviously unsatisfactory.

South America. "Don Carlos del Pozo has discovered in the Llanos of Monai, at the bottom of the Quebrada de Moroturo a stratum of clayey earth, which inflames spontaneously when slightly moistened, and exposed for a long time to the rays of the tropical sun. The detonation of this muddy substance is very violent. It is of a black colour, soils the fingers, and emits a strong smell of sulphur. ---Humboldt's Personal Narrative, vol. iv p. 253. Note." (R1)

X3. Spontaneous explosions of natural gas.

Staffordshire, England. The long duration and repetitiveness of the phenomenon near Old Hannah's Cave requires us to list them. To begin, we quote from an 1870 report: "A phenomenon of an extraordinary kind occurring at intervals in the parish of Wetton, Staffordshire, has of late years been familiar to the inhabitants of the village, either from personal knowledge or from current report....The cavernous nature of the mountain limestone is well known, but after all that can be advanced in support of the occurrence, some may be slow in believing that in the deep recesses of a limestone mountain inflammable gas is elaborated and fired by natural means; and that tremendous reports, accompanied by a lurid flame, issue from a crevice in the face of a rock. The circumstance may be without a parallel in the wide world, but that it is not contrary to the laws of nature can be made evident, and efficient witnesses can be brought forward to substantiate the occurrence; but before we introduce them a brief description of the locality is necessary to make intelligible the information gathered from them, when it will be seen that their independent relations have a very strong corroborative aspect. The south end of what is usually called Wetton-far-hill, terminates in an high rugged pile chequered with stunted bushes and bare weather-beaten limestone rock. The base of the mountain makes a near approach to the river Manifold, and between which runs the public road from Wetton to Wetton mill, &c. Towards the base of the hill, opposite to the road, where it and the river make a sharp turn, is a small but conspicuous cave, which is called 'Old Hannah's Hole;' and higher up, in the face of a steep crag, is a rent or hole, which serves as a vent to the explosions within." (R7)

In the interest of brevity, only one eye-witness account is reproduced from the above report: "The following occurrence happened when I was from home, but I am enabled to fix the date, namely, January 1st, 1855. It was much talked of in Wetton at the time, and I received the particulars from the witnesses. My first informant is George Fallows, who in company with Mr. Joseph Wint, both inhabitants of Wetton, were driving two cows along the road at the foot of the hill. When opposite to the rock their progress was arrested by a sudden loud report, which he said was if large blocks of stone were tumbling down the shaft of a deep mine; that the roaring noise was repeated with but short intermissions, and loud enough, but for the high wind that then prevailed, to be heard a mile from the place; and that a blue flame, edged with reddish yellow, issued from the cleft in the rock. The cows took fright and ran wildly up the road towards Wetton with their tails erect. Before they were out of sight they made a stand for breath, but a repetition of the roaring noise sent them off again." (R7)

A somewhat more recent account of the phenomenon was reprinted in a 1982 issue of the Bulletin of the National Speleological Society. The place was as above; the time, December 10, 1899. Two men heard explosions like rifle shots. "Realizing that no one was shooting, they looked up the cliff and witnessed an explosion which emitted a flash from a hole or fissure in the upper part of the cliff. This had a bluish column 'not of steam or fire or smoke, but apparently of aqueous vapour,' which travelled with immense force across the valley (approximately 12 m wide). Within minutes another discharge from higher up the cliff and then 'several ones with crackling sounds producing semi-transparent wavy streaks in the air, not smokey in appearance.' Next came a very loud explosion which 'we had the good fortune to see plainly.' Wardle describes this as 'like a gun but with crackling, a series of continuous reports, cleaving the air in a zigzag or riverlike course in a narrow band about 15 cm to 20 cm broad, of bluish colour.'" The scientific thinking seems to be that gases liberated by decaying organic material and, perhaps, geochemical reactions are ignited by static electricity. The phenomenon seems to have been extinguished by a recent landslip. (R21)

Indiana. The famous Waldron natural gas explosion is also treated in ETB3-X3.

"On August 11, (1890) at 9 o'clock A.M., the farmers near Waldron, which is eight miles southeast of Shelbyville, Ind., were startled by a terrific explosion. When they reached the Ogden graveyard, which is on a bluff near the Flat Rock stream, they discovered that fully ten acres of the earth was in commotion. Geysers were shooting up to the height of six and eight feet, and gas was blazing from ten to fifteen feet above the water of the geysers. The river bed was torn up and the water had stopped running below the graveyard. Flames are still shooting from fifty different fissures in the earth."

.....

"J.H. Lowe, who lives on the Cooper farm, heard a terrific report, and felt the earth quivering beneath his feet. He went toward the graveyard, and was soon confronted by a sheet of flame 200 feet high.

"Then fifty or more fountains of fire burst from the earth. These were interspersed with six or eight active geysers. At the east side of the eruption a large stack of straw was in flames, and a field of green corn was drooping before the excessive heat from the ten acres of flame. The river bed was torn to pieces, and huge fissures were receiving the river's water. Sheets of flame swept over the water, and an area of about one acre was quickly converted into a huge hole, from which a continuous roaring and rumbling noise proceeds." (R9; R12)

References

R1. "Detonating Mud in South America," Edinburgh Philosophical Journal, 1:423, 1819. (X2)
R2. "Burning Cliff," Gentlemen's Magazine, 2:20:359, part 1, 1827. (X1)
R3. Gentlemen's Magazine, 2:20:395, part 1, 1827. (X1)
R4. "Holworth Burning Cliff," Gentlemen's Magazine, 2:20:636, part 2, 1827. (X1)
R5. "Account of the Conflagration in the Quicksilver Mines of Idria, in 1803," Franklin Institute, Journal, 1:4:40, 1827. (X1)
R6. "Nebraska---Salt Wells and Burning Bluff," Scientific American, 4:183, 1861. (X1)
R7. Carrington, Samuel; "Explosions of Gas in Mountain Limestone," Reliquary, 11:27, 1870. (X3)
R8. "Volcanic Signs in Nebraska," Scientific American, 38:8, 1878. (X1)
R9. "Natural Gas Phenomenon in Indiana," Scientific American, 63:145, 1890. (X3)
R10. "Spontaneous Ignition of Coal," English Mechanic, 54:37, 1891. (X1)
R11. Dixon, H.T.; "Flames from Mud on a Sea-Shore," Nature, 66:151, 1902. (X1)
R12. Newsom, J.F.; "A Natural Gas Explosion near Waldron, Ind.," Journal of Geology, 10:803, 1902. (X3)
R13. Penhallow, D.P.; "A Blazing Beach,"

Popular Science Monthly, 70:557, 1907. (X1)
R14. English Mechanic, 86:582, 1908. (X1)
R15. "Burning Cliffs," Geological Magazine, 45:561, 1908. (X1)
R16. "Burning Cliffs on the Banks of the Mackenzie River, Etc.," Geological Magazine, 45:562, 1908. (X1)
R17. Grover, C.; "The Burning Cliffs, Lyme Regis, 1908," English Mechanic, 87:37, 1908. (X1)
R18. MacDonald, Donald F.; "Heating of Local Areas of Ground in Culebra Cut, Canal Zone," Science, 35:701, 1912. (X1)
R19. Williams, Edward H., Jr.; "The Heating in the Culebra Cut," Science, 35:892, 1912. (X1)
R20. "Internal Fires Make Mountain Move," Science News Letter, 23:211, 1933. (X1)
R21. Pounder, Colin; "Speculations on Natural Gas Explosions at Old Hannah's Cave, Staffordshire, England," National Speleological Society, Bulletin, 44:11, 1982. (X3)
R22. Havas, Magda, and Hutchinson, Thomas C.; "The Smoking Hills; Natural Acidification of an Aquatic Ecosystem," Nature, 301:23, 1983. (X1)
R23. Simon, C.; "'Severe' Effects of Natural Acidification," Science News, 123:52, 1983. (X1)
R24. Mathews, W.H., and Bustin, R.M.; "Why Do the Smoking Hills Smoke?" Canadian Journal of Earth Sciences, 21:737, 1984. (X1)

ESC5 Death Gulches and Valleys of Death

Description. Naturally created surface concentrations of gases that asphyxiate or poison unwary animals. Usually, the predominant gas is carbon dioxide, and the animals die from suffocation. These gas concentrations vary in size and potency due to wind conditions and the terrestrial sources of the gases.

Data Evaluation. All of the accounts found to date are rather popular in nature; some even seem to be embellished a bit. No scientific studies have been located. Rating: 3.

Anomaly Evaluation. Concentrations of naturally generated lethal gases in bowl-shaped depressions cannot be considered anomalous. Rather, this phenomenon is cataloged for its curiosity value. Rating: 4.

Possible Explanations. None required.

Similar and Related Phenomena. Lethal accumulations of gases in coal mines and caves. Pogonips and other ice fogs (GWD2); "blasting" fogs (GWD3).

Examples

X1. The Valley of Death, Java. The first account below is from an often-quoted report from 1831. Later descriptions of the site are less sensational in character.

"Early this morning we made an excursion to the extraordinary valley, called by the natives Guwo Upas, or Poisoned Valley: it is three miles from Balor, on the road to the Djiang. Mr Daendels had ordered a footpath to be made from the main road to the valley. We took with us two dogs and some fowls, to try experiments in this poisonous hollow. On arriving at the foot of the mountain, we dismounted and scrambled up the side, about a quarter of a mile, holding on by the branches of the trees, and we were a good deal fatigued before we got up the path, being very steep and slippery, from the fall of rain during the night. Within a few yards of the valley we experienced a strong nauseous suffocating smell, but, on coming close to the edge, this disagreeable smell left us. We were now all lost in astonishment at the awful scene before us. The valley appeared to be about half a mile in circumference, oval, and the depth from 30 to 35 feet, the bottom quite flat,---no vegetation,---some very large, in appearance, river-stones, and the whole covered with the skeletons of human beings, tygers (sic), pigs, deer, peacocks, and all sorts of birds. We could not perceive any vapour or any opening in the ground, which last appeared to be of a hard sandy substance. The sides of the valley from the top to the bottom are covered with trees, shrubs, &c. It was now proposed by one of the party to enter the valley; but at the spot where we were, this was difficult, at least for me, as one false step would have brought us to eternity, as no assistance could be given. We lighted our cigars, and, with the assistance of a bamboo, we went down within 18 feet of the bottom. Here we did not experience any difficulty in breathing, but an offensive nauseous smell annoyed us. We now fastened a dog to the end of a bamboo, 18 feet long, and sent him in, we had our watches in our hands, and in 14 seconds he fell on his back, did not move his limbs or look around, but continued to breathe 18 minutes. We then sent in another, or rather he got loose from the bamboo, but walked in to where the other dog was lying: he then stood quite still, and in 10 seconds he fell on his face, and never moved his limbs afterwards: he continued to breathe for 7 minutes. We now tried a fowl, which died in 1 1/2 minute. We threw in another, which died before touching the ground." (R1; R2, R8)

Now, a different version: "The researches of Junghuhn have shown that these accounts (i.e., R1) are much exaggerated, the 'valley of death' being a funnel-shaped depression but one hundred feet in diameter, instead of a valley a half 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 envelope 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 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 during his subsequent visits were the carcasses of six swine which were decomposed and putrid. At this time the absence of 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 easily 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." (R4) Note that the earlier 1831 report stated that the valley measured about a half mile in circumference, not in diameter. (WRC)

X2. Yellowstone Park, Wyoming. At least two "death traps" appear to exist within the park. The most reknowned, "Death Gulch", is described first:

"In an opening bordering on Cache Creek occur evidences of former hot springs in geyser-like deposits, a hot spring cone half washed away, a mound of travertine, and a little tepid sulphurous water at the edge of the stream. Besides, there are copious gaseous emanations rising through the waters of the creek 'mainly, no doubt, carbonic acid, although containing some sulphuretted hydrogen.' Above these is altered and crystalline travertine, besides a bank of sulphur and gravel cemented by travertine. In a lateral gully, the waters of its small stream, sour with sulphuric acid, flow in a channel cut through beds of dark gray volcanic tufa. The only springs now flowing are oozes of water, forming a creamy white deposit about the vents which is largely an alum (alumina sulphate). The odor of sulphur is strong. The bears and other wild animals of the region are often killed by the gases. Dead bears were found in all stages from skeletons to freshly killed, and with them were remains of an elk, squirrels, rock-hares, etc., and many dead butterflies and other insects." (R5; which is a summary of R4)

The lethal gases of Death Gulch are evidently variable: "In 1897 Dr. T. A. Jaggar, Jr., visited the gulch, finding the carcasses of seven grizzlies and one cinnamon bear.

"Tests made at various places along the bottom of the gulch failed to show sufficient gas to extinguish the flames of burning matches.

"A year or two later Capt. H. M. Chittenden visited the gulch and found no animal remains nor any evidence of noxious gases." (R6)

The other deadly area in Yellowstone is referred to as a "poison pool." "At Yellowstone National Park, mysteries and marvels seem to lie on every hand, but there are few things so startling as a little pool where hundreds of helpless birds meet their doom every year. The innocent-looking little depression, which we may refer to as "Poison Pool,' is in the Upper Terraces of the Mammoth Hot Springs formations.

"The spot is well shaded and bedded with luxuriant grass, an enticing retreat for any unwary member of the feathered clan that stops for a refreshing drink or bath. The water is safe enough to drink, but death lurks in the carbon-dioxide gas that continually bubbles to the surface. On still days the area is a vacuum of death. Since the carbon-dioxide gas is heavier than air, it then increases its concentration to such an extent that the rapid respiratory systems of its victims are overcome and they drop to a resting place on the ground.

"I am certain that these birds do not always lose their lives on the first trip, because wind sometimes keeps the area well ventilated and safe. Sooner or later, however, the birds remain too long on the wrong day." On some days, as many as 26 birds succumb. Mammals are seldom if ever overcome. (R7)

X3. Grotto del Cano, Italy. "The well-known Grotto del Cano, near Naples, is the most familiar example of such accumulations of carbonic-acid gas; and frequently visitors are entertained by the asphyxiation of a poor dog, while the guide, whose head rises above the gas, is not affected by it." (R4; R1)

References

R1. Loudon, A.; "Visit to the Valley of Death, in the Island of Java," Edinburgh New Philosophical Journal, 12:102, 1831. (X1, X3)

R2. "Origin of the Upas Tree Story," Scientific American, 2:41, 1846. (X1)

R3. "Valley of Death," Scientific American, 10:99, 1864. (X1)

R4. Weed, Walter H.; "A Deadly Gas-Spring in the Yellowstone Park," Science, 13:130, 1889. (X1-X3)

R5. "Emanations of Carbonic Acid, Sulphurous and Other Gases of 'Death Gulch,' Yellowstone Park," American Journal of Science, 3:39:320, 1890. (X2)

R6. Traphagen, F. W.; "Death Gulch," Science, 19:632, 1904. (X2)

R7. Ericson, Mildred J.; "An Invisible Deathtrap," Natural History, 59:380, 1950. (X2)

R8. Legg, James S., and Zimmer, John T.; "A Poisoned Valley," Natural History, 60:290, 1951. (X1)

ESC6 Violent Turnovers of Lakes

Description. The violent interchange, disruption, or turnover of stratified layers in lakes. This phenomenon may be accompanied by loud noises, the release of lethal gases, color changes, strong odors, and flashes of light.

Data Evaluation. Popular descriptions of violent lake turnovers are available for three African lakes. One of these, Lake Nyos, in Cameroon, has been the subject of intensive study since the 1986 turnover that resulted in over 1700 deaths. Previous to this, little research had been carried out, but now the quantity and quality of the data are improving rapidly. Rating: 2.

Anomaly Evaluation. The major unanswered questions about the turnover phenomenon are: (1) What is the nature of the initiating stimulus?; and (2) What is the source of the light flashes that have been reported on occasion? Several answers to the first question have been proposed: earthquakes, underwater landslides, and strong winds. These are reasonable possibilities; it only remains to determine which are active. As for the light flashes, they have been generally ignored, even though analogous phenomena have been seen in some coastal regions. (GSD2-X17) The catastrophic release of carbon dioxide---the generally accepted cause of deaths around lakes susceptible to turnovers---does not account for luminous phenomena. Although the light-flash data are poor, they could lead to important modifications of turnover theory. Rating: 2.

Possible Explanations. Magma-derived gases, mainly carbon dioxide, build up in deep lake strata, which are capped by denser layers. Through the stimulus of an earthquake or land-slide, or some other event, this unstable situation is corrected---violently---as the lower density layers rise to the top. The purported light flashes might result from the spontaneous ignition of methane.

Similar and Related Phenomena. Flashes of light associated with some offshore detonations (GSD1-X8, GSD2-X17). Death gulches (ESC5).

Examples

X1. Lake Monoun, Cameroon. August 15, 1984. The village of Njindom. About 11:30 PM, the villagers heard a loud explosion coming from Lake Monoun. Early the next morning, people in a van driving past the lake discovered the body of a motorcyclist. The air smelled like battery fluid. One of the van's occupants collapsed. The others ran for their lives toward Njindom. By 10:30 AM, authorities had found 37 bodies along a 200-meter stretch of road by the lake. Blood was oozing from the noses and mouths of the victims, and the bodies were rigid. Also, animals and plants along the shore had suffered. On August 17, the lake turned reddish brown, indicating that it had been stirred up somehow.

Although Lake Monoun is in a volcanic crater, chemical analysis of the water found little of the sulphur and halogens normally associated with volcanic activity. However, the analysis did find a very high level of bicarbonate ions, which form when carbon dioxide is dissociated. One theory is that an earthquake disturbed the carbonate-rich deep water of the lake, which as it rose to the surface and lower pressures released huge volumes of carbon dioxide---not unlike the opening of a soda bottle. The resulting cloud of gas caused death by asphyxiation. (R2)

X2. Lake Nyos, Cameroon. "On 21 August (1986) at about 2130 a series of rumbling sounds lasting perhaps 15 to 20 seconds caused people in the immediate area of the lake to come out of their homes. One observer reported hearing a bubbling sound, and after walking to a vantage point he saw a white cloud rise from the lake and a large water surge. Many people smelled the odor of rotten eggs or gunpowder, experienced a warm sensation, and rapidly lost consciousness. Survivors of the incident, who awakened from 6 to 36 hours later, felt weak and confused. Many found that their oil lamps had gone out, although they still contained oil, and that their animals and family members were dead. The bird, insect, and small mammal populations in the area were not seen for at least 48 hours after the event. The plant life was essentially unaffected." (R5)

Over 1700 people died during this event. The lake itself contained mats of floating vegetation and had turned from clear blue to rusty red. On the southern shore, the water surge reached a height of 25 meters. Study of the phenomena determined that the victims had been asphyxiated by carbon dioxide. No concurrent volcanic or earthquake activity was discovered. (R5)

Several theories have been proposed to account for the Lake Nyos (and also the Lake Monoun) events. G. W. Kling relates the most popular of these: "According to one theory, CO_2-rich gas of magmatic origin rising through the diatreme beneath the lake contacted local ground water. In turn, this ground water became the vehicle for gas transport into the lake's hypolimnion. Stable stratification prevented mixing of bottom water with surface water and allowed gas accumulation well in excess of atmospheric saturation. Some unknown disturbance of this unstable system culminated in the gas release." (R6) In common parlance, the lake "turned over."

On December 30, 1986, however, a French scientist reportedly observed three explosions, accompanied by flashes of light, all coming from Lake Nyos. No injuries or fatalities occurred. (R7) The flashes of light are difficult-to-explain in terms of the release of carbon dioxide; but, as revealed below (X3), such flashes are known from a third lake in Africa. (WRC)

X3. Lake Bosumtwi, Ghana. Lake Bosumtwi has a history of frequent, rather regular, turnovers. Nevertheless, it was scarcely mentioned in the literature cited in X1 and X2. We present next an account from a 1936 article:

"An old saying among the inhabitants around the lake is 'Bosumtwi has fired or exploded gunpowder' (Bosumtwo oto atuduru). At irregular intervals once or twice a year, but apparently not within recent years, the lake becomes rough for one or two days, the colour of the water changes to almost black, the surface is covered with dead or dying fish, and the atmosphere becomes full of a choking smell of 'gunpowder.' This phenomenon is accompanied by a loud detonation. No rumblings or earth tremors are noted. Although never observed by any European and never mentioned by the natives, this phenomenon is well known to every lake dweller. The recent volcanic origin of Lake Bosumtwi immediately suggests exhalations of gases, in particular hydrogen sulphide. According to T. Robertson such upheavals are due to gases from decomposed organic matter at the bottom of a lake without any outlet, in particular to marsh gas. This explanation would also account for another phenomenon, mentioned by Sir Albert Kitson, i.e. 'flashing lights, making noises like the discharge of artillery.'" (R1) Superficially, the phenomena of Lake Bosumtwi closely resemble those of the two Cameroon lakes, although marsh gas (methane) does not seem to have been released by the Cameroon lakes. The light flashes at Bosumtwi and Nyos, however, are compatible with the methane explanation! (WRC)

References

R1. Rohleder, Herbert P. J.; "Lake Bosumtwi, Ashanti," Geographical Journal, 87:51, 1936. (X3)
R2. Weisburd, S.; "The 'Killer Lake' of Cameroon," Science News, 128:356, 1985. (X1)
R3. Kerr, Richard A.; "There May Be More Than One Way to Make a Volcanic Lake a Killer," Science, 233:1257, 1986. (X2)
R4. Weisburd, S.; "Cameroon: The First Wave of Clues," Science News, 130:180, 1986. (X1, X2)
R5. Kling, George W., et al; "The 1986 Lake Nyos Gas Disaster in Cameroon, West Africa," Science, 236:169, 1987. (X2)
R6. Kling, George W.; "Seasonal Mixing and Catastrophic Degassing in Tropical Lakes, Cameroon, West Africa," Science, 237:1022, 1987. (X1, X2)
R7. Weisburd, S.; "Cameroon Lake: New Clues, New Clouds?" Science News, 131:36, 1987. (X2)

ESC7 Unusual Petrifactions and Lignifications

Description. The conversion of organic and inorganic material and objects into stone, wood, and other substances with great rapidity and/or under unlikely circumstances, such as in graveyards.

Data Evaluation. Most of the accounts presented below are popular in character and lacking in scientific method. The chemical processes involved, in particular, are not investigated. Even so, the "eye-witness" features of the phenomena are probably accurately portrayed. Rating: 3.

Anomaly Evaluation. The phenomena reported here may properly be characterized as bizarre; but bizarreness is not a measure of anomalousness. The rapidity of petrifaction and chemical alteration may seem surprising in some instances, but in actuality we know next to nothing about the chemical environments involved. The reaction times and processes may be entirely reasonable. Given this lack of chemical insight, it seems proper to relegate these poorly observed phenomena to the class of "minor curiosities." Rating: 4.

Possible Explanations. None required, considering what is now known.

Similar and Related Phenomena. Rapid coalification (ESC14); rapid growth of stalactites (ESC10).

Examples

X1. Petrifying springs. Several of these are remarkable for the speed with which they petrify objects.

France. "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." (R1) Of course, one must always take these old, unrefereed accounts with several grains of salt. (WRC)

England. "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." (R5)

X2. Graveyard petrifactions and other transformations. Unusual transformations of corpses have taken place after burial.

Wisconsin. "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 last, 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 stones made no more impression upon it than upon marble. In striking upon the body with metal, a hollow singing sound was produced. .... The ground in which she had been buried was a yellowish loam, and the body lay about three feet above the lime rock." (R2)

Ohio. "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." (R2)

New York. "A sensation was created some days since in the vicinity of Potter's Field, at the discovery of a body which had undergone a remarkable transformation. The body had laid under three tiers of corpses, says the New York Evening Post, and the head and feet had disappeared, while the remaining portion, which was somewhat enlarged above its natural dimensions, presented the appearance of wax of an alabaster brightness. In short, the whole muscular structure had been changed into the substance known as 'adipocere.' This is a species of soap formed upon a principle analogous to what is known as 'fatty degeneration in living bodies.' The acids of fat (the stearic and margaric) are formed, and combine with ammonia and lime, which are derived from the elements of the body." (R3)

Alabama. In August of 1894, a petrified human body was found one mile south of Tuskegee. The discovery was investigated by J. M. Stedman, Professor of Biology, Alabama Polytechnic Institute.

"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 the 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 a 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.

.....

"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." Many gruesome details have been omitted! (R6, R7)

X3. Lignification. This must be a very rare phenomenon, for only one example has been found.

Brazil. "Naturalists are indebted to Senhor Lopez Netto, Brazilian Minister to the United States, for introducing to their attention a specimen of a phenomenon which, although it had been regarded as possible, had never before been observed---that of an animal turned into wood. The specimen is that of a snake called the jararaca, one of the most venomous reptiles of the province of Matto Grosso, in Brazil, which, having crept into a crack in the bark of a tree, has died there, and afterward become lignified. As the cut (omitted) shows, but less plainly than the specimen itself, the head, neck, and other parts of the animal are clearly delineated, and the most delicate details of the organization are plainly visible in many regions---as in the nostrils and the eye-cavities, and in the disposition of the scales and the cephalic plate on a whole half of the surface of the head. And the identity of the figure with the little jararaca of Brazil has been acknowledged to be evident by persons who are acquainted with that reptile. M. Louis Oliver, of the Botanical Society of France, who has made an anatomical examination of the figure, reports that he has found it to be composed of cells and fibers like those of the secondary wood which surrounds it. 'The formation,' he says, 'can not be explained by saying that it has resulted from the deposition of the elements in a hollow, which, having been traversed by the animal, has preserved its form; for not only the contour of the serpent, but the whole relief of his form, is recognizable in the wood.' The entire body of the animal has been thus lignified, except the center, where the constituent elements of the animal still exist. Following the line of the projection of the head may be seen a cylindrical figure, also in relief, which seems to represent the larva of an insect. The deduction is therefore drawn that the reptile, pursuing the insect into a crack in the tree, had insinuated itself between the wood and the bark, or into the zone of the cambium, out of which the wood and inner bark are formed. Having died there, it went through the process of decay, in the course of which each animal particle as it was dissolved was replaced by a particle of woody tissue deposited by the cambium." Many scientists examined the actual specimen and concurred with the assessment just quoted. (R4)

X4. Other unusual petrifactions.

Washington, DC. A curious petrified log was found in an anomalous deposit of brightly colored sand in 1954. The sand was composed of red, white, and yellow bands. "This petrified log, which is cypress and fairly soft, shows several unusual features not present in any other specimens the writer has seen or heard of. The first had reference to drusy quartz crystals. While drusy quartz is common in local petrified wood, in this instance nature outdid herself in that every particle of exposed surface is completely covered with crystals from microscopic size up to one-fourth inch long, many being doubly terminated."

.....

"The second unusual feature noted is that all the log did not petrify. In fact, but little of it is turned to stone, since all fragments located and collected could be contained in three bushel baskets. A log 16 feet long and a foot through would measure greatly in excess of that. Petrifaction was not confined to any given part of the log but extended more or less through its whole length and diameter.

"And this leads to the third unusual feature which may explain, in a measure at least, why all the log did not petrify. The log had been riddled by worm borings, aided to a small extent by grubs....It is our impression that none of the log would have petrified had it not been for these worm borings. Not a specimen has been found that did not contain at least one." The author explains that the mineralized ground water doubtless entered via the worm holes.

.....

"Attention is now called to the final and probably the most unusual feature in this petrifaction. To date no one has been found who will even hazard a guess as to the cause. For want of a better name we call it the double cone formation..... The cones are rather uniform in diameter, averaging one quarter of an inch, while in length they range from a half inch to as much as four inches. The average would probably be less than an inch. The larger ones resemble a thin lead pencil sharpened at both ends, while the smaller ones resemble two ice cream cones attached base to base.....In addition to those attached to pieces of wood, small double cones were found in the soil for the whole length of the log, even when no wood was found in a foot of them.....The cones are formed around a hairlike filament, with crystals radiating outward from it." (R8)

Norway. During World War II, the German occupation forces in Norway strung tons of barbed wire along many beaches. Most of this was removed after the war, but some had been covered with windblown sand. After some winter storms, in 1981, some of the buried wire was exposed. It had been transformed into sandstone lumps. (R9) This represents an interesting example of rapid petrifaction; but it is probably not anomalous, since iron corrodes quickly in seawater. (WRC)

References

R1. "Remarkable Petrifying Spring," Scientific American, 2:335, 1847. (X1)
R2. Bancroft, J.W., and Goodwin, Jas. M.; "Petrifactions," Scientific American, 10:211, 1855. (X2)
R3. "Curious Phenomenon in Potter's Field," Scientific American, 13:329, 1858. (X2)
R4. "A Lignified Snake," Popular Science Monthly, 22:138, 1882. (X3)
R5. King, I. Charles; "Petrifying Springs," Scientific American, 60:181, 1889. (X1)
R6. Stedman, J.M., and Anderson, J.T.; "Observations on a So-Called Petrified Man," American Naturalist, 29:326, 1895. (X2)
R7. Stedman, J.M., and Anderson, J.T.; "Observations on a So-Called Petrified Man," Scientific American Supplement, 39:16116, 1895. (X2)
R8. Morgan, French; "Puzzling Petrifaction," Rocks and Minerals, 29:563, 1954. (X4)
R9. Wik, Olav; "Barbed Wire Placed in World War II Already Petrified," Creation Research Society Quarterly, 24:14, 1987. (X4)

ESC8 Geological Effects of Natural Combustion

Description. (1) The widespread existence in sedimentary deposits, especially the coal beds, of abundant charcoal-like material. The most common charcoal-like substance is fusain, or mother-of-coal, which is found in almost all coals worldwide. (2) Deposits of slags, clinkers, baked rocks, and thermally metamorphized rocks are also frequent occurrences. They, too, are usually found in associated with coal measures.

Data Evaluation. The characteristics of fusain have been detailed in many papers and books written on the genesis of coal; however, little has been published on other "charcoals" and carbonaceous deposits. The effects of "combustion metamorphism" are detailed in several papers. In particular the Mottled Zone Event, in Israel, has been studied extensively. Rating: 2.

Anomaly Evaluation. Fusain poses serious questions about the validity of our theories about coal formation. If, as widely believed, fusain is charcoal from forest fires, there seems to be too much of it and, as T.M. Harris puts it, "It would make the past a 'nightmare.'" (R8) But, even if we admit a nightmarish history for the planet during the formation of the coal beds, the character of the fusain is actually inconsistent with forest-fire origin, as discussed at length below. (X2) Either our notions about the origin of fusain are wrong, or the accepted theory of coal formation is incorrect, or both. Fusain, therefore, represents an important geological anomaly. In contrast, the more spectacular effects of combustion metamorphism are readily explained in terms of naturally ignited coal beds and other bituminous materials. Rating: 1.

Possible Explanations. Fusain may have a non-combustion origin in the sense that the chemical reactions involved are slow---not forest fires. Other thermally metamorphized materials seem well-accounted-for by natural fires, especially burning coal seams.

Similar and Related Phenomena. Widespread soot layers (ESD9); the controverted origin of coal (ESC14); natural fires (ESC4).

Examples

X1. Clinkers, slags, baked rocks. The thicknesses and areal extents of these fire-metamorphized rocks are very impressive, although not particularly anomalous.

Montana and the Dakotas. From a review printed in the American Journal of Science: "In this paper published in the Proceedings of the Boston Society of Natural History, Jan., 1874 (vol. xvi), Mr. J.A. Allen describes metamorphosed beds of clays and sands, accompanied by pumiceous and lava-like materials, looking like true volcanic products, occurring far from any volcanic region and due solely to the burning out of beds of brown coal. The thickness of the altered beds amounts in places to thirty or even fifty feet, but seldom exceeds eight to twelve feet. Generally the overlying clays and sands have been merely hardened and changed in color; but in some places, where the coal bed was thick, the deposit in immediate contact has been more or less fused, and has received occasionally a vitreous porcellanic or vesicular structure, and even the scoriaceous and pumice-like aspect of volcanic products. The lowermost of the burnt series consists of cinders and clinkers much like the residuum left in coal grates from the combustion of ordinary mineral coal.

"The region of the Bad Lands, on the Little Missouri, is one of the largest areas of this Lignitic metamorphism, it covers a breadth of twenty to thirty miles for 200 miles in length; all the ridges and buttes are capped or bounded with the reddened and indurated shales. Other such areas occur along the Yellowstone near the mouth of the Powder River, and along Powder River, and also on the Rosebud and Tongue Rivers. They were found by Dr. Hayden on the sources of the Tongue River, within a few miles of the Big Horn Mountains and on those of North Fork of the Shyenne River and elsewhere; and by Dr. Hines as far south as the 'foot slopes' of the same range on the Crazy Woman's Fork of Powder River. Nicollet long since described, but from report, the pseudovolcanoes, or smoking hills of the west, which were made, evidently, from the burning of the subjacent coal beds, and he attributes the fire to the action of decomposing pyrites on lignites and other material of a combustible nature.

"Mr. Allen states that the landscape is variously affected by the metamorphism. The baked rocks, besides giving their red tints to the country, arrest or greatly retard the erosion of the buttes and ridges consisting of them. Over areas of thousands of square miles they thus in great measure determine the surface contours and protect the hills from rapid denudation. Fragments of pumice have been found on the Missouri as far south as Port Pierre, and early explorers supposed them to be the products of unknown volcanoes, high up in the mountains." (R1) See ESC4 for information on the spontaneous ignition of coal beds.

The beds of clinkers and baked rocks described so well by Allen above are particularly well-developed in Wyoming. See for example the 1905 report of E.S. Bastin (R3) and the more recent magnetic studies of A.H. Jones et al. (R14)

Arizona. "In Coal Canyon, some eighteen miles northeast of Tuba city in Coconino County, Arizona, there outcrops a seam of sub-bituminous coal that is mined to supply fuel for the Indian School and Agency buildings at Tuba City. A part of this seam near the head of the canyon has burned. At this place the thickness of the seam was four to six feet and of the overburden about thirty-five feet.

"In most places, the chief effect on the overlying Mancos shale has been reddening and slumping, but locally, where natural chimneys formed, considerable melting took place. The melted rock flowed into and filled cracks in the surrounding shale and also collected in small masses. For the most part, the cracks developed in three systems, one horizontal, and two vertical, roughly at right angles to each other. They are presumably a consequence of the heating of the shale. The casting, formed by the liquid crystallizing in these cracks, has reproduced faithfully the pattern of the cracks in the original rock. When the shale is removed, the casting remains and is seen to be an intricate 'box' structure." Laboratory tests of the melted rock proved that complete liquifaction did not take place until 1212°C. (R6) Thus, we have here not only a delightful natural box-like structure but an estimate as to just how hot these natural fires became. (WRC)

California. Evidence of combustion metamorphism in southern California is widespread, as described in the Abstract of a 1976 paper in Science by Y. K. Bentor and M. Kastner: "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 rock recrystallized and partially melted to form pseudomagmas which intruded the country rocks." Bentor and Kastner studied the Grimes Canyon area, 5 kilometers south of Fillmore, in some detail. (R11)

Canada. Combustion metamorphism occurred on the North Saskatchewan River, 70 miles north of Edmonton, Alberta, when a lignite bed took fire. "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." (R2)

In ESC4, we mentioned the famed Smoking Hills of the Canadian Arctic. The coal beds in this region have been burning for at least 150 years and have produced considerable metamorphism. (R13)

Israel. One of the most thoroughly studied regions of combustion metamorphism is the so-called Mottled Zone of Israel.

"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 Gharen 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." Summarizing, the Mottled Zone has the characteristics of high-temperature metamorphism without an obvious source of heat. (R10)

In the absence of a heat source in the form of an igneous intrusion, the burning of fossil fuel seemed indicated. An analysis of oxygen and carbon isotopes in the Mottled Zone carbonates pointed to the burning of bituminous

Laminated rock with stony and glassy layers created by natural combustion. (X1) (M. Kastner) matter in the organic-rich Ghareb and Taqiya chalks and marls. (R12) The Mottled Zone has been dated at 13.2 million years. (R10, R17

Widespread occurrence. A most curious example of combustion metamorphism is found in the occasional discovery of peculiar rock-like clinkers in the hollow snags that are sometimes left after a forest has been burnt over. These clinkers generally have a greenish hue and thought by some to be meteorites. Weighing several pounds, they are actually fused wood ash. "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." (R15; R7)

X2. Natural charcoal deposits.

England. After commenting on the chalk sludge that is present in some of the English lowlands, D. V. Ager mentions a strange charcoal band: "Within the sludge there is a clear black horizon, only an inch or so thick, which has now been recognized all over southern Britain. The black coloration is due to charcoal fragments from burnt wood. In fact, at one stage in this study our thoughts ran on catastrophisms of a biblical kind and we pictured half-seriously a universal conflagration to account for the black band. It is more likely, however, that it represents a short period of dry climate when there were frequent brush fires. The snail fauna suggests the same thing and enabled the bed to be correlated with the Allerød oscillation of Denmark and northern Europe generally. This was a brief episode of climatic amelioration after the last glaciation. The charcoal made it possible to get a carbon-14 date on the deposit, giving an age of about 10 770 years before the present. This fits all over Europe and correlates remarkably with the Two Creeks horizon of the same kind around the Great Lakes in North America." (R9) It would be interesting to learn exactly how widespread this black band is. How is it related to the ubiquitous fusain or mineral charcoal, which we treat next?

Widespread occurrence. The term "fusain" (also called mother-of-coal and mineral charcoal) is applied to lumps of carbon found in the coal measures and in some other sedimentary rocks. Fusain is rather porous, crumbly, contains little if any volatile matter, and, under the microscope, is of obvious vegetable origin. The accepted theory-of-origin for fusain states that it is charcoal that has been incorporated into coal and some other rocks, and then mineralized or otherwise modified. Fusain is so common in coals of many different types and in different geological settings that one wonders how so much charcoal was ever created. Did our planet actually see so many forest fires during its history? (R8)

Indeed, the forest-fire theory is disputed by some and, despite what the textbooks say, the origin of fusain remains a geological conundrum, as emphasized by G.H. Cady:

> "The forest fire origin of fusain is disputed by many botanists who believe the presence of certain combustible components in fusain, such as resins, indicates that chemical causes operating under special conditions bring about the formation of fusain. No completely satisfactory explanation of the origin of fusain has been stated. It is found in all ranks of coal with relatively little difference in composition. There is also transitional material, between normallt coalified wood or bark and fusain, called semifusain. Because of its porosity, fusain is commonly mineralized into a hard and heavy substance; unmineralized fusain is soft and light. Fusain occurs in all sizes from particles of microscopic dimension to aggregates forming fairly continuous thin sheets or lenses several feet across and several inches thick." (R16)

The forest-fire theory for the origin of fusain also severely strains the major scenarios proposed for the creation of the coal beds. T. E. Savage explains: "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 the 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 (Illinois) 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 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 matter 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." (R5) In other words, the charcoal nature of fusain may not be due to the widespread and repeated incidence of forest fires, but rather to slower, in situ chemical processes. (WRC)

But even if one subscribes to the forest-fire theory of origin for fusain, E. C. Jeffrey has discovered an unsettling implication: "As the result of the investigation of coal by improved methods, which permit of the preparation of successful sections, even of the most resistent (sic) 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 is 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 bogshead or oil shales is almost universal, it follows that our ideas of the conditions under which coal has been formed must be radically modified." (R4)

References

R1. Allen, J. A.; "Metamorphic Products from the Burning of Coal-Beds of the Lignitic Tertiary in Dakota and Montana," American Journal of Science, 3:8:141, 1874. (X1)

R2. Tyrrell, J. B.; "Naturally Reduced Iron," American Journal of Science, 3:33:73, 1887. (X1)

R3. Bastin, E. S.; "Note on Baked Clays and

Natural Slags in Eastern Wyoming," Journal of Geology, 13:408, 1905. (X1)
R4. Jeffrey, Edward C.; "Nature of the Substance Known as Mother of Coal and Its Relation to the Process of Coal Formation," Geological Society of America, Bulletin, 24:715, 1913. (X2)
R5. Savage, T. E.; "On the Conditions under Which the Vegetable Matter of the Illinois Coal Beds Accumulated," Journal of Geology, 22:754, 1914. (X2)
R6. Brady, L. F., and Greig, J. W.; "Note on the Temperature Attained in a Burning Coal Seam," American Journal of Science, 237:116, 1939. (X1)
R7. Milton, Charles; "Stones from Trees," Scientific Monthly, 59:421, 1944. (X1)
R8. Harris, T. M.; "Forest Fire in the Mesozoic," Journal of Ecology, 46:447, 1958. (X2)
R9. Ager, Derek V.; "Catastrophic Stratigraphy," The Nature of the Stratigraphic Record, London, 1973, p. 40. (X2)
R10. Kolodny, Yehoshua, et al; "Fission Track Age of the 'Mottled Zone Event' in Israel," Earth and Planetary Science Letters, 11:269, 1971. (X1)
R11. Bentor, Y. K., and Kastner, M.; "Combustion Metamorphism in Southern California," Science, 193:486, 1976. (X1)
R12. Matthews, Alan, and Kolodny, Yehoshua; "Oxygen Isotope Fractionation in Decarbonation Metamorphism: The Mottled Zone Event," Earth and Planetary Science Letters, 39:179, 1978. (X1)
R13. Havas, Magda, and Hutchinson, Thomas C.; "The Smoking Hills: Natural Acidification of an Aquatic Ecosystem," Nature, 301:23, 1983. (X1)
R14. Jones, Alison H., et al; "Clinker Deposits, Powder River Basin, Wyoming and Montana: A New Source of High-Fidelity Paleomagnetic Data for the Quaternary," Geophysical Research Letters, 11:1231, 1984. (X1)
R15. Englis, Duane T., and Day, W. N.; "Peculiar Clinkers Found in Snags after Forest Fires," Science, 69:605, 1929. (X1)
R16. Cady, Gilbert H.; "Coal," McGraw-Hill Encyclopedia od Science and Technology, 3:238, 1977. (X2)
R17. Kolodny, Yehoshua, and Gross, Shulamit; "Thermal Metamorphism by Combustion of Organic Matter: Isotopic and Petrological Evidence," Journal of Geology, 82:489, 1974. (X1)

ESC9 Rocks and Sediments of Controverted Origins

Description. A collection of rocks and sediments for which no general consensus as to origin yet exists:

X1. Graphite
X2. Dolomite or dolostone
X3. Chalk
X4. Limestone
X5. Granite
X6. Graywacke
X7. Consolidated slabs on the Pacific floor
X8. Tube agate
X9. Methane hydrate
X10. The Chilean nitrate deposits
X11. Black shales
X12. Banded iron

Note that some materials of great scientific and historical importance have been accorded a higher level of classification: seawater (ESC11); petroleum (ESC13); coal (ESC14); and natural gas (ESC16).

The dozen rocks and sediments treated here on a collective basis are only those we have come across so far in our limited study of the literature; there are assuredly many more.

Data Evaluation. As in other collective categories, the data quality and data quantity vary from example to example. However, since most of the examples here have been subjects of considerable debate, the data file is substantial. Rating: 2.

Anomaly Evaluation. Anomalousness runs the gamut from curiosity-level (tube agate) to highly critical (methane hydrate). See each discussion for comments.

Possible Explanations. See individual entries.

Similar and Related Phenomena. See individual entries.

Examples

X1. Graphite. Graphite is a very soft form of carbon with a metallic sheen. It occurs in:

1. Bedded deposits
2. Disseminated deposits
3. Vein, or vein-like, deposits; which are classified as fissure veins, contact deposits, and pegmatite deposits.
4. Deposits with native iron and in meteorites. (R3)

The following paragraph, taken from the McGraw-Hill Encyclopedia of Science and Technology, provides us with the general scientific consensus as to the origin of graphite:

> "Graphite arises from the thermal and regional metamorphism of rocks such as sandstones, shales, coals, and limestones which contained organic products not exposed to an oxidizing environment. It can also form in a strongly reducing environment, such as in serpentines and limestones where hydrogen gas may reduce carbon dioxide. Platy graphite showing crude crystal surfaces often occurs speckled in coarsely crystallized marbles. The major sources of graphite are in gneisses and schists, where the mineral occurs in foliated masses mixed with quartz, mica, and so on. Noteworthy localities include the Adirondack region of New York, Korea, and Ceylon. In Sonora, Mexico, graphite occurs as a product of metamorphosed coal beds." (R41)

The anomalies associated with graphite so far all relate to the vein mode of occurrence. Several questions may be posed:

1. Does the mainstream explanation of graphite origin adequately account for the major deposits, such as those in Sri Lanka (Ceylon)?

2. Is some Precambrian graphite of biogenic origin, thus providing more evidence for the early appearance of abundant life on our planet?

3. Is there a relationship between graphite and anthraxolite (also called Precambrian coal)? See ESX4 for more on anthraxolite.

4. Is there any connection between graphite formation and the outgassing of methane from the earth's crust?

The Sri Lanka deposits. The graphite here is primarily found in veins measuring from a few millimeters to more than a meter in thickness. "Many and varied theories have been proposed to account for the origin of the Ceylon and similar deposits, but none have (sic) proven wholly satisfactory. Our knowledge of them is however sufficiently definite to permit us to rule out certain of these theories. The deposits are not metamorphosed interbedded coal, since they form irregular vein systems often cutting across the foliation of the enclosing rocks; on the other hand it is perfectly clear that the graphite was deposited along irregular fracture-planes. Any theory of origin through lateral secretion from the wall rocks is untenable because of the extreme sharpness of the vein walls and the scarcity or absence of graphite in the wall rocks. The suggestion that they represent fissures filled with asphalt or other carbonaceous material which was later metamorphosed into graphite, is untenable because in Ceylon and in a number of other localities where such veins occur they are themselves younger than any regional metamorphism or igneous intrustion capable of affecting (sic) such a change... It seems necessary to accept the only remaining hypothesis, that of deposition from some sort of a solution penetrating along fracture planes in the rocks. In short, they are true fissure veins. In conclusion, no theory of the origin of graphite veins can be satisfactory unless it takes into account not only the graphite but the accessory minerals, quartz, pyrite, and numerous silicates which are commonly present in these veins. Their presence imposes certain limitations which must be reckoned with." (R3) The accepted explanations of graphite origin say nothing about solutions per se. (WRC)

Possible biogenic origin of Precambrian graphites. Graphite deposits in Finland have carbon isotope ratios ($^{12}C/^{13}C$) that are strongly suggestive of a biological origin. (R8) This was reported in 1948.

In 1981, M. Schoell and F.-W. Wellmer confirmed this in a study of Canadian graphite deposits. "Some 35% of the Precambrian graphite samples measured have ^{13}C concentrations which lie outside the Phanerozoic range. Enrichment has usually been explained by the preferential loss of ^{12}C during metamorphism, but depletion is harder to account for. It has been suggested that depletion may be a consequence of higher CO_2 partial pressure in the Precambrian or may have come about because of the predominance of lipids depleted in ^{13}C in Precambrian organic matter." (R37) Obviously, this does not tell us much about Precambrian life---only that it may have been much more prolific than currently supposed. (WRC)

The anthraxolite connection. G.R. Morton quotes J.J. Mancuso and R.E. Seavoy in this regard:

> "Anthraxolite is a name suggested by E.J. Chapman for a black, combustible coallike solid found in Precambrian rocks that resembles anthracite coal but occurs in veins and fissures. It was regarded as having been formed by the low-grade metamorphism of liquid bitumen that was probably derived from algal remains. Deposits of coal or anthraxolite could well have been the source for high-grade graphite deposits. Occurrences of coal and anthraxolite have been reported and described from a number of localities in the Precambrian rocks of Michigan, Ontario, the Northwest Territories and northern Minnesota." (R29)

Note that anthraxolite's mode of occurrence closely parallels that of graphite, but that anthraxolite is not mentioned as a possible graphite source in many texts. We shall return to anthraxolite in ESX4. (WRC)

X2. Dolomite or dolostone. Strictly speaking, the word "dolomite" should apply only to the mineral $CaMg(CO_3)_2$, but it is also commonly used to designate limestone rock containing a substantial fraction of the mineral dolomite. The word "dolostone" is sometimes employed to describe dolomitic limestone.

From an encyclopedia: "Dolomite and dolomitic limestone are known from rocks of all ages but are more common in older rocks, particularly the Paleozoic. Dolomite is most often found in association with limestone, with which it may be interbedded or laterally graduational. Some dolomitized zones do not follow bedding planes and are thought to be controlled by faults or folds. Dolomitization of limestones may be highly selective: for example, the cores of the Silurian reefs of Illinois, Indiana, and Wisconsin are dolomite, whereas the reef-flank material may only be partially dolomitic. Modern dolomite has been found in supratidal flats in carbonate depositional areas such as the Bahamas and in a variety of hypersaline lagoons or arms of the sea in warm climates." (R40)

How was dolomite formed? A.N. Strahler gives the present position of the geological community: "Dolomite rock poses a problem of origin, since the mineral is not excreted by organisms as shell material. Direct precipitation from solution in seawater is not considered adequate to explain the great thicknesses of dolomite rock that are found in the geologic record. The most widely held explanation of the formation of dolomite rock is that it has resulted from the alteration of limestone by the substitution of magnesium ions of seawater for part of the calcium ions." (R35)

Actually, the phenomena of dolomite deposits, as developed below, allow for more than one mode of origin. Furthermore, some dolomite exists in cyclothems with limestone and also seems to display a periodicity in its occurrence in the stratigraphic record. In this sense, the presence of dolomite may be an indicator of environmental conditions quite different from those of today, since very little dolomite is being laid down today. Thus, there seem to be several unaccounted for-facets of the dolomite problem. (WRC)

Thickness and horizontal extent of dolomite strata; stratigraphic trends. "Ancient carbonate rocks contain abundant stratified dolostone bodies. In places dolostone beds thousands of feet in thickness underlie many thousands of square miles of the earth's surface. In contrast, recent sediments consist almost entirely of the minerals calcite and aragonite, both $CaCO_3$, which is thought to be forming the rock called limestone. The mineral dolomite, $CaMg(CO_3)_2$, is nearly lacking in modern sediments. The striking contrast between the composition of ancient carbonate rocks and recent carbonate sediments presents a problem of first magnitude." (R21) Two questions posed by this quotation are: (1) Can such immense deposits of dolomite be explained by simple alteration of limestone or by direct precipitation from seawater? (2) How and why did the ancient oceans differ from those of today? (WRC)

Interstratification, cyclothems, cyclic deposition. To some degree these three terms overlap, but the material presented below will show the precise field differences and geological implications.

First, consider interstratification, as described by F.M. VanTuyl: "In some instances the relationship of dolomite to limestone is such as to indicate that the alteration was accomplished by solutions which migrated from above downwards after the limestone was formed, or at least in the closing stages of its formation.

"It is an interesting fact that certain layers have sometimes been passed over during the dolomitization of adjacent ones, and show little or no sign of alteration. The so-called interstratification of limestone and dolomite cited by some as evidence in favor of some primary theory of origin is then, in some cases at least, rather a pseudo-interstratification produced by the selective dolomitization of an original limestone. Some layers which have been passed over have been noted to be coarser grained than the adjacent layers which have been altered and this would seem to explain their greater resisting power. At times, however, the unaltered layers do not appear to differ markedly from the altered ones. The phenomenon is then difficult to account for. Normally the contact lines between such interbedded layers of limestone and dolomite are fairly regular and definite, but in some instances they are known to be very irregular and may even simulate irregular contacts produced by disconformity. A remarkable example of pseudo-disconformity produced by uneven selective dolomitization has been observed in the St. Louis limestone near Farmington, Iowa. Here a bed of altered limestone is found resting very irregularly on a bed of dolomite. The two beds are very different physically and might readily be taken at first sight for two distinct formations, but when the contact is traced laterally for a short distance the lower bed loses its dolomitic character and passes into a limestone very similar to and continuous with the bed above." (R2)

The term "cyclothem" is applied to cases of rhythmic bedding, in which the same stratigraphic elements repeat over and over. (See ESR5.) If dolomite is really only altered limestone, the existence of long sequences of repeating limestone-dolomite couplets stretches this theory-of-origin. D. D. Sarin has found such rhythmic bedding near Charlton, Maryland. "The rocks exposed in this outcrop are cyclical, each cycle being composed of a dolomite member and a limestone member. In all, some 35 cycles were recognized and numbered in a section totalling 4300 cm." (R14)

While much more dolomite seems to have formed early in the earth's history, the study of deep-sea sediments has shown that pulses of dolomitization have occurred at surprisingly regular intervals over the past 130 million years. "(D.N.) Lumsden examined the reported dolomite content of 844 marine sediment samples cored during the Deep Sea Drilling Project from 127 sites in the Atlantic Ocean, Pacific Ocean, Mediterranean Sea, Red Sea, Black Sea and Gulf-Caribbean. In general, he found peaks in dolomite production at about 130 million years ago (Ma), 110 Ma, 90 Ma, 50 Ma and 10 Ma. The similarities of dolomite records at widely spaced sites convinced him that the fluctuations in dolomite concentration were not random, but were due to the same global cause. Lumsden believes that cause is tied to sea level changes; period of low dolomite formation appear to have corresponded to low sea levels, and dolomite peaked at high sea levels." (R31) This 40 Ma periodicity should be compared to the proposed cyclicity of climates, geomagnetic reversals, and asteroid/comet impacts. (WRC)

Mottling. "Another striking relationship of limestone to dolomite is exhibited in a certain layer of an interbedded series of limestones and dolomites of the Beekmantown in the old Walton Quarry near Harrisburg, Pa. The beds dip south here at an angle of 30°. The layer in question is represented by dolomite six feet in thickness in the upper part of the quarry face and on each side of it appear good limestone layers. Now in the lower part of the quarry the lower half of this layer passes abruptly into limestone and continues to the quarry floor as two distinct layers each 3 feet thick. Samples of the dolomite at the point where it passes into limestone yielded 18.1 per cent of $MgCO_3$ while the limestone itself yielded only 0.83.

"It will be noted that in the above instances the gradation of limestone into dolomite is abrupt, but in many cases the gradation takes place through transition zones of limestone mottled with dolomite. There can be no doubt but that these mottled limestones represent an incipient stage in the process of dolomitization and it is believed that many dolomites have passed through such a stage in the progress of their formation. In most cases the phenomenon of mottling appears to be of purely inorganic origin, having resulted from a process of dolomitization which began at certain favorable centers and spread outwards. In come cases, however, it has been produced by the selective alteration of areas suggesting algae and fucoids in the limestone first, and the spreading out of the dolomite from these as nuclei."

.....

"It has been observed that the spreading of dolomitization from certain centers in limestone may give rise to mottling on a large scale if these centers be few and far apart. For example there is a conspicuous bed of dolomite pseudo-bowlders in the St. Louis limestone at Alton, Ill., which appears to have been formed entirely in this manner. These bowlder-like masses range from a few inches up to six feet in diameter and contain 32.39 per cent of $MgCO_3$ while the limestone matrix bears only 3.39. That they were formed in place is clearly indicated by the fact that the contact of the bowlders with the limestone matrix is occasionally graduational and that the stratification lines of the limestone may at times be traced directly through the bowlders." (R2)

Modern formation of dolomite. It has sometimes been stated that dolomite is not now being laid down. This is almost correct; the known examples are few and minor. C. C. vonder Borch et al have reported modern dolomite in small saline lakes in southeastern South Australia. (R15) Some is also forming in a hypersaline lagoon in southern Kuwait. (R30)

Facts favoring the limestone-alteration hypothesis. "(1) the lateral gradation of beds of dolomite into limestone, sometimes very abruptly; (2) the mottling of limestones by irregular patches of dolomite on the borders of dolomite masses; (3) the existence of remnants of unaltered limestone in dolomite, and of nests of dolomite in limestone; (4) the irregular boundaries between certain beds of limestone and dolomite; (5) the presence of altered oolites or fossils in many dolomites; (6) the protective effect of shale beds; and (7) the obliteration of structures and textures." (R2)

Facts favoring the precipitation hypothesis. "While some dolostones are the result of replacement, others seem to have been directly precipitated from water. Some dolostones have extremely delicate and well-preserved primary sedimentary structures such as simple lamination, ripple lamination, small scale cross-bedding, graded bedding, drying cracks and fossils. If replacement had occurred, most of the structures would be obliterated. Many of the laterally extensive dolostones are underlain and overlain by limestones that show no alteration. The contacts between beds of dolostone and limestone are sharp and well defined. If replacement had occurred the contacts would be expected to show alteration. Strata of dolostone which are laterally persistent for thousands of miles can be best explained by direct precipitation." (R21)

A Precambrian dolomite that seems to be a direct precipitate from seawater is the Beck Spring Dolomite, which outcrops in eastern California. This dolomite shows sedimentary structures on both broad and microscopic scales. In addition, isotopic trends were typical of precipitated material. (R24, R28) The interpretation here is that Precambrian seawater may have been considerably different than modern seawater, which does not precipitate dolomite. (WRC)

X3. Chalk. Chalk is a very fine-grained, porous, friable variety of limestone. The rock consists almost entirely of the shells of tiny marine organisms cemented together by a structureless calcite. In some deposits up to one third of the chalk consists of shells and other organic debris. Of special interest are tiny (less than 0.1 mm) spherical bodies found in chalk; are they of organic or inorganic origin? Another interesting feature of chalk is its apparently simultaneous appearance in the stratigraphic record in many parts of the world. (ESD9)

In chalk, we find a manifestation of the "limestone compaction engima," introduced in ESP4 and taken up again here and in ESC4. A major implication of this engima is that chalk could be a chemical precipitate rather than a conventional sedimentary rock; that is, the calcite matrix is derived directly from chemicals dissolved in seawater. The case for the chemical origin of chalk was presented by W. A. Tarr in 1925:

> "The lack of mechanical wear (of the contained shells); the evident absence of currents, as shown by massiveness and lack of stratification; the perfectly preserved minute spheres and cells; and the absolute lack of any evidence of an organic origin of the dense material (matrix), all favour the view that the Chalk was inorganic in origin." (R4)

Tarr suggested that the calcite matrix of the chalk was simply a precipitate of calcium carbonate from saturated seawater. Such a precipitation process would entrain the shells of tiny organisms and preserve the delicate structures without crushing them.

Interestingly enough, some hard varieties of limestone are considered by some to be of inorganic origin. (X4) In the context of hard, fine-grained limestone, however, inorganic origins are not anomalous. (WRC)

X4. Limestone. One of the most common of all sedimentary rocks, limestone is mostly calcium carbonate ($CaCO_3$). Clay minerals and silica (quartz grains and chert) are often incorporated in limestone, giving it a wide range of colors, textures, and physical properties. Some limestones contain abundant shells and other fossils. Limestones are also associated with dolomite (X2), with which they have a complex relationship.

The limestone-dolomite relationship. During Precambrian times especially, the formation of dolomite predominated over limestone; but, perhaps due to major changes in ocean chemistry, limestone formation has been much more common in later geological periods, as described in X2. This transition from dolomite to limestone production constitutes a major geological puzzle. (R24)

Also mentioned in X2 were the dolomite-limestone cyclothems; that is, the repetitive couplets of dolomite and limestone strata. This regular alternation must betoken significant cyclic changes in environmental conditions. (R14)

Precipitated limestone of inorganic origin. The inorganic precipitation of calcium carbonate directly from seawater is a recognized and accepted process in limestone formation. This is mentioned here because of the emphasis placed on the subject in the preceeding item on chalk. (ESC9-X3) Usually, inorganic limestone is considered a minor contributor to the extensive limestone family, except perhaps in the case of formations like the Franciscan Limestone of California. This is a fine-grained rock which contains only minor quantities of organic material. (R16)

The limestone compaction enigma. The laboratory demonstration that the delicate shells incorporated in many limestones could have survived intact after considerable mechanical compaction actually eases the problem of explaining the origins of some fine-grained limestones. For years it had been thought that the survival of fragile shells meant that limestone compaction did not occur. This constraint made it difficult to explain how the fine-grained matrix was deposited. (R23) Obviously, we cannot claim any anomaly here.

Limestones as eruptive rocks. In view of the general belief that limestones are exclusively sedimentary in origin, the notion that they might have a magmatic source comes as a surprise.

"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 nepheline. 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." (R9)

The so-called "carbon problem." Limestone, especially, but also dolomite and other carbonate rocks represent a truly immense reservoir of carbon near the earth's surface. Even if one ignores the carbon fixed in oil and coal deposits, the carbon in the carbonates is many times that contained in today's atmosphere in the form of carbon dioxide. Does the sheer volume of the carbon in the carbonates represent an anomaly, or can mainstream science provide a reasonable source?

To explore this largely neglected problem, we present, first, an appreciation of the quantity of carbon tied up in the form of limestone; and, second, one possible solution of the dilemma.

G.R. Morton on organic carbon deposits: "It must, however, be admitted that the number of biospheres which would be needed to account for the organic portion (of limestone) is quite large. For instance, the estimated 10,000 cubic miles of broken crinoid plates, if spread evenly over the earth's surface would form a layer over three inches deep. This is the organic material from just one limestone bed from northwestern North America. Other beds conceivably could add as much. The upper Devonian limestones of the mid-continent are up to 80 or 90 percent shell material. The Austin chalk upon which Dallas is built is little more than several hundred feet of dead microscopic animals. The Monterey Formation in California is composed primarily of dead diatoms ---thousands of feet of them." (R29)

T. Gold, who has hypothesized the existence of large quantities of methane in the earth's core, adds the following two paragraphs to our discussion of the "carbon problem."

"We have discussed how petroleum and natural gas may be the products of the outgassing process which brings up carbon compounds from deep down in the Earth. We suppose that this process is one that has supplied all the carbon which is so abundant on the surface and in the sediments, and which amounts to something on the order of 20 kilograms per square centimetre for the global average surface. Of this the atmospheric and oceanic carbon dioxide, and the active biosphere, contain only about 8 grammes per square centimetre. The entire remainder, which is the bulk of the surface carbon, is in long-lived or permanent deposits, either as calcium carbonate (limestone) or calcium magnesium carbonate (dolomite) in the sediments, as calcite cements (also calcium carbonate), both in sediments and in rocks of the crystalline basement, and in the various forms of unoxidized carbon, such as graphite, coal, and the substances referred to as kerogen, and of course petroleum, tar and methane. If all that carbon has originally been supplied from below, which deposits were formed by that upward stream and which by the deposition, through biology and otherwise, of carbon that had reached the atmosphere.

"The greatest quantity, about 85 percent of all the deposited carbon, is in the form of the carbonate rocks, and they mostly give clear evidence of having been formed by a precipitation in water. They often contain marine fossils, and in fact the carbonate fossils themselves make up a significant fraction of all limestone. There can be no question that all this derived from atmospheric carbon dioxide which intermixes on a short timescale with oceanic carbon dioxide, and with the carbon of all the plants on land and in the ocean. This pool of carbon would be depleted by the deposition of limestone and other sediments in a time as short as 10,000 years if there were not a constant resupply of fresh carbon from below." (R42) In other words, the simple existence of so much limestone is evidence of a continuous supply of carbon at the earth's surface. This constitutes an important anomaly.

While T. Gold looks inward for the source of carbon, we should not forget that carbon is also arriving continually from outer space in the form of meteoric and cometary matter. In fact, L. A. Frank has presented evidence that enough small, icy comets strike the earth each day to contribute substantially to the volume of seawater. Since comets are known to contain carbonaceous matter, some fraction of the carbon continually added to the surface may be extraterrestrial. See ESC11. (WRC)

X5. Granite. "Granite is a light-colored igneous rock and is grayish to pinkish depending upon the variety of potash feldspar present. Its density, about 2.7 g/cm^3, is comparatively low among the intrusive rocks." (R35) Many descriptions of granite, like this one, imply that all granites are igneous; that is, magmatic; in origin. Such is not the case.

Some granites are metasomatic. They began as sedimentary or metamorphic rocks, but they have subsequently been changed into a rock closely resembling magmatic granite by a process called "granitization." The recognition of the granitization process came about through field observations, such as those now summarized:

"Rocks that were originally sandstones, limestones and slates have been found mysteriously changed by nature into granite. This is a most surprising phenomenon, since geologists heretofore have classed granite as a type of igneous rock that developed from a molten mass of material formed at considerable distances below the earth's surface.

.....

"Some of the striking features upon which Dr. Anderson based his conclusions are the preservation of the apparent bedding of the original sediments, the sedimentary relics found in the transposed granite, and the gradation of remnant sedimentary material into the granite. Numerous chemical analyses of different samples of the granite combined with petrographical studies substantiated Dr. Anderson's discovery." The scientist mentioned was G. H. Anderson, who made this discovery in the Inyo Mountains of California, circa 1934.

Modern geology recognizes that all granites are not magmatic, although many popular works perpetuate the simplistic view. C. A. Chapman paints the true picture:

"Just how granite forms constitutes a major problem of geology. Three principal types of processes appear to be operative: magmatic, metamorphic, and metasomatic; these may act independently or in various combinations. Magmatic granite forms by slow crystallization of a deeply buried granitic melt (magma). Metamorphic recrystallization (reconstitution by heat, pressure, and volatiles) may transform volcanic or sedimentary rocks into granite. A wide variety of sedimentary or igneous rocks may be changed to granite, in essentially the solid state, by the introduction of certain elements, such as alkalies and silica, and the removal of others, such as iron, magnesium, and calcium. This process of replacement or metasomatism is involved in the phenomenon of granitization." (R11)

Granite, therefore, is a rock of diverse origins, most of which are still being debated. Such a situation is common in science and not necessarily particularly anomalous, since no basic tenets of geology are being challenged. Perhaps the most difficult problem is understanding the exact mechanisms at work in the granitization of massive bodies of sedimentary and metamorphic rocks. How do fluids penetrate such great distances into solid rock, carrying some chemicals in and removing others? (WRC)

X6. Graywacke. "The term graywacke is used to denote a type of sandstone with rock or mineral fragments in a dominant, grayish 'clay' matrix. The unsorted character of graywackes with larger often angular fragments in the dark fine-grained matrix is easily distinguished from other sandstones. Graywackes commonly have graded bedding but some show cross bedding. They are worldwide in their occurrence (about 10 to 15 per cent of all sandstones are graywackes).

"Explaining the origin of graywacke has been perplexing to uniformitarian geologists. The first problem concerns the origin of the graded bedding. Pettijohn wrote in the first edition of his book, Sedimentary Rocks, concerning graywacke:

'Very rapid deposition is implied by the muddy matrix (indicating thereby a lack of sorting), by the massive and unstratified nature of the thicker beds; by the lack of cross-bedding and ripple marks (which are the evidence of reworking and sorting and are possible only if the sedimentation is not too rapid); by the graded bedding of some phases (each graded bed possibly representing a single year's accumulation); and by the extraordinary thickness of sedimentary deposits characterized by graywackes.'

"In his second edition Pettijohn recognized that turbidity currents may have deposited the graded beds. Instead of considering each graded bed as the result of a 'single year's accumulation' (first edition) he proposed that each was the record of a 'single semicatastrophic event' (second edition). His words in the second edition were:

'If the theory of deposition of graywackes by submarine-generated turbidity flows is correct, it is clear why such deposits have never been observed to form despite the fact that graywackes are a relatively common type of sandstone found in all geologic ages. Each graywacke bed is the record of a single semicatastrophic event ---a short-lived episode which is completely hidden from ordinary observation.'

.....

"A second problem with graywacke concerns the origin of the unsorted character (the larger fragments in the fine-grained matrix). A great deal of research has been done on modern turbidity current deposits but none of these sediments is a graywacke. W. A. Cummins said:

'A major difficulty with any hypothesis involving a detrital origin for the characteristic graywacke matrix is the failure to find a modern sediment of graywacke type.'" (R21)

Besides the two problems just mentioned, the sheer size of some graywacke deposits deserves notice here. The Franciscan assemblage of rocks in California contains sufficient sand to cover the entire state of California to a depth of 10,000 feet. (R16)

Geologists today believe that graywackes are created in the very deep waters by turbidity currents. But if each graywacke bed is the consequence of a single catastrophic event, just what were these events, and why did they repeat? And where did all of the sand come from? (WRC)

X7. Consolidated slabs on the Pacific floor. Dredge hauls from the floor of the Eastern Pacific indicate that the bottom is littered with tabular masses of material---largely phillipsite---coated with manganese dioxide. The properties of these slabs and their disposition on the sea floor are most interesting:

"(1) The slabs are large, thin, relatively uniform in thickness, and commonly very angular. (2) They are coated with a few millimeters to several centimeters of ferromanganese oxides, suggesting that they have been exposed on the sea floor for 10^4-10^5 years. (3) They contain some unaltered minerals and fragments of volcanic glass but phillipsite and other alteration products are the most common constituents. (4) Slabs cover as much as 40 per cent of the bottom in some areas. (5) They appear to decrease in thickness to the west. (6) None of the slabs is on top of others. (7) Some slabs appear to lie in a reticulate pattern rather than being randomly distributed. (8) Manganese nodules cover much of the bottom between slabs in many places. (9) The nodules were formed after the slabs were deposited. (10) The fraction of the bottom covered by nodules and slabs varies systematically over an area of more than 10^6 km^2." (R13)

Scientific opinion is that the bulk of the slab material is volcanic in origin. See ESC10 for a treatment of manganese nodules. (WRC)

X8. Tube agate. Many are the peculiarities of the mineral world. Tube agate is just one of a class, which we hope to catalog more completely in future editions of the Catalog of Anomalies.

"Tube-formed agate is something of a mystery to mineralogists. Very little is known as to its mode of formation."

.....

"In the 'Agate Book' the late Dr. H. C. Dake calls attention to the similarity of tube agate to stalactites. This similarity does not hold for hollow agate tubes, however. According to Dr. Dake, hollow tubes have been observed in agate found at Antelope, Oregon. In some instances the interior of the tubes was coated with a thin layer of iron minerals. He also cites the theory of Charles Ridgway of Riverton, Wyoming, and Jesse Green of Bozeman, Montana, that agate first forms a geode in a cavity or cast of a tree and that agate stalactites then build downward from the roof of the cavity until the entire cavity becomes filled with agate. The presence of a capillary tube extending along the axis of each tube is said to be characteristic of this type of agate.

"Theodore C. Vanasse in 'Lake Superior Agate' associates tube agate formation with cavity 'sweating.' He adds, 'Such tubes could also be formed by a process resembling laboratory experiments with waterglass and copper salts, in which dendritic tubes rise through water---one simulation of the Liesegang phenomena. Such structures in Lake Superior agates were probably caused by the presence within the cavities of an excess of an iron mineral, for agates have been found that merge with jasper." This article is accompanied by many photos of tube agate. (R17) As with most of the mineral oddities, we have here a problem of mode of origin---a situation more perplexing than anomalous.

X9. Methane hydrate. Only in recent years has methane hydrate been recognized as an exceedingly common rock. Methane hydrate is a form of water ice combined with methane. The addition of methane to the ice at high pressures raises the freezing point. Thus, methane hydrate can survive in the ocean depths where the ambient temperature is just a bit above the freezing point of unmethanated ice.

The Glomar Challenger has found methane hydrate in many locations during the Deep Sea Drilling Project. Here follows an account of one accidental encounter off Central America on Leg 67:

"On Leg 67, the unexpected discovery of gas hydrates prevented the scientists from drilling deeply enough to sample the landward wall of the trench. This time the crew was prepared, and successfully extracted a core of white methane hydrate. The drill hit a three- to four-meter-thick layer of gassy ice at 249 meters beneath the seafloor. At room temperatures, the hydrates melt to residual water, and yield more than one hundred times their volume in gas." (R25)

Characteristics of methane hydrate. "Gas hydrates are stable, three-dimensional lattices of water molecules with methane molecules in the intervening voids. The resultant solid has a consistency like ice. An ideally saturated methane hydrate in which every void is filled with a gas molecule can contain huge amounts of gas. One cubic metre of gas hydrate can store an astonishing 170 cubic metres (at atmospheric pressure) of methane gas.

"Sufficiently high pressures and low temperatures for the formation of natural gas hydrates occur naturally beneath the sea floor in regions where the water depth is in excess of about 1000 metres. Nearly 90 per cent of the world's seafloor falls into this category. When a gas hydrate is heated it 'melts' and reverts to free gas and water." (R49)

Methane hydrate is known to exist in the permafrost regions of the northern hemisphere and, more abundantly, at thousands of locations in the bottoms of deep ocean trenches and the polar oceans.

It is the sheer abundance of methane hydrate that boggles the imagination. According to T. Gold: "One Soviet estimate is that the global sea floor sediments contain one billion cubic kilometres of gas in the form of methane hydrates, which, in terms of our previous notation, equals 0.14 kilogram per square centimetre, to be compared with the estimate of 3 kilograms per square centimetre of all other forms of unoxidized sedimentary carbon. It far exceeds the total of all other estimated sources of natural gas.

"If all this methane had been produced from biological materials, much larger deposits would have to be invoked, even larger than for the production of all the other hydrocarbons and of coal. Yet some of these hydrates on the ocean floor, or in the permafrost of the northern regions, do not overlie enormously deep sedimentary deposits. Their presence in such large quantity fits readily with the assumption that methane seeping up from deep levels is a widespread phenomenon and that the quantities involved are large enough to have supplied all the carbon on the Earth's surface." (R42)

Since present geology does not countenance immense seepages of methane from the interior of the earth, their inference from the existence of methane hydrate represents an important anomaly. Also, it is not clear just how huge deposits of ice formed underwater, assuming deep ocean waters were always above freezing. Incidentally, the carbon in methane hydrate, coal, oil, and the carbonates (limestone and dolomite), etc., constitute collectively "the carbon problem." Where did all this carbon comes from? Inside the earth or from extraterrestrial bombardment? (WRC)

X10. The Chilean nitrate deposits. The Chilean nitrate deposits are huge in quantity and extensive in distribution. They stretch in a band 30 kilometers wide and 700 kilometers long, generally parallel to the seacoast, and mostly at altitudes of 1000-2000 meters, with a few concentrations at near 4000 meters.

G. E. Ericksen has nicely summarized the nature and enigma of these curious accumulations of nitrates: "The nitrate deposits in the extremely arid Atacama Desert of northern Chile are among the most unusual of all mineral deposits. In fact, they are so extraordinary that, were it not for their existence, geologists could easily conclude that such deposits could not form in nature. The nitrate deposits consist of water-soluble saline minerals that occur as cement in unconsolidated surficial material---alluvial fill in valleys, loose rock debris on hillsides, and windblown silt and sand---and as impregnations and veins in porous and fractured bedrock. They are found chiefly along the eastern side of the Coastal Range, but also within the Coastal Range, in the Central Valley to the east, and along the lower Andean front. Features of the deposits that appear to defy rational explanation are their restricted distribution in a desert characterized throughout by saline soil and salt-encrusted playas; the wide variety of topography where they occur; the abundance of nitrate minerals, which are scarce in other saline complexes; and the presence of other, less abundant minerals containing the ions of perchlorate, iodate, chromate, and dichromate, which do not exist in any other saline complexes. Iodate, chromate, and dichromate are known to form under such conditions, but no chemical process acting at temperatures and pressures found at the earth's surface is known to produce perchlorate." (R26)

The origin of the Chilean nitrate deposits are, to quote G. E. Ericksen, "obscure." Dozens of published reports fail to provide an adequate explanation for all their features. Most of the theories employ biological mechanisms to fix atmospheric nitrogen; examples: seaweed and marine vegetation in inland arms of the sea, vegetation in saline lakes, seabird guano (transported by water and/or wind), soil bacteria, and microorganisms of unspecified nature. (R26)

X11. Black shales. Black shales are found widely in Precambrian and Paleozoic deposits. "These widespread black shales comprise a unique lithofacies the origins of which have been the subject of considerable speculation. The typical rocks are black, thinly laminated shales. Chert, commonly in thin beds, and thinly bedded black limestones may be present in some sections.

"Pettijohn described the black shales as follows: 'They are exceptionally rich in organic matter. They also tend to be rich in iron sulfide, usually pyrite, which replaced fossils, forms nodules, or occurs as finely disseminated grains. Black shale rarely contains any fossils, or at best, has a sparse, depauperate, and restricted fauna.' Black shales of Ordovician, Silurian, and Early Devonian age commonly bear graptolites. In addition, remains of certain other planktic organisms such as small, straight nautiloids, are present locally. Pettijohn also noted that some black shales have an 'unusual concentration of certain trace elements, notably V, U, Ni, and Cu.

"Sequences of rocks representative of the black shale facies may range from several hundred to perhaps a few thousand meters in thickness. Such sequences of Early Paleozoic age are areally extensive, commonly being traced in linear belts for many tens to several hundreds of kilometers in length. The black shale facies is common to and widespread in Lower Paleozoic rock sequences that formed in what has been considered geosynclinal areas." (R36)

Black shales also occur in cyclothems (ESR5). For example, Pennsylvanian cyclothems often contain a black shale between two marine limestones. It has also been noted that the Milankovitch cycles of climatic change often affect strata containing black shales in the Cretaceous. (R33) The 'blackness' of these shales originates in the large amounts of organic carbon contained. It is probable that black shales were deposited under oxygen-poor conditions, and that they are markers in the sedimentary record of important changes in the earth's biosphere. (WRC)

X12. Banded iron. "Banded iron formations may be the most beautiful, economically important and enigmatic rocks ever created on this planet. They are made up of alternating layers of iron ore and silica; some layers only a fraction of a millimeter across extend uninterrupted for kilometers. The worldwide heyday of banded iron formations was about 2 billion years ago. After that, their numbers fell dramatically." (R32)

D. Ager was also impressed by the banded iron formations: "The occurrence of banded ironstones around the world in late Precambrian rocks is well known. Particularly noteworthy is the economically important Animikie Basin, with the fabulous Mesabi, Marquette and other ranges at the west end of Lake Superior in North America. Others of about the same age (i. e. about 2000 million years B. P.) are the Transvaal Basin in South Africa, the Hammersley Basin in Western Australia and the Dharwars Series of India. All have banded or varved iron formations that are characteristic of this episode in earth history. Even more remarkable, however, is the fact that individual bands can be traced over vast areas. Thus in the valuable Brockman Iron formation of the Hammersley Basin, bands about an inch thick are said to be correlatable over an area of some 20,000 square miles and even microscopic varves within these bands can be traced over 185 miles." (R34)

Banded iron formations are usually thought of as a Precambrian eccentricity, but they actually are present from the oldest Precambrian to Recent deposits. It is true, however, that the greatest development of banded iron deposits occurred between 2,600 and 1,800 million years ago. It is also interesting that the very early banded iron formations are closely associated with the enigmatic greenstone belts (ESG7). (R46)

An important implication of the presence of banded iron deposits is that they "prove" that our planet's early atmosphere was oxygen-deficient; that is, a reducing atmosphere. The reasoning being that the banded iron could not have formed in an oxygen-rich environment. (R48) However, the existence of banded iron throughout geological history, at times when oxygen was plentiful, undermines this "proof." (R46)

Many hypotheses have been suggested to explain banded iron, but no consensus exists. Most theories involve the oxidization and precipitation of iron dissolved in seawater. The obvious periodicity of the varves and bands in banded iron formations has been ascribed to seasonal "blooming" of oxygen-producing organisms or cyclic upwellings of iron-rich waters. (R32)

References

R1. Winchell, Alexander N.; "A Theory for the Origin of Graphite as Exemplified in the Graphite Deposit near Dillon, Montana," Economic Geology, 6:218, 1911. (X1)

R2. VanTuyl, Francis M.; "New Points on the Origin of Dolomite," American Journal of Science, 4:42:249, 1916. (X2)

R3. Clark, Thomas H.; "The Origin of Graphite," Economic Geology, 16:167, 1921. (X1)

R4. Tarr, W. A.; "Is the Chalk a Chemical Deposit?" Geological Magazine, 62:252, 1925. (X3)

R5. Gee, Haldane; "Inorganic Marine Limestone," Journal of Sedimentary Petrology, 2:162, 1932. (X4)

R6. "Granite from Sandstone and Shale," Science, 80:sup 6, July 13, 1934. (X5)

R7. "Limestones as Eruptive Rocks," Nature, 142:704, 1938. (X4)

R8. Rankama, Kalervo; "New Evidence of the Origin of Pre-Cambrian Carbon," Geological Society of America, Bulletin, 59: 389, 1948. (X1)

R9. Ford, Robert B.; "Occurrence and Origin of the Graphite Deposits near Dillon, Montana," Economic Geology, 49:31, 1954. (X1)

R10. Bott, Martin Harold Phillips; "A Geophysical Study of the Granite Problem," Geological Society of London, Quarterly Journal, 112:45, 1956. (X5)

R11. Wyllie, Peter J.; "Granite," McGraw-Hill Encyclopedia of Science and Technology, 6:278, 1977. (X5)

R12. Walton, Matt; "Granite Problems," Science, 131:635, 1960. (X5)

R13. Menard, H. W.; "Consolidated Slabs on the Floor of the Eastern Pacific," Deep-Sea Research, 7:35, 1960. (X7)

R14. Sarin, Dev. D.; "Cyclic Sedimentation of Primary Dolomite and Limestone," Journal of Sedimentary Petrology, 32:451, 1962. (X2, X4)

R15. von der Borch, C. C., et al; "Modern Dolomite from South Australia," American Journal of Science, 262:1116, 1964. (X2)

R16. Northrup, Bernard E.; "Book Review: Franciscan and Related Rocks, and Their Significance in the Geology of Western California," Creation Research Society Quarterly, 6:161, 1970. (X4, X6)

R17. "Tube Agate," Earth Science, 23:175, 1970. (X8)

R18. Salotti, Charles A., et al; "Abiotic Carbon and the Formation of Graphite Deposits," Economic Geology, 66:929, 1971. (X1)

R19. Erdosh, George; "Abiotic Carbon and the Formation of Graphite Deposits," Economic Geology, 67:383, 1972. (X1)

R20. Salotti, Charles A., et al; "On the Origin of Vein Graphite Deposits," Economic Geology, 67:384, 1972. (X1)

R21. Nevins, Stuart E.; "Stratigraphic Evidence of the Flood," in A Symposium on Creation, III, Donald W. Patten, ed., 1971, p. 33. (X2, X6)

R22. Deelman, John C.; "Dolomite Synthesis and Crystal Growth," Geology, 3:471, 1975. (X2)

R23. Shinn, Eugene A., et al; "Limestone Compaction: An Enigma," Geology, 5:21, 1977. (X4)

R24. Smith, Peter J.; "Was Precambrian Seawater Different?" Nature, 296:309, 1982. (X2, X4)

R25. Simon, C.; "DSDP: Rethinking the

Accretion Model," Science News, 121: 231, 1982. (X9)

R26. Ericksen, George E.; "The Chilean Nitrate Deposits," American Scientist, 71:366, 1983. (X10)

R27. Wenk, H.R., and Zenger, D.H.; "Sequential Basal Faults in Devonian Dolomite, Nopah Range, Death Valley Area, California," Science, 222:502, 1983. (X2)

R28. Tucker, Maurice E.; "Diagenesis, Geochemistry, and Origin of a Precambrian Dolomite: The Beck Spring Dolomite of Eastern California," Journal of Sedimentary Petrology, 53:1097, 1983. (X2)

R29. Morton, Glenn R.; "The Carbon Problem," Creation Research Society Quarterly, 20:212, 1984. (X1, X4)

R30. Kastner, M.; "Control of Dolomite Formation," Nature, 311:410, 1984. (X2)

R31. Weisburd, S.; "Digging at the Dolomite Dilemma," Science News, 128:343, 1985. (X2)

R32. Weisburd, Stefi; "The Banded Iron Formation Mystery," Science News, 130: 361, 1986. (X12)

R33. Meyers, Philip A., and Arthur, Michael A.; "Black Shales in Ocean Targeted for Drilling," Geotimes, 31:11, September 1986. (X11)

R34. Ager, Derek V.; "The Persistence of Facies," in The Nature of the Stratigraphic Record, 1973 p. 1. (X12)

R35. Strahler, Arthur N.; "How Mainstream Geology Views Earth Structure and Dynamics," in Science and Earth History, 1987, p. 177. (X2)

R36. Berry, William B.N., and Wilde, Pat; "Progressive Ventilation of the Oceans ---An Explanation for the Distribution of the Lower Paleozoic Black Shales," American Journal of Science, 278:257, 1978. (X11)

R37. Schoell, M., and Wellmer, F.-W.; "Anomalous ^{13}C Depletion in Early Precambrian Graphites from Superior Province, Canada," Nature, 290:696, 1981. (X1)

R38. Jacobsen, Stein B., and Pimentel-Klose, Mario R.; "Nd Isotopic Variations in Precambrian Banded Iron Formations," Geophysical Research Letters, 15:393, 1988. (X12)

R39. Vahrenkamp, Volker C., et al; "Constraints and Interpretation of $^{87}Sr/^{86}Sr$ Ratios in Cenozoic Dolomites," Geophysical Research Letters, 15:385, 1988. (X2)

R40. Siever, Raymond; "Dolomite Rock," McGraw-Hill Encyclopedia of Science and Technology, 4:293, 1977. (X2)

R41. Moore, Paul B.; "Graphite," McGraw-Hill Encyclopedia of Science and Technology, 6:287, 1977. (X1)

R42. Gold, Thomas; "The Origin of Petroleum," in Power from the Earth, 1987, p. 151 (X4), p. 162 (X9).

R43. Penrose, R.A.F.; "The Nitrate Deposits of Chile," Journal of Geology, 18: 1, 1910. (X10)

R44. Singewald, Joseph T., Jr., and Miller, Benjamin LeRoy; "The Genesis of the Chilean Nitrate Deposits," Economic Geology, 11:103, 1916. (X10)

R45. Whitehead, W.L.; "The Chilean Nitrate Deposits," Economic Geology, 15:187, 1920. (X10)

R46. Goldich, Samuel S.; "Ages of Precambrian Banded Iron-Formations," Economic Geology, 68:1126, 1973. (X12)

R47. Hargraves, R.B.; "Precambrian Geologic History," Science, 193:363, 1976. (X12)

R48. Austin, Steven A.: "Did the Early Earth Have a Reducing Atmosphere?" ICR Impact Series No. 109, July 1982. (X12)

R49. White, Bob; "Frozen Energy in the Depths of the Oceans," New Scientist, 106: 29, July 4, 1985. (X9)

R50. Morton, G.R.; "The Flood," The Geology of the Flood, Dallas, 1987, p. 92. (X4, X12)

ESC10 Unusual Growth Structures

Description. Cave stalactites, sea-ice stalactites, lava spines, manganese nodules, and other geological structures apparently formed by accretion and other growth mechanisms.

Data Evaluation. Common as stalactites are, we have found surprisingly little in the way of scientific research on them---perhaps because they have been considered well-explained! Manganese nodules, in constrast, have been accorded considerable attention---probably because everyone agrees that they are poorly understood. Composite rating: 2.

Anomaly Evaluation. Although manganese nodules are very puzzling in several ways and the growth of stalactites is not as straightforward as usually maintained, the complete explanation of these growth structures will probably not require any significant changes in any of our scientific laws---actually, we need only more research. Perhaps the most surprising aspect of these growth structures is in the involvement of life forms, microscopic and macroscopic, in promoting growth and affecting the distribution of the structures. Rating: 3.

Possible Explanations. Mundane chemical processes will probably suffice, but there is also the possibility that life forms take a much more active role than generally thought.

Similar and Related Phenomena. "Internal" accretion structures, such as geodes and concretions (ESA). Tufa columns (ETM12-X2).

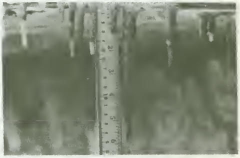
Examples

X1. Cave stalactites. "Stalactites, stalagmites, dripstone, and flowstone are travertine deposits in limestone caverns, formed by the evaporation of waters bearing calcium carbonate. Stalactites grow down from the roofs of caves and tend to be long and thin, with hollow cores. The water moves down the core and precipitates at the bottom, slowly extending the length while keeping the core open for more water to move down. Stalactites are banded concentrically to the center." (R20)

Such a simple growth structure seems unlikely to have anomalous features. There are, nevertheless, two items of contention: (1) The real speed of stalactite growth in caves and whether stalactite sizes can be used as proof of great age; and (2) The role of living organisms, especially bacteria, in the growth of stalactites.

Speed of stalactite growth. It is thought, scientifically and popularly, that stalactites grow very, very slowly (less than a millimeter per year), and that the large growths found in some caves must be millions of years old. Creationists, however, point to many cases of dripstone under bridges, in man-made tunnels, and similar localities, where stalactite growth is rather rapid (centimeters per year). Interestingly enough, the two discussions presented below, one by a geologist and the other by a creationist, conclude that stalactite size is not a good measure of age.

"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,



Rapidly growing dripstone under an Ohio bridge. (X1) (L.S. Helmick)

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." (R1)

"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."

.....

"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! When 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." (R8) All that has been demonstrated is that stalactite size is an extremely unreliable measure of age.

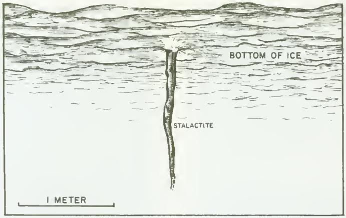
This being so, despite what the popular books and cave tour guides say, scientists have applied other methods in dating cave deposits. Quoting A.N. Strahler: "Speleothems can be dated by uranium-isotope ratios. In a report by R.S. Lively (1983) this method was applied to speleothems in the Driftless Area of southeastern Minnesota. Calcium carbonate samples of stalagmites and flowstone were analyzed for the ratios U-234/U-238 and Th-230/Th-232. From a large number of samples there emerged four distinct periods of speleothem deposition. Individual samples ranged in age from as recent as a few hundred years to as old as 285,000 y." Strahler also noted that magnetostratigraphy dates for cave sediments are much older than the 6,000 years desired by creationists. (R17) Creationists, however, have little faith in radiometric dating (see ESP12), which is essential to both methods just mentioned. So, the debate is really unresolved as far as the creationists are concerned, although one can hardly call it a crucial debate! (WRC)

The role of microorganisms in stalactite growth. First, a rough translation of the introductory paragraph from an article in Science et Vie:

> One has always held that the calcareous concretions in caves are the work of water and the chemical constituents of the rock. Surprise! The true workers in the kingdom of darkness are living organisms. (R18)

It is true! All references consulted state unequivocally that stalactites and stalagmites are created by dripping water that is charged with minerals, calcium carbonate in particular. That stalactites contain crystals of calcium carbonate is shown clearly in the Science et Vie photographs, but the pictures also show that a web of mineralized bacteria is also an integral part of the stalactite's structure. Laboratory work in France has shown that microorganisms take an active role in the process of stalactite formation. (R18) If this French work is confirmed, the popular theory of stalactite growth will have to be jettisoned.

X2. Ice stalactites under sea ice. "The Antarctic ocean produces its share of strange phenomena. Pictured here is an ice stalactite of about 1.5 metres length and 10 cm diameter. 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. These protuberances may also give clues to the formation of Antarctic bottom water. The saline water is dense and thus settles



Salty stalactite growing under Antarctic ice. Length 1.5 meters. (X2)

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." (R3; R23)

Laboratory work by S. Martin has simulated the streamers of cold brine rejected by the upper layer of sea ice into seawater held at the freezing point. Some of the factors, but not all, affecting stalactite growth have been clarified. (R5) Just how the brine is concentrated by the sea ice is also puzzling.

X3. Lava spines. G. A. MacDonald introduces this fascinating phenomenon: "So far as I know, the actual process of formation of the spines has been witnessed only once. In 1920, R. H. Finch was studying the development of the Mauna Iki lava flow on the flank of Kilauea volcano. At lunch time he found a comfortable place to sit on the surface of the flow itself, and it was not long until he realized that the landscape was moving slowly by him. He was on a moving part of the flow! He finished his lunch at leisure, enjoying his ride, and as he went he watched a nearby part of the flow where the lava crust remained unbroken. All over it little spines were growing, as Finch put it, much like tiny plants sprouting from the ground. What can be the cause of these sprouts? They are not the result of growing crystals or chains of crystals: most of them are largely glassy. Possibly they are the result of the formation of polymers in the glass, perhaps linkages of silica tetrahedra similar to the structure we believe may be the cause of the greater viscosity of silica-rich magmas." (R4)

X4. Manganese nodules on the seafloors. More than a century ago, the dredges of the Challenger Expedition discovered that manganese nodules are very common on the ocean floors. Despite considerable research since then, the growth mechanism, the distribution, and the disposition of these manganese nodules remains largely unexplained. Here, we catalog information on eight puzzling facets of the manganese nodule problem: (1) Growth rate is less than sedimentation rate; (2) Far fewer nodules are buried than are on the seafloor proper; (3) The nearly equal spacing and general sphericity of the nodules; (4) The apparent turning over of nodules; (5) Highly variable growth rates; (6) The existence of organisms on the surfaces; (7) The association of benthic animals with the nodules; and (8) The anomalous helium ratio in some nodules.

Overview of manganese nodule characteristics. The first discussion is by H. W. Menard: "At the time when manganese nodules were discovered, the universally accepted model of deep-sea sedimentation was an unremitting rain of sediment from the surface. Soon rates of sedimentation were found to be much faster than nodule growth, and it became apparent that the nodules are somehow supported near the sediment surface. This was only the best known of many puzzling features: many nodules are spherical, many have nuclei which are fragments of older nodules, many are layered like onions. Since sediment collects on the tops of some nodules, the top is identifiable and it can be shown that many nodules have turned over. Some have even come to rest on or beside others and have been fused to them. Nodules commonly occur in pavements that are only one nodule thick."

.....

"Although they are known from thousands of sea-bottom photographs, samples, and chemical analyses, few statements can be made about them with certainty: nodules occur in all marine environments, their distribution is patchy on all scales from centimeters to hundreds of kilometers, and correlations with environmental parameters can be expressed only as probabilities. Thus nodules occur in and on all types of sediment, but they are associated with only 12.4% of samples of calcareous ooze in the deep Pacific, whereas 42.6% of siliceous clay samples contain nodules." (R6)

Nodule growth rates. Manganese nodules, slabs, and coatings display remarkably variable growth rates, as explained by P. J. Smith: "Part of their scientific attraction undoubtedly lies in their ability to grow remarkably rapidly under suitable circumstances.... Burnett and Piper report the discovery of a ferromanganese crust which apparently grew at a rate in excess of 800 mm per million years. This figure may be put in perspective by the claim of Scott et al. that deep sea ferromanganese crusts and nodules generally grow at rates of 1-10 mm per million years.... Some of the most astonishing rates of growth, however, were discovered by Goldberg and Arrhenius who reported finds on the sea floor of an approximately 50-yr old naval shell with a Mn-Fe coating almost 30 mm thick and a World War II shell with a coating about 15 mm thick, indicating growth rates of about 60,000 and 100,000 mm per million years respectively." It is interesting, too, that although the shells were found in shallow coastal waters, which may not be comparable to sea-bottom waters, their ages are known with great precision. In constrast, nodule dating must invoke radiometric or some other physicochemical form of dating. (R9)

Nodule relationships with life forms. "It has recently been discovered that many species of microscopic, one-celled animals make their homes on the surfaces of these nodules. The animals, members of the Foraminifera class of protozoans, construct variously shaped shelters, called 'tests' from a variety of available sediment particles which are held together by a cementing agent secreted by the organism. Thus far, over 20 identified species and as many similar but unidentified forms have been found. Since many of these animals are too small to be clearly seen even with an optical microscope, a scanning electron microscope must be used. What is actually seen is the test that the animals constructed rather than the organism itself." (R11) One immediately makes an anology to the possible role of bacteria in stalactite growth (ESC10-X1) (WRC)

Some scientists have endeavored to explain the vertical and horizontal distribution of manganese nodules through work of sea-floor currents, but the activities of life forms under and around the nodules provide another possibility: "The alternative hypothesis, that benthonic fauna nudge nodules upward when they burrow under them for food or shelter, was proposed on the grounds that such organisms and burrows were evident around slabs and nodules in some of the first photographs of the deep Pacific taken by C. J. Shipek and N. L. Zenkevitch. The correlation between nodules and organisms has been confirmed by most of the thousands of photographs taken in the basin since then. This is in contrast to photographs of nodules with evidence of currents---which are locally impressive but generally restricted to a few regions." The rolling over of nodules, the relatively even spacing of nodules, and even their concentration near the surface of the sea-floor can be related to the work of marine creatures. (R6)

$^3He/^4He$ ratios for manganese nodules. From the abstract of a paper by Y. Sano et al: "Here we present new He isotope data for ten marine ferromanganese nodules, together with isotope compositions for Ar and chemical compositions. The observed $^3He/^4He$ ratios are extraordinarily high, with values up to 59.3×10^{-6}. Considering that the direct supply of materials from the deep mantle is an insignificant factor in the area studied, the negligible contribution of radiogenic ^3He, and the improbability of artificial nuclear fallout debris, the most likely explanation appears to be conglomeration of extraterrestrial matter." (R16) This isotopic anomaly might be related to the proposed cometary source of ocean water (ESC11) and/or extraterrestrial material supplied by impacts. (WRC)

Final thoughts. Manifestly, the manganese nodules continue to offer many challenges to science, especially as regards growth rates, distribution, and their relationships with living organisms and, possibly, the influx of extraterrestrial matter. For example, if some nodules are formed around fragments of older nodules, how were the older nodules fractured? And, do microorganisms play key roles in nodule growth? The questions keep coming, and in doing so, confer a relatively high level of anomalousness on the manganese nodules. (WRC)

References

R1. ver Steeg, Karl; "Unusual Occurrence of Stalactites and Stalagmites," Geological Society of America, Bulletin, 43:250, 1932. (X1)

R2. Fisher, Lloyd W.; "Growth of Stalactites," American Mineralogist, 19:429, 1934. (X1)

R3. "A Salty Finger in the Cold Sea," New Scientist, 50:368, 1971. (X2)

R4. MacDonald, Gordon A.; Volcanoes, 1972, p. 83. (X3)

R5. Martin, Seelye; "Ice Stalactites under Sea Ice," Eos, 53:424, 1972. (X2)

R6. Menard, H. W.; "Time, Chance, and the Origin of Manganese Nodules," American Scientist, 64:519, 1976. (X4)

R7. Margolis, Stanley V., and Burns, Roger C.; "Pacific Deep-Sea Manganese Nodules: Their Distribution, Composition, and Origin," Annual Review of Earth and Planetary Sciences, 4:229, 1976. (X4)

R8. Helmick, Larry S., et al; "Rapid Growth of Dripstone Observed," Creation Research Society Quarterly, 14:13, 1977. (X1)

R9. Smith, Peter J.; "Ferromanganese Deposits: Fast, Fast, Slow," Nature, 265:582, 1977. (X4)

R10. Cannell, Eric B.; "Rapid Stalactite Formation Observed," Creation Research Society Quarterly, 15:9, 1978. (X1)

R11. Dugolinsky, Brent K.; "Mystery of Manganese Nodules," Sea Frontiers, 25: 364, 1979. (X4)

R12. Heath, G. Ross; "Burial Rates, Growth Rates, and Size Distributions of Deep-Sea Manganese Nodules," Science, 205: 903, 1979. (X4)

R13. "Fast Caves," Ex Nihilo, 2:4, November 1983. (X1)

R14. Luck, J. M., and Turekian, K. K.; "Osmium-187/Osmium-186 in Manganese Nodules and the Cretaceous-Tertiary Boundary," Science, 222:613, 1983. (X4)

R15. Taylor, Ian T.; "Old Earth, Young Earth," in In the Minds of Men, Toronto, 1984, p. 336. (X1)

R16. Sano, Yuji, et al; "$^3He/^4He$ Ratios of Marine Ferromanganese Nodules," Nature, 317:518, 1985. (X4)

R17. Strahler, Arthur N.; "Landscapes of Denudation---Evolutionary or Catastrophic," in Science and Earth History, Buffalo, 1987, p. 218. (X1)

R18. Dupont, Georges; "Et Si les Stalactites Etaient Vivantes?" Science et Vie, p. 86, August 1987. Cr. C. Maugé. (X1)

R19. "Rapid Stalactites," Ex Nihilo, 10:5, no. 2, 1988. (X1)

R20. Siever, Raymond; "Stalactites and Stalagmites," McGraw-Hill Encyclopedia of Science and Technology, 13:35, 1977. (X1)

R21. Menard, H. W., and Shipek, C. J.; "Surface Concentrations of Manganese Nodules," Nature, 182:1156, 1958. (X4)

R22. Bender, Michael L., et al; "Manganese Nodules: Their Evolution," Science, 151: 325, 1966. (X4)

R23. Dayton, Paul K., and Martin, Seelye; "Observations of Ice Stalactites in McMudro Sound, Antarctica," Journal of Geophysical Research, 76:1595, 1971. (X2)

ESC11 The Possible Extraterrestrial Origin of Ocean Water

Description. A variety of data that are consistent with an extraterrestrial origin of the earth's seawater. Such sources might be icy comets and ice-volatile planetesimals.

Data Evaluation. The data include satellite observations of dark spots on the earth's upper atmosphere, microwave detection of water-vapor 'events', observations of comets and other solar system ices, the direct observation of small objects entering the earth's upper atmosphere, etc. While these data have been acquired using modern scientific instrumentation, their interpretations are highly controversial. For example, the data may be in error or explicable in more conventional ways. Here, however, we rate only the quality of the data, not the interpretations derived from them. It is also relevant that the data in question say little about the validity of the now-accepted outgassing theory of the oceans' origin. Rating: 3.

Anomaly Evaluation. Few scientists would deny that the solar system contains many icy objects, varying from tiny comets to huge, ice-covered satellites. The anomalous aspect of the data described below is their consistency with several hypotheses sharply opposed to the prevailing outgassing theory of ocean origin. In this sense, the data are highly anomalous---even revolutionary. Rating: 1.

Possible Explanations. The data are misinterpreted; they are erroneous, at least in part. The earth's oceans have an extraterrestrial origin, at least in part!

Similar and Related Phenomena. The iridium spikes and other anomalous concentrations of elements in the stratigraphic record, which may have an extraterrestrial origin (ESC1).

Examples

X0. Background. Up until 1950, the classical view of the oceans' origin was that the earth had had both oceans and atmosphere from the time it had cooled from a molten mass. Accumulating evidence, however, began to suggest that the earth had actually began as a cool, solid body. In 1950, W. W. Rubey brought the theory of the oceans' origin into line with the cold-earth hypothesis. Rubey proposed that the oceans were formed from volatiles leaking upward from within the earth. Much geochemical evidence supports this idea. For example, some volatiles---water, carbon dioxide, chlorine, nitrogen---are much too common in the earth's oceans and atmosphere to have come from the weathering of rocks. Rather, these "excess" volatiles were more like the gases emitted by volcanos and hot springs. Rubey's "outgassing" theory soon became mainstream doctrine. (R1, R3) It still is; and our purpose here is the presentation of data that seem to support a different, more radical notion: that the earth's oceans are largely composed of extraterrestrial water!

X1. The observables. The "icy comet" controversy began in 1986, when L. A. Frank et al published their observations of dark spots that they observed on satellite images of the earth's airglow. Frank interpreted these dark spots as cool regions created by the impact of small, icy comets in the earth's upper atmosphere.

Frank's theory and its chilly reception by the scientific community were described by P. Huyghe in Oceans: "These comets are not occasional visitors, he (Frank) says, like the one that comes by every 76 years and---lucky for us---never drops in. No, these are very small, comet-like objects that enter our atmosphere at a rate of 20 per minute, he says. These comets, which he believes must contain about 100 tons of water apiece, vaporize on impact with the atmosphere and fall as rain or snow. Now that may seem like one sizable cold shower, but on a yearly basis he says it's actually only a tiny fraction of the annual precipitation. Then again, over a span of 4.5 billion years, which is about how old the earth is, that's enough water, he says---trumpets blaring ---to create the oceans." (R2)

Well-respected scientists ridiculed the icy-comet theory with such adjectives as: crazy, preposterous, or with "a case of Halley's fever".

But by 1988, additional evidence from diverse sources tended to substantiate the reality of Frank's icy comets: (1) The water in Halley's comet had the same abundances of two key isotopes as the earth's oceans; (2) The rocket detection of unexpected amounts of water vapor in the earth's upper atmosphere; (3) The microwave detection of unusual water-vapor events in the upper atmosphere; (4) The Lyman-alpha detection of hydrogen concentrated near the earth; and (5) The photographic detection of small, incoming objects with the characteristics of the debated icy comets. (R11) Data such as these are usually cataloged under Astronomy (A) and Geophysics (G). Revisions of the catalog volumes already published in these disciplines will cover these topics in greater detail.

X2. The question of quantity. Can the inferred flux of small, icy comets contribute substantially to the oceans' volume? L. Frank answered as follows, based upon the numbers of spots observed by the Dynamics Explorer I spacecraft: "The mass of these objects is estimated at $\sim 10^8$ gm each, and the total flux is $\sim 10^7$ small comets per year. If this flux is representative of the average flux over geologic time, then the water influx is sufficient to fill the earth's oceans."(R4) The influx rate, in terms more readily grasped, is one 100-ton comet every 3 seconds. The volume of all the oceans is about 1.3×10^9 cubic kilometers. In sum, the icy comets postulated by L. A. Frank do seem adequate to fill the ocean basins, given the earth's age of 4 billion-years-plus.

Actually, from a quantitative standpoint, the terrestrial oceans could conceivably have come solely from the flux of large comets thought to exist in the early solar system. "Recent compilations of the lunar impact record, combined with the mass-scaling law for crater diameters in the large-body (gravity-scaling) regime, allow an estimate of the total mass incident on the Moon during the period of heavy bombardment... The results imply that the Earth would have acquired an exogenous ocean of water between ~ 4.5 and ~ 3.8 Gyr ago if comets comprised $\gtrsim 10\%$ by mass of the impacting population." (R8)

X3. The question of seawater chemistry. To be completely convincing, any extraterrestrial source of water should be chemically consistent with present seawater chemistry, as modified by reactions with terrestrial sediments.

In X1, it was mentioned that cometary water is known to contain two isotopes in the same proportions as seawater; these isotopes are deuterium and oxygen-18. (R11) At the present time, we have found nothing beyond these suggestive data.

P. Wilde, however, has provided some fascinating chemical data regarding solar-system ices, which as a class include cometary material:

"...the discovery of Ice and Sulfur satellites of Jupiter, Saturn, and Uranus suggest the possibility of ice and other volatile planetesimals characteristic of the Gas Giant planets being present during the formation of the Earth and the Solar System. For example, the volume of the Earth's ocean (1.3×10^9 km^3) is between the equivalent water volume of the Saturnian satellite Rhea (1×10^9 km^3) and Iapetus (1.6×10^9 km^3). Comparable ice-volatile planetesimals may be the original source of the ocean. Such a primordial ocean would only develop in the late stages of accretion after the Earth reached sufficient size to have a gravity high enough to prevent escape of volatiles through the atmosphere and cool enough to support liquid water. Subsequent differentiation and outgassing of stony planetesimals combined with cycling of the volatiles through oceanic ridges and erosion of the continents resulted in the additional 'salt' content of the present oceans whose elements are in geochemical balance. The relative constancy of oceanic salinity in the last 600 million years may be a relict of the mean content of the impacting ice planetesimals as 60% by weight of the salinity is Cl^- and $SO_4^=$. The Dittmarian conservancy of the Rubey volatiles may be the result of the initial composition of the ice-volatile planetesimals modified by reactions with stony planetesimals over Geologic time. The volume of the oceans would grow or decline from the initial volume as a function of the ratio of the amount of volatiles escaping into space to the amount outgassing from the crust and mantle." (R5)

In summary, it seems that the chemistry and volumes of extraterrestrial ice-volatiles are not inconsistent with the size and chemistry of today's oceans, especially when modified by long contact with terrestrial rocks and sediments. While L. A. Frank postulates a steady rain of small, icy comets; others prefer to see the ices acquired early in the earth's history. (WRC)

References

R1. "Oceans from the Interior?" Scientific American, 184:28, January 1951. (X0)
R2. Huyghe, Patrick; "Origin of the Ocean," Oceans, 19:8, August 1986. (X1, X2)
R3. Strahler, Arthur N.; "Biochemical Speculations on Life's Beginning," in Science and Earth History, Buffalo, 1987, p. 517. (X0)
R4. Frank, L. A.; "On the Presence of Small Comets in the Solar System," Eos, 68: 343, 1987. (X2)
R5. Wilde, Pat; "Primordial Origin of the Oceanic Rubey Volatiles as a Consequence of Accretion of Ice-Sulfur Planetesimals," Eos, 68:1337, 1987. (X3)
R6. Frank, L. A., et al; "On the Influx of Small Comets into Earth's Upper Atmo-

sphere," Eos, 68:1343, 1987. (X1)
R7. Feldman, Paul D.; "Encounters of the Second Kind," Nature, 330:518, 1987. (X1)
R8. Chyba, Christopher F.; "The Cometary Contribution to the Oceans of Primitive Earth," Nature, 330:632, 1987. (X2)
R9. Hecht, Jeff; "Snowballs from Space 'Filled Earth's Oceans'," New Scientist, p. 38, May 12, 1988. (X1, X2)
R10. Monastersky, R.; "Comet Controversy Caught on Film," Science News, 133:340, 1988. (X1)
R11. Huyghe, Patrick; "Oceans from Comets ----New Evidence," Oceans, 21:9, April 1988. (X1, X3)
R12. Kerr, Richard A.; "Ocean Crust's Role in Making Seawater," Science, 239:260, 1988. (X0)
R13. "Oceans from Space," New Scientist, p. 40, January 7, 1988. (X2)

ESC12 Chemical Anomalies of Lakes and Ground Water

Description. Unusual concentrations of chemicals, particularly salt, in lakes and groundwater.

Data Evaluation. Although the studies of these phenomena are not abundant, they are recent and of good scientific quality. Rating: 2.

Anomaly Evaluation. The most anomalous aspect of salt and/or salt water in elevated, inland locations is the possibility that they may have been carried there via marine incursions, implying catastrophic flooding in recent times. Generally, however, the position of mainstream science is that the salt is simply of "unknown" origin, or, in the case of old seawater in lake bottoms, due to the recent elevation of the land. Rating: 2.

Possible Explanations. Marine incursions.

Similar and Related Phenomena. Violent lake turnovers (ESC6); chemical spikes in the stratigraphic record (ESC1); recent marine fossils found far inland (ESB5); topographical evidence of possible marine incursions (ETV5, ETV9).

Examples

X1. Inland lakes containing old seawater. Some inland lakes, perched above the present sealevel, have at their bottoms old, trapped seawater. This seawater, thought to be thousands of years old, could have been deposited when sealevels were much lower or, equivalently, the land surface was depressed. A marine incursion of a temporary or catastrophic nature is still another possibility. All such lakes seem to be in the far north.

U.S.S.R. Over a century ago saline lakes were reported in Nova Zembla (Novaya Zemlya), in the Soviet Arctic. We have found no additional information on these lakes, and it is not known whether they actually do contain old seawater. They are included here because they were used by H. H. Howorth as proof that the north polar regions were once submerged. (R1) There are, of course, thousands of saline lakes on all continents, but most derive their chemical constitution from surrounding sediments, not relict seawater. (WRC)

Norway. "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 large number of landlocked 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 postglacial land rise must have occurred but recently."

.....

"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, Botnvatn, in the district of Salten, northern Norway (67°N.), the altitude of the lake surface being 12 m.

"Lake Ovrevatn, a land-locked fjord near Botnvatn, 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 Botnvatn, of about 10 m., and that 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/l.)	9.24	7.26
Salinity (gm./kgm.)	16.71	13.14
Temp. (°C.)	5.20	4.75

"As in the case in Lake Tokka, 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 Tokko, 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." (R3) Details on Lake Tokke may be found in R2.

Other Norwegian lakes with seawater remaining in their bottoms were subsequently reported: "Large areas of Norway are believed to have been flooded by the sea about 10,000 years ago, after the last great glacier disappeared.

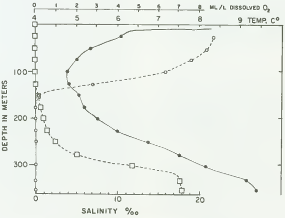
This conclusion is drawn from recent discoveries of salt water in the bottom layers of two Norwegian lakes. Writing in Nature, 207:156, 1965. Dr. Hans Holtan, Norwegian Institute for Water Research, concluded that the salt water 'originated from seawater left behind after the last glacial period.'

"The lakes are Tronstadvatn and Birkelandsvatn in southwestern Norway. The former is about seven miles from the coast and is about 323 feet deep. The latter is about 22 miles inland with a depth of about 227 feet." Holtan opined that present sealevel is about 132 feet lower than during the final days of the Ice Ages. (R5)

Canada. "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 Columbia coast. However, the southern end of the lake (49°53' N., 124°32'W.) is separated from the adjacent strait of Georgia by a rocky sill 46 m. above sea-level.

.....

"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 depths exceeded 350 m. The considerable rise in temperature of nearly



Distribution of temperature, salinity, and dissolved oxygen in Powell Lake, Canada. (X1)

5°C. from 100 m. to the bottom was the first indication that the deeper water needed a significant salt content for stability..... density and electrical conductivity values for the deep-water samples agreed closely with those for seawater 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.

"The saline water is presumed to have entered the Powell Lake Valley first during the disappearance of the last Cordilleran ice sheet close to 13,000 years ago. At this period the land was submerged in the vicinity of the Strait of Georgia at least locally to the 175 m. contour." (R4)

X2. Glacier brines and salty lakes in Antarctica. The source of the Antarctic salt is uncertain. One rather heretical notion is that the salt arrived via a marine incursion.

Taylor Glacier/Lake Bonney. "A saline discharge from beneath Taylor Glacier has abundant halite (NaCl), aragonite ($CaCO_3$), and other salts. The quantities and varieties of salts in the discharge and in lakes and in soils of other places in Victoria Land are too great to reflect present weathering. No simple origin of all salts is indicated." To amplify the above Abstract of R. F. Black et al, we append the following data from the article proper: A saline discharge from Taylor Glacier created a striking reddish-yellow ice cone, extending more than 150 meters over the old ice of Lake Bonney. Lake Bonney is about 50-75 meters above sealevel and 21 miles from the sea. The total volume of the discharge, which may not be all salt-rich, is 3,000-6,000 cubic meters. (R8)

Lake Vanda. The chemical composition of Lake Vanda is similar to that of Lake Bonney. The two lakes are located in adjacent valleys. From the Abstract of R. A. Ragotzkie and I. Friedman: "Lake Vanda in Victoria Land, Antarctica, is permanently ice-covered and permanently stratified, with warm, salty water near the bottom. Deuterium analyses of lake water from several levels indicate that the lake has a low deuterium content, and that it is stratified with respect to this isotope. This low deuterium content supports the evidence from the lake's ionic content that the saline layer is not of marine origin, and it indicates that evaporation from the ice surface has taken place." (R6; R10)

Possibly related to the salty deposits in Victoria Land are the evidence for catastrophic fluvial erosion (ETV9-X2) and the presence of mummified seals far inland. (ESB5) Since a marine incursion does not seem to explain all the chemical data, C.R. Warren has hypothesized volcanism under the ice sheet. (R7)

X3. C^{13} enhancement in aquifers. F.H. Chapelle et al have reported that water from a 100-feet-deep aquifer, near Hilton Head, South Carolina, is abnormally rich in carbon-13. They attribute this enrichment to the action of bacteria present at these depths, which preferentially select this carbon isotope when producing carbon dioxide. (R9) In the stratigraphic record, however, enhancement of the carbon-12 isotope is presumed to be due to the preferential selection of the lighter isotope during photosynthesis. (ESC1-X3)

X4. Chemical anomalies of hydrothermal vent fluids.

Loihi Seamount, off Hawaii. The hydrothermal fluids emitted by the high-temperature springs on this seamount have an unusual chemical composition: "The springs are emitting water at about 30°C, which is strongly enriched over seawater in barium, SiO_2, and particularly in iron, manganese, methane and dissolved CO_2 and bicarbonate. The solutions appear oxidizing, with abundant sulphate and no detectable sulphide. Associated with the vents are deposits of iron oxides and smectitic silicates reminiscent of the deposits that form on older crust near to the Galapagos spreading centre. The source of the carbon is not at all clear. It is about 150 times greater in abundance than that in the ambient sea water, and it is difficult to see how such concentrations of CO_2 can be produced in the fluid phase alone." (R12)

References

R1. Howorth, Henry H.; "Recent Elevations of the Earth's Surface in the Northern

Circumpolar Regions," Royal Geographic Society, Journal, 43:240, 1873. (X1)
R2. Strom, Kaare; "A Lake with Trapped Sea-Water?" Nature, 180:982, 1957. (X1)
R3. Strom, Kaare; "A Second Lake with Old Sea-Water at Its Bottom," Nature, 189: 913, 1961. (X1)
R4. Williams, P.M., et al; "A Lake in British Columbia Containing Old Sea-Water," Nature, 191:830, 1961. (X1)
R5. "Seawater in Lakes Trapped Centuries Ago," Science News Letter, 88:95, 1965. (X1)
R6. Ragotzkie, Robert A., Friedman, Irving; "Low Deuterium Content of Lake Vanda, Antarctica," Science, 148:1226, 1965. (X2)
R7. Warren, Charles; "Wright Valley: Conjectural Volcanoes," Science, 149:658, 1965. (X2)
R8. Black, Robert F., et al; "Saline Discharge from Taylor Glacier, Victoria Land, Antarctica," Journal of Geology, 73:175, 1965. (X2)
R9. Monastersky, R.; "Bacteria Alive and Thriving at Depth," Science News, 133: 149, 1988. (X3)
R10. Angino, Ernest E., and Armitage, Kenneth B.; "A Geochemical Study of Lakes Bonney and Vanda, Victoria Land, Antarctica," Journal of Geology, 71:89, 1963. (X2)
R11. Holtan, Hans; "Salt Water in the Bottom Layers of Two Norwegian Lakes," Nature, 207:156, 1965. (X1)
R12. Cann, J.R., and Strens, M.R.; "Surprises of Different Kinds," Nature, 335: 495, 1988. (X4)

ESC13 Anomalies Associated with the Origin of Oil

Description. Phenomena of the chemistry and geological occurrence of Petroleum deposits that do not square well with the accepted biogenic theory of oil's origin.

X1. Conversion of organic material into oil poorly understood
X2. Odd-carbon predominance diminishes in older oils
X3. Decline of optical activity in older oils
X4. The carbon-13 depletion of oils
X5. Radioactive oils
X6. Porphyrins not necessarily biogenic or petroleum-derived
X7. Hydrogen-saturation of oils
X8. Commonality of chemical signatures in oils
X9. Bacteria in oil
X10. Unique geochemical character of Ordovician oil
X11. Chemical affinities of oil and coal
X12. Chemical affinities of oil and volcanic products
X13. Nonmarine petroleum
X14. Organic signatures decrease in older oils
X15. Possible conversion of atmospheric methane to oil
X16. Oil in crystals, basalt vesicles, etc.
X17. Indigenous Precambrian petroleum
X18. Oil in basement rocks
X19. Lack of oil in most recent sediments
X20. Anomalous oil in some recent sediments
X21. Geographical association of oil deposits and volcanos
X22. Geographical association of oil deposits with crustal defects
X23. Geographical association of oil and helium
X24. Geographical association of oil and coal
X25. Oil deposits transcend local geology
X26. The vertical stacking of hydrocarbon deposits
X27. General cut-off of petroleum deposits at 15,000 feet
X28. Oil deposits in the deep-ocean floors
X29. Geologically isolated oil deposits
X30. Giant oil fields
X31. The carbon problem

X32. The problem of oil migration
X33. The existence of abundant extraterrestrial hydrocarbons

Background. Oil's origin has been debated for over a century, with the biogenic camp now holding the upper hand. In opposition are some Russian geologists and, in the West, T. Gold and a few like-thinking colleagues; all of whom favor an abiogenic origin. More specifically, they envision an origin deep beneath the earth's surface, where they believe that primordial methane still exists in large quantities. Understandably, many of the anomalies offered below have been underscored by these heretics.

Data Evaluation. Petroleum is a common, commercially valuable, well-researched substance. Rating: 1.

Anomaly Evaluation. The biogenic theory of oil's origin, which involves the conversion and migration of buried biological materials, is held with almost religious tenacity by mainstream science. All contradictory facts are, therefore, highly anomalous. Rating: 1.

Possible Explanations. Besides the mainstream biogenic theory (see X0 below), we have the challenging abiogenic theory, which proposes that primordial hydrocarbons, relics of the earth's formation, well up from deep inside the earth.

Similar and Related Phenomena. The controverted origins of coal (ESC14) and natural gas (ESC16). The so-called "carbon problem" (ESC9-X4); bacteria in oil (ESB9); oil in geodes and crystals (ESA5, ESA3, ESI1); supergiant oil fields (ESD7); oil in unusual places (ESX4, ESG9).

Examples

X0. The accepted theory of oil's origin. A. N. Strahler summarizes the position of mainstream science nicely: "There is general agreement in mainstream science that petroleum had its origin in organic matter that became incorporated into marine muds and clays accumulating in subsiding basins. Two sources of organic matter are recognized. One is a terrestrial source and consists of fragments of land plants carrying waxes that are hydrocarbon compounds of distinctive chemical formulation. These are carried to the sea and deposited mostly in nearshore environments. A second source, and by far the most important in terms of quantity, are hydrocarbons (oils, fats) produced by plankton (floating organisms). Upon death, the organism sinks to the ocean floor and what remains of it is incorporated into mud or clay, that may be calcium carbonate, silicate mineral matter, or a chemical precipitate (salt, anhydrite, chert).

"An important point on which agreement is general is that the various kinds of hydrocarbon compounds described above account for no more than 10 to 15 percent of the hydrocarbons actually found in petroleum. Thus the bulk of petroleum is a product of chemical change, thought to be the result of prolonged heating of the compacted sediment." (R51)

Why does mainstream science take such a firm stand on this subject. C. E. Melton summarizes: "Scientifically, those who believe in a biological origin of petroleum cite six observations that they claim support their belief. These are briefly outlined and discussed later in detail. The 'proofs' are:

(1) Traces of compounds such as nickel and vanadium porphyrins which are claimed to be associated with some biological matter are found in a few petroleum deposits. In actual fact, only iron and magnesium porphyrins are known in zoological and biological matter. (See X6.)

(2) The isotopic abundance of carbon in most petroleum shows that carbon-13 has been depleted. For example, if the carbon-12 abundance is standardized at 98.89% and that for carbon-13 at 1.11%, then the carbon isotopes in petroleum usually have an abundance of at least 98.92% for carbon-12 and 1.08% for carbon-13..... (See X4.)

(3) Petroleum often contains variable quantities of optically-active hydrocarbon compounds. (See X3.)

(4) Nearly all petroleum accumulations are found in sedimentary formations.

(5) Many petroleum fields have nearby rock formations that contain small dispersions of compounds similar to those found in the petroleum. These rock formations are called 'source rock' by the biogenic believers, and they say the occurrence of 'source rock' shows where the petroleum came from. (See X32.)

(6) Most petroleum accumulations occur in sedimentary formations that are younger

in geologic age than Cambrian (about 600 million years), with major concentrations found in strata having ages younger than Devonian, (400 million years), times during which biological activity flourished." (R47) (See X17.)

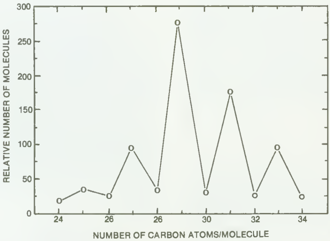
Below we present a large array of phenomena which tend to contradict or at least question the mainstream position. (WRC)

X1. A general observation: The chemical conversion of organic material into oil is not really well-understood. In a historical review of science's attempts to explain the origin of petroleum, R. Robinson contributed these comments:

> "On account of the very great political and industrial importance of oil, every circumstance bearing on its occurrence, recovery, and use has been fully explored as far as it is possible to do so. However, the mode of genesis of the first oil is still not certainly known in spite of repeated statements to the contrary. Russian scientists were pioneers in considering an inorganic origin. After an early idea of Lomonosov, postulating underground transformation of coal, Mendeleev suggested the formation of metallic carbides which would yield hydrocarbons by reaction with water. The theory could apply only to the simpler paraffins and the necessary supplementary hypotheses were not formulated. Later observers noted that petroleum shows many signs of organic origin and they recognized these as consistent with the idea of the laying down, in brackish waters, of vast quantities of remains of small organisms in the sedimentary rocks. It was, and is, agreed that the conversion of the organic matter into oil is inexplicable, but this was regarded as a matter of small significance." (R25)

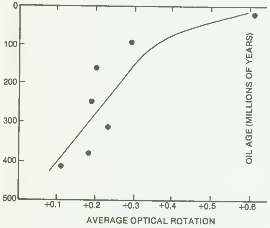
X2. Odd-carbon predominance diminishes in older oils. One of the important 'proofs' of the organic origin of oil is the well-known propensity of the molecules constituting oil to have odd numbers of carbon atoms; i.e., 27, 29, 31, 33, etc. carbon atoms per molecule. It has been demonstrated that the formation of hydrocarbons in plants leads to the odd-carbon hydrocarbons. Therefore, oils showing the odd-carbon effect are considered biogenic.

Older oils, however, show little or no odd-carbon predominance. R. Robinson (R25) and others consider this a sign that these



Distribution of heavy n-paraffins from recent sediments in the Catalina Basin. (X2) old oils are abiogenic. T. Gold points out that the transition from oils with odd-carbon predominance to those with almost none-at-all may be a consequence of the higher temperatures encountered by the older, deeper oils. The higher temperatures have precluded bacterial activity in these oils--- a phenomenon which Gold believes creates the odd-carbon predominance in the younger oils nearer the surface. (R50) Gold, in fact, holds that most petroleum is abiogenic.

X3. Decline of optical activity in older oils. The optical activity of a substance; that is, the ability to rotate the plane of polarized light; is generally taken as proof positive of biogenic origin for oil and other substances. But like the odd-carbon-predominance phenomenon (X2), it varies with the oil's apparent age. E. W. Biederman, Jr., states: "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." (R35) Quantitatively, Tertiary oils are five times as optically active as the older Silurian oils. (R24) One implication is that the older oils contain a larger fraction of abiogenic oil. Another interpretation, that of T. Gold, is that bacteria were less active in the deeper, hotter oils. (R50)



Average optical activity of oil versus age. Older oils are less active and, presumably, more abiogenic. (X3)

X4. The carbon-13 depletion of oils. "Biochemical processes, especially photosynthesis, selectively utilize carbon-12, so that the resulting metabolic products are enriched in carbon-12 relative to the carbon source. Coals, plants, animal tissues and all petroleums so far examined (from sediments of Pre-Cambrian to Pleistocene age) exhibit carbon-12 enrichment. The high carbon-12 content of petroleum is a very significant piece of evidence favouring its organic origin." (R25) Of course carbon-12 enrichment is equivalent to carbon-13 depletion. See ESC1.

Based on the above quotation, carbon-13 depletion in petroleum would seem to indicate strongly that oil is biogenic, and that photosynthesis has probably been an important process in creating the organic products needed for its formation. Nevertheless, the proponents of an abiogenic origin are not dismayed. They point to the observation that methane (not oil) is less depleted in carbon-13 at greater depths. This, they say, suggests than a nonbiological isotope fractionating process is depleting the methane as it ascends through the crust. (R50) The implication is that all terrestrial hydrocarbon deposits may undergo isotopic fractionation of a nonbiological nature. (R47) Many purely physical isotopic fractionation processes are known, as in the uranium enrichment process utilizing gaseous diffusion.

X5. Radioactive oils. "Smaller accumulations of oil and bitumen are widespread in igneous and crystalline rocks, and indeed a few of them are exploited commercially. Some of the bitumen in igneous rocks is radioactive. The association of such heavy hydrocarbons with radioactive minerals suggests that they have been formed from lighter fractions, which have been polymerized by alpha bombardment, and the absorption of energy. Most people argue that these radioactive bitumens are abiogenic." Interestingly enough, some igneous rocks contain nonradioactive bitumen. (R24) See X18 for more on this.

X6. Porphyrins not necessarily biogenic or petroleum-derived. "...crude oil also contains minor organic constituents in addition to hydrocarbons. Most significant of these are the porphyrins which are certainly derived from biological material, probably from chlorophyll." This quotation is from P. Sylvester-Bradley; and it certainly seems to imply that the presence of porphyrins in oil proves its biological nature. However, Sylvester-Bradley goes on to suggest that porphyrins in petroleum may be secondary; that is, carried there in solution from an organic environment. Such migration of porphyrins does occur, as evidenced by the presence of porphyrins in calcite veins of igneous rocks. (R24)

On a slightly different tack, C. E. Melton maintains that the porphyrins in crude oil need not be biogenic in the first place. He states that porphyrins can be easily synthesized in the laboratory from methane, ammonia, and water. (R47)

X7. Hydrogen-saturation of oils. Petroleum is usually mostly saturated with hydrogen, whereas geochemists would normally anticipate that buried biological materials would be deficient in hydrogen. (R48)

X8. Commonality of chemical signatures in oils. Writing in the Atlantic Monthly about T. Gold's abiogenic theory of petroleum's origin, D. Osborne remarks: "Gold also raises questions about trace elements in oil, principally nickel and vanadium. In many parts of the world these metals occur in large regional patterns. Along the west coast of South America, for example, most of the oil is very high in vanadium. Throughout Venezuela the ratio of nickel to vanadium is remarkably constant. The oils of the Persian Gulf, the Ural Mountains (in the USSR), and parts of west Africa each have constant ratios of nickel to vanadium as well. Gold believes that a deep origin is the only logical explanation for such precise patterns over hundreds of miles." (R49) See R50 for more technical detail.

X9. Bacteria in oil. "All crude oils contain live, active bacteria. These are able to withstand high pressures, relatively high temperatures and a complete absence of air. The products of their activity contribute of course to the total content of the oil, and could account for all its biological properties. Those who do not believe in abiogenic oil claim that these bacteria are responsible for converting the organic matter found in sediments into oil. Those who do not believe in biogenic oil claim the bacteria alter the constitution of the oil, producing more odd-carbon molecules and making it optically active. They also claim that the porphyrins and other nitrogenous compounds found in oil are formed by the bacteria." (R24)

The conventional view of petroleum formation relies on pressure and heat applied for millions of years to convert organic material into oil. The role of bacteria in promoting this conversion, however, is becoming more obvious in modern research. (R45)

Another point of view is that of T. Gold, who thinks that bacteria, including methane-consuming bacteria, could convert methane gas streaming up through the crust into an enormous reservoir of organic material. This reservoir might then be converted into petroleum. (R49)

X10. Unique geochemical character of Ordovician oil. "Oils from Ordovician source rocks worldwide have interested geologists and organic geochemists because of the unique organic geochemical character of 'Ordovician Oil': a strong odd preference in normal alkanes from C_{11} to C_{19}, very low relative amounts of heavier normal alkanes, virtual absence of isoprenoids (including pristane and phytane) and porphyrins, and low relative amounts of steranes and heptanes." It is thought that the distinctive character of these oils derive from a specific organic-walled microfossil, Gloeocapsamorpha prisca. (R59) It is quite possible that an anomaly does not exist here, but it was thought worthwhile to record this interesting fact. (WRC)

X11. Chemical affinities of oil and coal. Oil and coal are customarily assumed to have had completely different origins. Chemically, though, there are strong similarities: "The specialist in the field of bituminous coal, natural asphalt and oil is struck with the relation of these substances. They consist of aliphatic, semi-aromatic and aromatic compounds. The presence of bituminous coal and oil in the same localities, but in different strata, for instance, near Pittsburgh, forces one to the point of view that both substances were formed from the same original material." (R3) This quotation is over 50 years old and certainly not representative of modern geological thought. (WRC)

Frequently coal beds overlie oil deposits. (See X24 for a fuller treatment.) T. Gold interprets this oil-coal geographical correlation in terms of his abiogenic theory. "This produces one of the interesting relationships between biogenic and abiogenic carbon. Clearly identifiable plant debris, like peat or lignite (brown coal in which the structure of the original plants can still be seen), may be found to overlie deposits of oil or gas, giving perhaps the suggestion that plant deposits in earlier times had also been responsible for the deeper carbonaceous materials." The common element here would have been the upwelling of hydrocarbons from deep sources---abiogenic hydrocarbons of course---which formed the petroleum and also kept oxygen away from the upper plant debris, thereby partially preserving it. (R50)

X12. Chemical affinities of oil and volcanic products. Long before T. Gold advanced his particular theory of abiogenic oil and gas, E. Coste staked out similar theoretical territories: "The volcanic origin of natural gas and petroleum is strongly advocated by Mr. Eugene Coste in a paper read before the Canadian Mining Institute (March 5). The author points to the complete analogy of the products of the oil and gas fields with the products of volcanic solfataric action. These products are water, chloride salts, sulphur, sulphuretted hydrogen, carbonic acid, and hydrocarbons. He brings forward facts upon which he bases his view that all the petroleum, natural gas, and bituminous fields or deposits are essentially the products of solfataric volcanic emanations, condensed and held in their passage upward in the porous tanks (sands, limestone, &c.) of all ages from the Archaean to the Quaternary. He instances the occurrence of carbon and hydrocarbons in gneisses and various ancient plutonic rocks. He likewise refers to the dolerite of the Lothians, in which cavities of the rock are filled with a mineral wax not unlike the ozocerite of Galicia. The oil shales through which the igneous rocks were intruded were, in Mr. Coste's opinion, impregnated by solfataric emanations, for their bituminous character is local, and in proximity to the igneous rocks. Allusion is made to the occurrence of asphalts and oils along the faulted and broken margins of the Gulf of Mexico and the Caribbean Sea, the great asphalt deposit of Trinidad filling the crater of an extinct volcano. Again, natural gas and petroleum are associated with mud volcanoes. The author therefore concludes that carbon and hydrocarbons are derived from deep-seated fluid magmas, in which they exist probably in the form of carbides." (R1) This historical intrusion also emphasizes the geographical correlation of oil deposits and volcanos. More recently, geologists, especially those favoring the abiogenic theory of oil, have pointed out the same geographical correlations. See X21 and X22.

X13. Nonmarine petroleum. Mainstream geology usually states unequivocally that oil is of marine origin. (R50) This is an oversimplification, because a minority of oil deposits are widely admitted to be of freshwater origin. China, for example, has several oil deposits that seem to be completely isolated from marine source rocks. (R9) Besides geological isolation from marine rocks, a preponderance of high-molecular-weight hydrocarbons is usually taken as evidence of a nonmarine origin; viz., Utah's Green River Shale and Uinta Basin Crude. Some Chilean petroleum is also thought to be nonmarine based on geochemical considerations. (R32) The question of marine vs. nonmarine origin naturally pales when compared to the biogenic-abiogenic argument. (WRC)

X14. Organic signatures decrease in older oils. We have already touched upon this subject in X2 and X3, but two other facets must be mentioned. Again, we rely on the work of R. Robinson: "The signature tunes of biologically produced hydrocarbons are based on four themes, each of which is loudly proclaimed in the recent sediments, but fades away and is only just audible in the most ancient 'crude oils'." Robinson's four themes are: (1) odd-even carbon predominance (covered in X2); (2) optical activity (in X3); (3) predominance of naphthenes with one and four rings in each molecule; and (4) the presence of porphyrins. (R27) Porphyrins were introduced in X6, but not in the context of their diminishment with the age of the petroleum. As before, the major implication of these "age effects" is the abiogenic nature of at least some of the petroleum. (WRC)

X15. Possible conversion of atmospheric methane to oil. Although few hold that our immense and diverse petroleum deposits all originated through the polymerization of the methane atmosphere of the ancient earth, it is worthwhile to at least catalog this possibility as a potential source of some oil. We begin with the abstract of a paper by A. C. Lasaga et al: "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." (R31)

Certainly large amounts of methane could have existed in earth's primordial atmosphere. The potential for its polymerization leads to what might be called the "atmospheric origin of oil". L.P. Gaucher stated this theory as follows: "Instead of assuming that oil was formed under surface and atmospheric conditions similar to those that we find on earth today, as the organic theory does, I suggest that oil was formed through chemical reactions of components of the atmosphere at the time when the earth was still hot and devoid of life." (R33)

X16. Oil in crystals, basalt vesicles, etc. That at least some oil and other hydrocarbons must be abiogenic is demonstrated by their presence in closed cavities in rocks that were once molten. In fact, many mineral collections sport crystals with fluid-filled bubbles. Methane, ethane, and even solid hydrocarbons occur commonly in quartz and other igneous crystals. Bubbles in opals may contain liquid oil. (R24) Vesicles in basalt from Brazil are filled with petroleum; some Manchurian basalts have their pores filled with solid bitumen. (R2) These are just a few examples on record.

X17. Indigenous Precambrian petroleum. Until fairly recently, the notion of drilling into Precambrian sediments for oil was likely to be ridiculed. After all, Precambrian life was simple and very sparse---hardly a good source of raw material for the formation of petroleum. Opinion was that any significant quantities of oil found in Precambrian rocks must have migrated there from younger source rocks that tectonic movements had placed at lower levels.

But "indigenous" Precambrian petroleum has now been found in commercial quantities. At the same time, we have more and more evidence that rich Precambrian biological assemblages did indeed exist, making the concept of Precambrian oil more reasonable.

G. E. Murray et al have summarized the situation as of 1980: "Since 1965, a dramatic increase in publications which document worldwide occurrences of Precambrian life forms discloses that, by the end of the Proterozoic, organic evolution had produced diversified assemblages of relatively highly developed macroorganisms. Some of these organisms have generated crude oil in the Nonesuch Shale of northern Michigan and kerogen (which yielded hydrocarbons) in stromatolitic carbonate rocks in Africa. Kerogen has been extracted from ~2,300-m.y. old Transvaal (Africa) stromatolitic limestone containing coccoid and complex filamentous cyanophytes (a type of algae). Also, aromatic and aliphatic hydrocarbons have been obtained from the ~2,800-m.y. old Bulawayan stromatolitic limestone of Rhodesia." The Irkutsk Basin, in Russia, contains large amounts of oil in the Lower Cambrian and gas in the upper Proterozoic. The Cambrian and Precambrian hydrocarbons are different, were probably generated separately, and are likely indigenous. (R39)

Previously, the reality of abundant Precambrian oil might have been used to support an abiogenic origin. Now, the issue is clouded by the increasing appreciation of Precambrian organic sources for petroleum formation. (WRC)

X18. Oil in basement rocks. Igneous and metamorphic basement rocks, unlike Precambrian sediments (X17), are thought to be completely devoid of indigenous organic material, except perhaps for minute ammounts of abiogenic hydrocarbons trapped in crystals and vesicles (X16). Any large petroleum deposits in basement rocks must have migrated there from nearby, younger source rocks. Normally, no one drills into basement rocks looking for oil, but some sizeable deposits have been located accidentally. K. K. Landes et al have described deposits in Venezuela, California, Kansas, and Morocco. (R18) All of these accumulations were at higher altitudes than flanking sediments and could therefore be accounted for by invoking oil migration. Sometimes, however, oil migration can be essentially ruled out, as with some deposits in igneous rocks in Russia:

> "The most interesting accumulations are in the Kola peninsula in the north-west corner of arctic Russia, where there is a complete range of the heavier bitumens and of all grades of crude oil, including natural gas. I. A. Petersil'ye, who has been studying these constituents, is convinced that they were formed at the same time as the igneous rock, and that they are biogenic. The alternative theory postulates that the oil has migrated from some other source, such as sedimentary rock. The migration theory however is difficult to support: these oil deposits are found underlying sedimentary rock and, because oil floats on water, it is unlikely to have migrated downwards to the igneous rock." (R24)

The amount of oil found in igneous and metamorphic rocks is considerable, as related by S. Powers and F. G. Clapp as long ago as 1932:

> "Abstract. Oil, gas, and residues of petroleum ranging from asphalt to graphite are found in igneous and metamorphic rocks. More than 15,000,000 barrels of oil have been produced from igneous and metamorphic rocks; one gas field produces from a basalt flow, and millions of tons of asphalt, representing the residue of more than 200,000,000 barrels of oil, are known in serpentine in one area---northern and northwestern Cuba. Seepages of oil connected with igneous intrusions led to the discovery of some of the largest oil fields in the world---in Mexico. Seepages and traces of oil, gas, and bitumen in igneous rocks point to the possibility of commercial production in many parts of the world where oil has not yet been found." (R52)

T. Gold also cites such examples in support of his abiogenic theory. (R50)

X19. Lack of oil in most recent sediments. The standard explanation of petroleum's origin assigns millions of years for the slow cooking of organic debris under high pressures. However, one geological school of thought does admit the formation of oil soon after deposition. But, a survey of many likely recent sediments, from all over the world, has found no evidence for oil in any recent sediments. (R10-R12) See also X20 following.

X20. Anomalous oil in some recent sediments. Despite the thoroughness of the survey mentioned above, in X19, P. V. Smith, Jr., reported in the early 1950s the discovery of oil in recent sediments in the Gulf of Mexico. (R10-R12) According to radiometric dating, this oil is only a few thousand years old, and thus difficult-to-account-for in the context of accepted theory. The composition of this very recent oil is reported to be quite different from normal crudes. Its mode of formation is not clear. (R14)

Petroleum has also been dredged up from active hydrothermal mounds in the Guaymas Basin off the North American Pacific coast. (R43) Such sites could also produce 'recent' oil abiogenically. (WRC)

X21. Geographical association of oil deposits and volcanos. In X12, we noted some gross similarities between the chemical compositions of hydrocarbon deposits and volcanic emissions. An allusion was also made to a possible geographical correlation of oil deposits and volcanos. This geographical correlation is not particularly strong, but it does exist. Here is how T. Gold expresses it: "Proximity to active volcanos is also worth noting. There are several volcanoes on whose flanks oil and gas are being produced in commercial quantities. The north island of New Zealand, which is generally very gas-rich and which once had the gigantic eruption that created Lake Taupo, has gas production on the flanks of its largest presently active volcano, Mount Egmont. Mount Etna in Sicily has commercial oil and gas production on its flanks." (R50)

Proponents of biogenic oil believe that oil found near volcanos is simply oil from buried organic material that has been force-cured by volcanic heat. In contrast, the abiogenic-oil side considers volcanos as channels in the earth's crust which allow large quantities of deep-seated hydrocarbons to come closer to the surface. (WRC)

Volcanos, in fact, represent just one of a whole class of crustal defects or weaknesses which may act as conduits for upwelling abiogenic hydrocarbons. See X22 and X12.

X22. Geographical association of oil deposits with fissures, salt domes, and other crustal defects. Expanding on X21's theme of crustal weaknesses and their associated oil deposits, the Russian scientist, V. B. Porfir'ev, generalizes thusly:

"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." (R34)

T. Gold has identified additional associations of hydrocarbon deposits and crustal flaws: (1) Most of the Middle East oil lies along continental plate boundaries; (2) One finds rich hydrocarbon deposits all long the seismically and volcanically active line running from New Guinea through Indonesia and into Burma and China; (3) U.S. Oil-rich fields include the overthrust belt of the Rockies, the San Andreas fault in California, and regions overlying ancient rifts in Oklahoma and Texas. (R49, R50).

Not all oil deposits are associated with zones of crustal activity or weakness. In X29, for example, oil deposits are described which are bounded by seemingly impervious rock formations.

X23. Geographical association of oil and helium. T. Gold, in his case against the biogenic origin of petroleum has stated: "... perhaps the greatest problem for the theories of biological origin was the association with helium. Many of the areas of the Earth that bear petroleum and methane are also rich in helium. Natural gas is the source of all commercial helium. Very few areas of the Earth have high concentrations of helium in underground gases without methane being the dominant partner. It is impossible to explain this relationship if the methane originated from biological materials buried in the sediments. Biology can have had no part in the process of concentrating helium, a chemically inert gas. The explanation that helium just happens to be caught in the same traps that hold methane is quite inadequate when one realises that many traps happen to have no methane in them. Why do these not have high proportions of helium?" (R48; R58)

Gold has singled out for attention a region in the United States, stretching through many western states from Texas to Montana, where thousands of oil wells are helium-rich. He emphasizes that, "It is doubtful that one could find any feature of the chemical makeup of the sediments that would account for the presence of so much helium in this large connected region.... Presumably, this has to be attributed to a large out-gassing pattern from mantle depths." (R49)

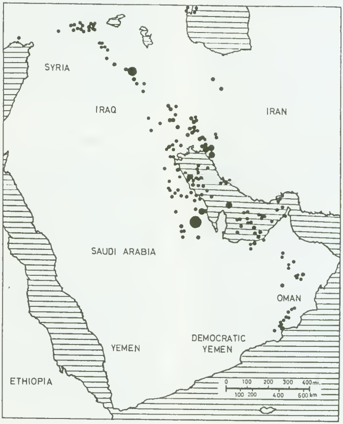
X24. Geographical association of oil and coal. Oil and coal are both hydrocarbons with gross chemical similarities. (See X11.) For many years it has been maintained that the two substances were unrelated geographically or generically. But, T. Gold notes that there is now considerable evidence to the contrary:

"The coal and oil maps of South America are quite striking in this respect. Indonesia is another striking example. The local lore among those who drilled for oil was, 'Once we hit coal, we knew we were going to hit oil'. In Wyoming, some coal is actually within the oil reservoirs, and in many sedimentary basins, including the San Juan Basin of New Mexico and the Anadarko Basin of Oklahoma, coal overlies oil and gas. Alaska, Iran, Saudi Arabia, the Ural Mountains, all known for their oil fields, also possess large amounts of coal. The same is true of many other oil-producing areas, such as Venezuela and neighbouring Columbia, Pennsylvania and the Appalachian Mountains, and so on." (R50)

X25. Oil deposits transcend local geology. As a corollary of X22, where hydrocarbon deposits were seen to be correlated with regional crustal defects, T. Gold maintains that hydrocarbons often correlate poorly with local geology:

"The way in which hydrocarbons occur globally also provides problems for the theories of biological origin. Why is the Middle East so rich in hydrocarbons? The mountains of southeastern Turkey, the valley of the Tigris, the folded mountains of Persia, the Persian Gulf and the flat plains of Saudi Arabia have little in common with each other, except that they form one connected region that is enormously well supplied with oil and gas. No one has discovered a unifying feature for the region as a whole. The oilfields span different geological ages, have different rocks that bear the gas and oil (reservoir rocks) and different rocks, called cap rocks, holding down the contents of these reservoirs. Attempts to find sediments rich in biological debris have generally failed, and there is no consensus as to the source that produced such a wealth of oil and gas." In many other parts of the world, says Gold, oil and gas deposits span different geological settings. (R48; R50)

X26. The vertical stacking of hydrocarbon deposits. In addition to the distinctive geographical distribution of hydrocarbon deposits, they exhibit another striking geometrical characteristic. "It is the vertical distribution of hydrocarbons in any such area; the fact that it quite common to find every level that the drill passes on the way down to contain



Mideastern oil and gas fields are found in markedly different geological settings. (X25) oil or gas (Kudryavtsev's rule). The quantities that may be recoverable at the different levels may vary greatly, as porosity and permeability vary, but the entire vertical column has hydrocarbons in its pore spaces. At first sight one might argue that this would just result from a prolific supply at the deepest level. But when, as often happens, the deepest level is in fact the crystalline basement or a very ancient non-fossil-bearing sediment just overlying the basement, then such an explanation seems inadequate." (R50; R48)

X27. General cut-off of petroleum deposits at 15,000 feet. Petroleum occurs only infrequently below the 15,000-foot level. Since some oil has been found at much deeper, much hotter levels, the standard explanation that oil is unstable at the temperatures encountered at 15,000 feet and below is not convincing. (R50) T. Gold explains this cut-off in terms of the transportation of abiogenic hydrocarbons by upwelling supercritical methane.

X28. Oil deposits in the deep-ocean floors. It is surprising to find evidence of substantial petroleum at great depths in ocean-bottom sediments. Where are the source rocks required by theory for these very deep deposits?

The first exhibit is the abstract of R. D. McIver's 1974 paper: "Cores from the Deep Sea Drilling Project contain evidence that liquid hydrocarbons are migrating in or into near-bottom sediments at three widely separate locations. The first occurrence noted was the highly publicized, visually observed accumulation of immature petroleum in sediments on the Challenger Knoll (3,572 meters deep) in the Gulf of Mexico. Later, systematic chemical analyses revealed two more possible examples of migrated hydrocarbons. The first of these was a low-grade bitumen enrichment in a thin porous zone in Pleistocene sediments on the Shatsky Rise (4,282 meters deep) in the western Pacific Ocean. The second was a small but geochemically significant quantity of gasoline-range hydrocarbon and wet gas that apparently has seeped upward into Miocene sediments in the Balearic basin of the western Mediterranean Sea. These migrated hydrocarbons, in addition to the methane gas frequently found in the deep-ocean cores, reveal that hydrocarbon source rocks must be present, at least locally, in deep-ocean sediments, because liquid as well as gaseous hydrocarbons have begun to migrate." (R29) An alternate interpretation is that there are no "source rocks" per se, and that the hydrocarbons are rising from deep in the crust. (WRC)

Also of interest is the discovery, via seismic reflection, of structures resembling salt domes at a depth of 15,000 feet, northwest of the Cape Verde Islands. Since salt domes are commonly associated with oil deposits on land, abyssal oil fields may exist. (R28)

X29. Geologically isolated oil deposits. The isolation of oil deposits from source rocks or, in the case of the abiogenic theory, the postulated upwelling hydrocarbons from deep in the earth's crust can take two forms: (1) the deposit can be isolated by impervious rocks; or (2) the deposit can be cut off by distance, lack of gravity gradient, and nonexistence of suitable rock conduits.

The first of these possibilities has been described by E. W. Biederman, Jr.:

Isolated Oil Sandstones. "The hypothesis of inorganic origin through deep faulting would appear to have considerable difficulty in explaining the entrapment of petroleum in reservoirs isolated by shales on all sides. As Silver pointed out, examples of such accumulations are present in some of the sandstones of the San Juan and Denver-Julesburg basins; the Muddy Sandstone of the Powder River basin; the Cherokee sandstones of eastern Oklahoma and Kansas; the Atoka limestone and Morrow sandstones of the deeper Delaware basin; the shoestring sandstones of Michigan; the fractured Niobrara Shale reservoirs of Colorado, Wyoming, and other parts of the Rockies; and many sandstone reservoirs in Pennsylvania, West Virginia, and Ohio. Also included in the isolated category are the many pinnacle-reef reservoirs such as the Silurian reefs in Michigan. These fields are commonly unconnected with faults or other structures and, furthermore, the ages of these reservoirs are for the most part much older than early Miocene." (R35)

Moving on to the second variety of geological isolation, the Canadian Athabaska oil sands appear to be effectively cut off from any reasonable source rocks. Hundreds of billions of barrels of bitumen seem to have been formed in situ. "The oil sands seem to lie too flat to have induced oil migration. There is no suggestion of artesian or metamorphic fluid movement into the area from without. The sand appears to be saturated throughout most if not all of its horizontal extent; there seems to be no large additional sand area whence the oil in the saturated area might have migrated. No deeper porous bed is known which might have brought oil into the area from remote sources." (R7)

X30. Giant oil fields. Here and there in the preceding entries, we have mentioned the frequent apparent lack of source rocks for some petroleum reservoirs. This is puzzling enough, but when the truly giant bitumen deposits are considered, particularly those of the Middle East and the Canadian oil sands, the lack of suitable source rocks becomes embarrassing to conventional theory. Such source rocks, if they exist, should harbor even more oil that the giant fields themselves, because only a small fraction of the oil in the source rocks will migrate. Those who prefer the abiogenic origin of oil consider the existence of giant oil deposits to be powerful evidence in their favor, as the following quotation from V. B. Porfir'ev demonstrates:

"The cornerstone of 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 accumulate 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." Porfir'ev believes that these facts by themselves refute the biogenic theory of oil. (R34)

X31. The carbon problem. Most of the carbon in the earth's outermost crust is to be found in the carbonate rocks---some 85% is in this form. But the hydrocarbon deposits are not negligible either, as evidenced by the giant oil fields of X30. Oil and bitumen deposits constitute part of the so-called "carbon problem", which is really a question of origin. For a fuller discussion, see ESC9-X4.

X32. The problem of oil migration. The transport of immense quantities of oil over great distances from the postulated source rocks to the reservoir rocks lacks an acceptable mechanism. E. G. Baker considers the solution to the oil migration problem to be even "more elusive" than the explanation of the origin of the oil itself. (R17) The seriousness of the problem is accentuated by the tentative manner in which J. M. Hunt approaches the subject in his article in the McGraw-Hill Encyclopedia of Science and Technology:

> "The mechanism by which the water carries the oil is uncertain. The oil cannot travel as droplets or colloidal particles because neither are capable of penetrating the fine pore openings of a clay mud. The oil probably travels in solution as hydrocarbons, which are soluble in the low-molecular-weight range, and as precursors (nonhydrocarbons), which are soluble in the high-molecular-weight range. The latter could be converted to hydrocarbons, through mild cracking reactions, after entering the reservoir rock." (R37)

Until the problem of oil migration is solved to everyone's satisfaction, the baseline or mainstream explanation of oil's origin will be in question. (WRC)

X33. The existence of abundant extraterrestrial hydrocarbons. Proponents of abiogenic oil usually take satisfaction in pointing out that many other solar system planets, some asteroids, some meteorites, and even comets apparently possess substantial inventories of carbon in one form or another. (R6, R13, R15, R16, R21, R22, R44, R48, R50) Since the earth is believed to have been created from similar solar-system stuff, the earth, too, must contain much carbon. But it is a curious fact that the primary rocks of the earth's crust (granite, basalt, etc.) are actually deficient in carbon, when compared to the solar-system-as-a-whole, where carbon is the fourth most abundant element. (R50) The implication is that deep in the earth there resides a large reservoir of carbon, some of which is carried to the surface by gases and fluids to form the carbonate rocks, the hydrocarbon deposits, the carbon in the biosphere, and atmospheric carbon dioxide.

The existence of extraterrestrial carbon does not, of course, prove the abiogenic origin of oil, but it is consistent with it. (WRC)

References

R1. "The Origin of Natural Gas and Petroleum," English Mechanic, 77:294, 1903. (X21)
R2. Powers, Sidney; "Notes on Minor Occurrences of Oil, Gas, and Bitumen with Igneous and Metamorphic Rocks," American Association of Petroleum Geologists, Bulletin, 16:837, 1932. (X16)
R3. Berl, E.; "The Origin of Natural Oil," Science, 81:18, 1935. (X11, X24)
R4. Brooks, Benjamin T.; "Origin of Petroleum," Science, 81:176, 1935. (X0)
R5. Henderson, Junius; "Are Fishes the Principal Source of Petroleum," Science, 81:176, 1935. (X0)
R6. Van Tuyl, F.M., and Parker, Ben H.; "Extraterrestrial Hydrocarbons and Petroleum Genesis," American Association of Petroleum Geologists, Bulletin, 19:900, 1935. (X33)
R7. Ball, Max W.; "Athabaska Oil Sands: Apparent Example of Local Origin of Oil," American Association of Petroleum Geologists, Bulletin, 19:153, 1935. (X29, X30)
R8. Bergmann, Werner, and Lester, David; "Coral Reefs and the Formation of Petroleum," Science, 92:452, 1940. (X0)
R9. Pan, C.H.; "Non-Marine Origin of Petroleum in North Shensi, and the Cretaceous of Szechuan, China," American Association of Petroleum Geologists, Bulletin, 25:2058, 1941. (X13)
R10. Smith, Paul V., Jr.; "Preliminary Note on Origin of Petroleum," American Association of Petroleum Geologists, Bulletin, 36:411, 1952. (X19, X20)
R11. Smith, Paul V., Jr.; "The Occurrence of Hydrocarbons in Recent Sediments from the Gulf of Mexico," Science, 116:437, 1952. (X19, X20)
R12. Smith, Paul V., Jr.; "Studies on Origin of Petroleum: Occurrence of Hydrocarbons in Recent Sediments," American Association of Petroleum Geologists, Bulletin, 38:377, 1954. (X19, X20)
R13. Pratt, Wallace E.; "Oil According to Hoyle," American Association of Petroleum Geologists, Bulletin, 40:177, 1956. (X33)
R14. Stevens, Nelson P., et al; "Hydrocarbons in Sediments of Gulf of Mexico," American Association of Petroleum Geologists, Bulletin, 40:975, 1956. (X20)
R15. Link, Theo. A.; "Whence Came the Hydrocarbons?" American Association of Petroleum Geologists, Bulletin, 41:1387, 1957. (X33)
R16. Pratt, Wallace E.; "Whence Came the Hydrocarbons," American Association of Petroleum Geologists, Bulletin, 41:2584, 1957. (X31, X33)
R17. Baker, E.G.; "Origin and Migration of Oil," Science, 129:871, 1959. (X32)
R18. Landes, Kenneth K., et al; "Petroleum Resources in Basement Rocks," American Association of Petroleum Geologists, Bulletin, 44:1682, 1960. (X18)
R19. Went, F.W.; "Organic Matter in the Atmosphere, and Its Possible Relation to Petroleum Formation," National Academy of Sciences, Proceedings, 46:212, 1960.
R20. "Oil from the Forest Haze," New Scientist, 7:514, 1960.
R21. Wilson, A.T.; "Origin of Petroleum and the Composition of the Lunar Maria," Nature, 196:11, 1962. (X33)
R22. "Lifeless Origins for Oil Become More Plausible," New Scientist, 18:475, 1963. (X33)
R23. Robinson, Robert; "Duplex Origin of Petroleum," Nature, 199:113, 1963. (X2)
R24. Sylvester-Bradley, P.; "The Origin of Oil---and Life," Discovery, 25:37, May 1964. (X2, X3, X5, X6, X10, X16, X18)
R25. Robinson, Robert; "The Origin of Oil," New Scientist, 27:624, 1965. (X1-X4, X31)
R26. Murray, Grover E.; "Indigenous Pre-

cambrian Petroleum," American Association of Petroleum Geologists, Bulletin, 49:3, 1965. (X17)
R27. Robinson, Robert; "The Origins of Petroleum," Nature, 212:1291, 1966. (X14)
R28. "Abyssal Oil?" Scientific American, 221:54, July 1969. (X28)
R29. McIver, Richard D.; "Evidence of Migrating Liquid Hydrocarbons in Deep Sea Drilling Project Cores," American Association of Petroleum Geologists, Bulletin, 58:1263, 1974. (X28)
R30. Rudakov, George; "Transformation of Subsurface Petroleum," Nature, 225:370, 1970. (X28)
R31. Lasaga, Antonio C., et al; "Primordial Oil Slick," Science, 174:53, 1971. (X15)
R32. Didyk, Boris M., and McCarthy, Eugene D.; "Non-Marine Character of a Chilean Petroleum," Nature (Physical Science), 232:103, 1971. (X13)
R33. Gaucher, Leon P.; "The Rain Came and It Was Oil," Intellectual Digest, 3:36, March 1973. (X15)
R34. Porfir'ev, V. B.; "Inorganic Origin of Petroleum," American Association of Petroleum Geologists, Bulletin, 58:3, 1974. (X17, X22, X30)
R35. Biederman, Edwin W., Jr.; "Inorganic Origin of Petroleum: Discussion," American Association of Petroleum Geologists, Bulletin, 59:880, 1975. (X2-X4, X9, X22, X29, X30)
R36. Wilson, H. H.; "Time of Hydrocarbon Expulsion, Paradox for Geologists and Geochemists," American Association of Petroleum Geologists, Bulletin, 59:69, 1975. (X32)
R37. Hunt, John M.; "Origin of Petroleum," McGraw-Hill Encyclopedia of Science and Technology, 10:67, 1977. (X0, X32)
R38. Mossop, Grant D.; "Geology of the Athabasca Oil Sands," Science, 207:145, 1980. (X29, X30)
R39. Murray, Grover E., et al; "Indigenous Precambrian Petroleum Revisited," American Association of Petroleum Geologists, Bulletin, 64:1681, 1980. (X17)
R40. Mackenzie, Andrew S.; "A Hydrothermal Plume Remobilizes Sedimentary Organic Matter," Nature, 295:187, 1982. (X20)
R41. Snelling, A.; "The Recent Origin of Bass Strait Oil and Gas," Ex Nihilo, 1:43, October 1982. (X20)
R42. Pemberton, S. George; "Trace Fossils from the Athabasca Oil Sands, Alberta, Canada," Science, 217:825, 1982. (X29, X30)
R43. Simoneit, Bernd R. T., and Lonsdale, Peter F.; "Hydrothermal Petroleum in Mineralized Mounds at the Seabed of Guaymas Basin," Nature, 295:198, 1982. (X20)
R44. Hayatsu, Ryolchi, et al; "Comparative Structural Study of Meteoritic Polymer with Terrestrial Geopolymers Coal and Kerogen," Meteoritics, 18:310, 1983. (X33)
R45. Raloff, J.; "Viewing Fossil Fuels' Bacterial Sources," Science News, 126:372, 1984. (X10)
R46. Morton, Glenn R.; "The Carbon Problem," Creation Research Society Quarterly, 20: 212, 1984. (X31)
R47. Melton, Charles E.; "The Origin and Location of Petroleum Deposits," Ancient Diamond Time Capsules, Hull, 1985, p. 81. (X0, X3, X4, X6)
R48. Gold, Tom; "Oil from the Centre of the Earth," New Scientist, p. 42, June 26, 1986. (X7, X23, X25, X26, X30, X33)
R49. Osborne, David; "The Origin of Petroleum," Atlantic Monthly, 257:39, February, 1986. Cr. C.H. Stiles. (X8, X10, X22, X23, X25, X30)
R50. Gold, Thomas; Power from the Earth, London, 1987. (X2-X4, X8, X10-X12, X18, X21, X23-X27, X29-X33)
R51. Strahler, Arthur N.; "Petroleum and Ore Deposits of the Flood," Science and Earth History, Buffalo, 1987, p. 235. (X0)
R52. Powers, Sidney, and Clapp, Frederick G.; "Nature and Origin of Occurrences of Oil, Gas, and Bitumen in Igneous and Metamorphic Rocks," American Association of Petroleum Geologists, Bulletin, 16:719, 1932. (X18)
R53. Sellaris, E.H.; "Oil Fields in Igneous Rocks in Coastal Plain of Texas," American Association of Petroleum Geologists, Bulletin, 16:741, 1932. (X18)
R54. Brown, Arthur B., and Kew, W. S. W.; "Occurrence of Oil in Metamorphic Rocks of San Gabriel Mountains, Los Angeles County, California," American Association of Petroleum Geologists, Bulletin, 16:772, 1932. (X18)
R55. Lewis, J. Whitney; "Occurrence of Oil in Igneous Rocks of Cuba," American Association of Petroleum Geologists, Bulletin, 16:809, 1932. (X18)
R56. Hedberg, Hollis D.; "Geologic Aspects of Origin of Petroleum," American Association of Petroleum Geologists, Bulletin, 48:1755, 1964. (X0)
R57. Ourisson, Guy, et al; "The Microbial Origin of Fossil Fuels," Scientific American, 251:44, August 1984. (X0)
R58. Gold, Thomas, and Soter, Steven; "Biogenic and Abiogenic Petroleum," Chemical & Engineering News, 64:2, April 21, 1988. (X23, X25)
R59. Jacobson, Stephen R., et al; "Middle

Ordovician Organic Matter Assemblages and Their Effect on Ordovician-Derived Oils," American Association of Petroleum Geologists, Bulletin, 72:1090, 1988. (X10)

ESC14 Anomalies Associated with the Origin of Coal

Description. Phenomena of the chemistry and geological occurrence of coal deposits that do not support the accepted peat-bog/coastal-marsh theory

X1. Frequent absence of plant fossils and vegetable "structure"
X2. Presence of fusain or "mother-of-coal"
X3. Anomalous trace elements
X4. Excess methane in the coal measures
X5. Geographical correlations of coal and oil
X6. Coal deposits and "fire clays"
X7. Marine fossils associated with coal seams
X8. Anomalous nature of coal fossils
X9. Anomalous species of plant fossils in coal
X10. Present horizontal position of some coal seams
X11. Anomalous thickness of some coal seams
X12. Great areal extent of some coal measures
X13. Cyclothems and cyclic nature of coal formation
X14. Lack of compressing overburden for coal seams
X15. Intrusive or vein-like coal deposits
X16. Low mineral content of most coals
X17. Coal inclusions that bear on its origin
X18. Piercement or polystrate structures in coal beds
X19. Lack of coal formation in today's peat bogs
X20. Observations of rapid coalification
X21. The existence of extraterrestrial coal-like substances

Data Evaluation. Humans have been mining coal for many centuries. During this time, miners have accumulated much practical lore about coal seams, their disposition and contents. This knowledge has been supplemented by chemical and microscopic analysis in the laboratory. In short, science knows a lot about coal. Rating: 1.

Anomaly Evaluation. Taken together, the anomalies detailed below cast much doubt upon the presently accepted theory of coal's origin. The chemical constitution of coal, its geological associations with oil and gas, its fossil contents, its stratigraphy, its inclusions, and its occurrence in nonsedimentary situations suggest strongly that processes other than simple deposition, compaction, and heating of vegetable matter have contributed---perhaps heavily ---to the genesis of the coal measures. Since the peat-bog/coastal-marsh theory is dogmatically presented by science, the anomalies presented below must be considered very significant. Rating: 1.

Possible Explanations. Coal-seam formation may involve the chemical alteration of accumulated plant material by circulating fluids and gases containing abiogenic carbon. Coal would thus be of duplex origin (biogenic and abiogenic). Coal seams and other carbonaceous deposits, such as graphite, might be intrusive in origin; that is, the consequence of the injection of carbonaceous fluids and gases. Such deposits could be wholly abiogenic.

Similar and Related Phenomena. The origin of oil (ESC13); the origin of graphite (ESC9-X1); the origin of methane (ESC16); cyclothems and cyclic bedding (ESR5); anthraxolite (Precambrian coal) (ESX4); fusain (ESC8); coal balls (ESA2); oil in coal (ESX4, ESG9). See the Index under Coal.

Examples

X0. The accepted theory of coal's origin. As in the case of the origin of petroleum (ESC13), the genesis of coal is explained with great assurance in all the text books and general reference books. For a baseline against which to evaluate anomalies, we quote two paragraphs from the McGraw-Hill Encyclopedia of Science and Technology:

"Coal may originate from isolated fragments of vegetation, but most coal represents the carbonification of woody plants accumulated in peat beds. These are mainly of two kinds: autochthonous deposits representing accumulations at the place of plant growth, such as those found in the Great Dismal Swamp of Virginia, and allochthonous deposits accumulated elsewhere than at the place of growth by the drifting action of stream, lake, or sea currents, such as the Red River 'rafts.' Generally autochthonous coal deposits overlie seat rock, or underclay containing traces of plant roots called Stigmaria in the case of coals of Paleozoic age.

"Biochemical activity modifies the character of the unsubmerged, lightly submerged, or lightly buried peat. The process consists in part of general oxidation, but mainly of attack by aerobic bacteria and fungi that can live only where oxygen is available where water or thin sediments cover the peat. Fires set by lightning or other causes may consume part of the peat from time to time, leaving in places a residue of charcoal which may eventually be incorporated into the coal bed in the form of fusain, known to miners as mineral charcoal, mother-of-coal, and mother coal." (R14)

Entire books have been written about coal and its formation, but the above two paragraphs summarize prevailing opinion well: coal is altered, accumulated vegetable matter. As we introduce various anomalies that contradict this general picture, we will also mention how the accepted theory may be modified to explain some of the anomalies.

X1. Frequent absence of plant fossils and vegetable "structure". By "structure', we refer here to any aspects of coal's physical make-up that indicate its presumed vegetable origin rather than to "cleat" and larger-scale jointing, which are covered in ESP10. The following quotation will demonstrate that, even a century ago, the textbook writers were slanting their discussions of coal's origin a bit.

"I must here warn the reader against a fallacy usually implied, though not definitely expressed in our geological textbooks. Pictures are there shown of the calamites, the sigilaria and stigmaria, the lepidodendrons, tree ferns, &c., of the coal measures, and the reader who only learns from books, without actual field-work, concludes when Lyell tells him that 'no less than 250 ferns have already been obtained from the coal strata', that coal itself has been proved to be made of these, that ordinary coal is visibly composed of such fossil vegetation, and that the pictures represent fossil specimens found in the coal itself.

"This is not the case; ordinary coal displays little or no definite vegetable structure. It is true that Professor Goeppert found in certain samples of German coal indications of structure corresponding to the fossil plants known as those of the coal measures, but the fossils which are pictured in the books are those found in the rocks above and below the actual coal seams, not in the coal itself. Thousands of years may have elapsed, must have elapsed in some cases (such as the celebrated fossil tree in Cragleight quarry), between the deposition of the coal itself and that of the fossil plants in the other rocks. Great geological changes must have occurred in order that pure vegetable matter, deposited where it grew, should be succeeded in the same place by a subaqueous deposit of sandstone, fifty or sixty or more yards in thickness. All this sandstone was certainly formed under water, and that water must have been deeper than its own thickness. If the coal was formed on the land, it must have been submerged either by a great convulsion or a series of ordinary changes extending over a vast duration of time, before the great sandstone or shale deposit could be formed over it.

"The same reasoning applies conversely to the fossils found in rocks below the coal seams. Many of the coal-fossil specimens in our museums have come from rocks that are as much as 100 ft. above or below any workable coal seam. I once collected a cartload of fine specimens from the materials of a sinking in Flintshire which failed to reach coal.

"I do not, however, assert that vegetation corresponding to these fossils found in the rocks have not contributed to the formation of the coal itself, but that the conditions of their deposition were quite different from that of the coal seams, and that they represent only those particular species of plants that are capable of retaining their structure under the circumstances of deposition. In the rocks where these fossils occur there are ten thousand or more parts of mineral matter to one of vegetable matter. In the coal there are forty or fifty of vegetable matter to one of mineral---less mineral matter than is found, on the average, in living plants." (R2)

Of course, the lack of obvious plant material in the coal matrix itself does not mean that the coal was not created from plant-based matter. It means only that some process may have obliterated most signs of plant structure. However, this general lack of vegetable structure also frees us to imagine that considerable non-vegetable carbonaceous material could have been added to the coal matrix from an abiogenic source. (WRC)

X2. Presence of fusain or "mother-of-coal". Many coals display substantial bits and even sheets of a charcoal-like substance called fusain. Woody structure is seen in fusain, but the basic substance has been drastically altered by some undetermined agency. Some claim that widespread forest fires created fusain, but the subject is still being debated, especially because fusain still contains combustible components. See ESC8 for a fuller treatment of fusain. (R6, R14, R26)

Fusain is reintroduced here to emphasize the possibility that the formation of coal many have involved physical and chemical processes that are not part of the standard explanation of coal. (WRC)

X3. Anomalous trace elements. Germanium, mercury, uranium, gallium, and other trace elements are concentrated in coal far beyond the levels found in other sedimentary rocks. Germanium, in particular, is unusually concentrated, with levels reaching 10,000 times those found in other sediments.

How could such concentrations occur in the peat-bog scenario? Where did the germanium and other elements come from? Ground water might have helped carry these trace elements into the coal, but the chemistry involved and the high concentration factors do not favor this explanation. (R20)

X4. Excess methane in the coal measures. "It has often been noted that some coal fields contain and produce more methane than could possibly be produced by the existing coal. It is true of course that coal could give off methane, but one could not expact that more than a small fraction of the hydrogen content of the coal could ever be assembled into methane molecules, and this places a severe limitation on the maximum total methane production that is possible."

T. Gold, author of the foregoing paragraph, calculates that the indigenous methane in a 6-foot-thick coal seam, 50 million years old, would by now have lost through diffusion all but 1/5000 of its coal-generated inventory of methane. These calculations notwithstanding, some modern mines, even with considerable ventilation cannot avoid high concentrations of methane and occasional explosions. (R50)

At least three implications are possible here: (1) Methane from other sources has permeated the coal measures in the past and still remains in high concentrations; (2) Methane is seeping into coal mines at the present time from external sources; and (3) The process that created the coal was different from that now promulgated. These three implications are not necessarily mutually exclusive, because methane from external sources (viz., the earth's interior) may have been instrumental in the creation of the coal measures millions of years ago. (WRC)

X5. Geographical correlation of coal and oil. In ESC13-X24, it was noted that coal and oil occur frequently in the same localities. (R50) We will not repeat this discussion here. It is pertinent perhaps that the famous vein-like, intrusive, Albertite coal, found in New Brunswick, Canada, is adjacent to an oil-rich shale. This shale can, in fact, sustain combustion. The Albertite "coal" (see X15) is disposed in the rocks in such a way that it seems to have been in a liquid state at one time. (R1)

X6. Coal deposits and "fire clays". Fire clays are refractory clays that often underly coal seams: "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 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."

.....

"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?" (R3)

The first three phenomena are difficult-to-account-for if we insist that their refractory character is to be accounted for only as the consequence of the reducing and leaching action provided by the overlying coal bed. But it is the fourth phenomenon that is worth elaboration upon:

"(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." The author of this paragraph, T. C. Hopkins, suggests that many of the fire clays were formed elsewhere and then transported to their present location. (R3)

The possibility is open, then, that neither the fire clays nor the coal seams were formed in situ, but may have been transported from some distances. In other words, the carbonaceous material constituting the coal seams may have been in liquid or slurry form---already coal-like instead of vegetable-like---before transportation to the coal measures! (WRC)

X7. Marine fossils associated with coal seams. Coal seams are commonly topped with a layer of fossils of marine creatures. The accepted theory of coal formation seems to accomodate these fossils, as now described by J. Weir:

"During the last twenty years much of the work that has been done on the stratigraphy of the British Coal Measures and on their structure and environments of deposition has been profoundly influenced by researches on certain fossil bivalve shells that occur in these rocks ---commonly in the roofs of the coal seams, but also at other horizons in the thickness of sandstones and shales (with occasional fire-clays and coal seams) that make up the rock succession of the Coal Measures. These molluscs lived in waters adjacent to the swampy coastal forests, which were later transformed into coal seams by the compaction and carbonisation of their vegetation. The first stage in this process was flooding by the waters, doubtless not fully marine, in which the bivalves lived. Hence the frequent occurrence of these fossils in the roofs of coal seams. The fossil shells are well known to miners, who call them 'mussels,' an accurate term conveniently used by all Coal Measures geologists.

"Sometimes mussels occur in enormous numbers, tightly packed together in shell beds that may be three or four feet thick and extend underground for miles. Such shell beds ('musselbands' is the technical name) are important stratigraphical units and in certain British coalfields have long been used as marker bands in mining operations.

"Mussels do not always occur in musselbands, however. In all coalfields they may occur in mudstone or shale as more or less isolated individuals, and particularly is this true of the South Wales Coalfield." (R8)

Two aspects of these marine strata are bothersome: (1) The incredible quantity of shells in some coal measures. Where did they all come from? Are offshore mudbanks this rich in mussels? (2) The areal extent of some coal seams, which in North America may extend for hundreds of miles, with little change in character and dimensions. Is such widespread, uniform marine flooding reasonable geologically speaking? Possibly, but certainly we see no peat bogs or coastal swamps forming today where marine flooding could deposit mile after mile of thick musselbands! (WRC)

While the prevailing theory of coal formation can provide a coal seam's top dressing of marine fossils by postulating an episode of marine flooding as the final phase of formation, this same theory cannot deal as well with those marine fossils that appear throughout the coal seam. American scientific creationists have pointed out one coal fossil, Spirorbis, a small tubeworm, that is present in coal seams from top to bottom. H. G. Coffin, a creationist, supplies the following facts and draws conclusions from them:

"Spirorbis is abundant in the fossil record, being found in all periods from the Ordovician to the Recent. The white calcareous tubes are so similar to those now living in the oceans that there is no hestitancy about placing them in the same genus. Attempts to designate species among fossil specimens have not been very successful. Marine fossils often carry attached Spirorbis tubes. Their arrangement on some pelecypods suggests a commensalism whereby the worm benefited from the water currents caused by the feeding of the clam.

"If coal deposits are not allochthonous (transported), but have originated from swamps and marshes where plant materials have accumulated to considerable depth over much time----the present popular view---then the discovery of marine organisms within the coal would not be expected. Usually coal is quite devoid of animal fossils, although there are numerous exceptions. However, Spirorbis is a frequent constituent of Carboniferous coal-measures. They are found attached to plant debris and mixed into coal seams. They also may be cemented to any marine organisms that are present. This has been known from the time when coal and associated strata were beginning to receive detailed attention over 100 years ago.

"The swing in the early nineteenth century by geologists to concepts of uniformity and geological ages influenced the paleoecological interpretation of Spirorbis. Obviously the 'bog theory' of coal formation cannot accommodate the abundant presence of a marine organism. Through the years this small annelid has been declared a salt-water worm throughout the geologic column except in the coal measures, where the supposed evidences for the in situ origin of coal made difficult the interpretation of Spirorbis at its face value.

"Consequently, seemingly without much question on the part of geologists and paleontologists through the decades, this worm when found in coal and coal-bearing rocks has been designated a fresh-water dweller. This position has been taken despite the facts:

(a) that Spirorbis today is completely limited to the marine environment,

(b) that it reproduces by means of a trochophore larva, which, though characteristic of several marine phyla, is unknown for any fresh water invertebrates, and

(c) that is it associated with obviously marine organisms throughout the geologic column, including the Carboniferous period." (R10)

If the Spirorbis fossils found in coal beds are truly the remains of marine creatures, the challenge to the peat-bog/swamp hypothesis is obvious. (WRC)

X8. Anomalous nature of coal fossils. In the foregoing entries, the tendency of coal fossils to be concentrated at the tops of the coal seams (or even farther above) has been noted. The body of the coal seams may, as in some Alaskan coals, be essentially devoid of fossils, but taking all coals collectively some fossils do turn up in the main bodies of the coal beds. It is the nature of these coal fossils that severely tries the reigning peat-bog/swamp theory of coal genesis.

Most coal fossils are "replacement" fossils; that is, the plants often so beautifully preserved are not coalified but rather outlines of plant structure formed from pyrite (fool's gold) or some other replacement mineral. This aspect of coal fossils instills doubt (to some at least) that chemically processed vegetable matter is really the basic stuff of coal.

A more disturbing sort of coal fossil comprises those plant fossils, also showing great structural detail, that are filled with coal. In other words, plants which were originally just a few percent carbon are now 90% carbon. If plant material forms the basic matrix of coal seams, why do some plants survive in exquisite perfection while all those around have been reduced to carbon soup? (R50)

T. Gold has pointed out still another problem: "Secondly there is the other dilemma: how did the coaly material enter the structure of the fossil without destroying it? As solid coal? It certainly could not do that. Like the pyrite fossil, the coal fossil is an infusion product, and the coaly material must have been at some stage in the form of a sufficiently thin liquid so that it could penetrate into the structure of the plant debris. Just as we recognize petrified wood as having been petrified by an infusion process, so coalified wood has similarly been infused.

"But if the substance now found inside the structure of the fossil is the same as the homogeneous coal exterior to it, then we can readily suppose that all that homogeneous coal was also at one time in the form of a fluid---liquid or gas---before it laid down the seam. Is that indeed a possibility? Is it possible that the coal seam, like the coal fossil within it, is the product of a deposition from a fluid flow?" (R20) Obviously, Gold believes the answer is probably "yes".

X9. Anomalous species of plant fossils in coal. I. Velikovsky, in his book Earth in Upheaval, writes that many of the plants fossilized in coal do not regularly grow in marshes. Therefore, they must have been rafted in---cataclysmically, according to Velikovsky. If coal is not formed mainly from marsh-loving plants, the peat-bog/swamp theory is in trouble! (R9) Velikovsky (uncharacteristically) gave no reference for the above assertion.

X10. Present horizontal position of some coal seams. "The widespread horizontality of the Coal Measures deposits, coarse and fine alike, recalls conditions observed on the Siberian Steppe and other river regions. The folding of the beds (in North America) proceeded from a common cause, lateral pressure applied at the east. The violence of plication decreases with notable regularity toward the west, until in western Pennsylvania and in Ohio, along a line of more than 100 miles, the folds become so gentle that they can be traced only by close study. Dips of more than one degree are unusual, while at times and for considerable distances the dip is barely one half of a degree. The same condition exists in a great part of West Virginia. The regular decrease in steepness of the folds leads to the belief that originally the beds were, to all intents, horizontal throughout the basin, the condition being that observed on the great river plains of comparable extent." (R4)

Ordinarily, the horizontality of coal beds would hardly be considered anomalous. Peat bogs and marshes are certainly flat naturally. What is remarkable, however, is that near-horizontality has been retained over immense areas, during millions of years, while: (1) thick layers of vegetation were being compressed by perhaps thousands of feet of accumulated strata; (2) overburden was being removed by erosion after coal compression; (3) new coal beds were formed and compressed in like manner; and (4) and so on through as many cycles as there are coal beds stacked one over the other. The singular nature of the whole cyclic process is further underscored in X11, X12, X13, and X14.

X11. Anomalous thickness of some coal seams. Given that coal seams may be 50 feet and more thick, cover thousands of square miles, all the while maintaining considerable uniformity in thickness and character; two questions arise: (1) Where could all of this postulated vegetable matter have come from? and (2) How can successive peat bogs grow on top of one another, without soil to sustain them, in sufficient quantity to make 50 feet of coal?

An appreciation of these problems appears in F. Hitching's book The Neck of the Giraffe:

"Also, there is a problem in explaining the vast quantities of vegetation required to produce the huge coal deposits. As Dr. Heribert Nilsson, Professor Emeritus of Botany of Lund University in Sweden, wrote:

> 'From the point of view of the amount of material available, the results must be considered highly improbable. A forest of full-grown beeches gives material only for a seam of 2 cm. It is not unusual that they are 10 metres thick, and such a seam would require 500 full-grown beech forests. Whence this immense material? How was it all deposited at once? Why did these masses of organic material escape decay, why was it not completely decomposed?' (R15)

Example of an impressively thick coal bed. Morwell, Victoria, Australia. "These deposits are in places nearly eight hundred feet thick and in the open workings which are at present being operated are of a depth of nearly two hundred feet. In one of these are prodigious quantities of generally admirably preserved tree trunks, which in many instances have not undergone even the slightest compression. A microscopic examination of a number of these has shown that they are either Araucarian Conifers, or Proteaceae. The Araucarians are certainly not bog plants and the only reasonable explanation of their presence in coal deposits is their having been water-borne from some more or less distant site." (R25)

One way to circumvent the problem of growing dozens of successive forests on top of one another---without soil, for coal beds are almost devoid of soil---is to assume that floods rafted vegetable debris in from elsewhere. But such flooding would hardly create uniformly thick, almost fossil-less beds, hundreds of miles in lateral extent. With these problems, one can understand why some scientists propose a primarily abiogenic, carbonaceous soup. (WRC)

X12. Great areal extents of some coal measures. D. Ager has written about the "remarkable persistence" of some facies. One of these facies is coal, more specifically, the Pennsylvanian coal measures. Ager takes the global view: "Whatever the vertical and lateral changes in the Coal Measures, we still have to account for a general facies development in late Carboniferous times that extends in essentially the same form all the way from Texas to the Donetz coal basin, north of the Caspian Sea in the U. S. S. R. This amounts to some 170° of longitude, and closing up the Atlantic by a mere 40° does not really help all that much in explaining this remarkable phenomenon." (R22) Ager's remark about closing the Atlantic refers to the attempt to explain the similarity of European and North American Pennsylvanian coal measures in terms of a common depositional environment existing before continental drift.

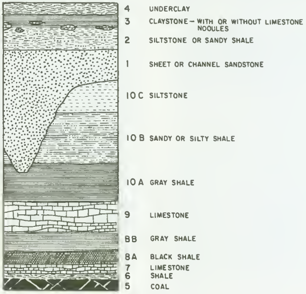
"Persistence" in Ager's book does not necessarily imply physical continuity of coal beds. Nevertheless, it is easy to find statistics demonstrating phenomenal areal continuity. For example, the Pennsylvanian coal-bearing cyclothems of eastern North America extend unbroken for at least 55,000 square miles and probably much more. (R23) The extraordinary persistence of these coal measures and their attendant slate binders was remarked upon almost a century ago by W. S. Gresley in his description of the Pittsburg coal bed:

"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 or 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 on 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-plus 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 Pittsburgh 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." (R24)

X13. Cyclothems and cyclic nature of coal formations. One of the more fascinating phenomena in geology, already alluded to above, is the appearance of cyclothems in the stratigraphic record. Cyclothems are groups of strata that repeat many times over. For example, a typical cyclothem containing a coal seam may consist of shale, limestone, coal, fire clay, shale, and sandstone. This grouping of strata repeats, one cyclothem above the other, with occasional variations. In Ohio, more than forty such cycles can be found in the coal measures. Welsh coal measures boast more than one hundred coal seams stacked one above the other in their cyclothems. Such cyclicity is not restricted to the coal measures; in this Catalog, it receives a fuller treatment in ESR5.

Cyclothems are generally thought to represent manifestations of either cyclic marine transgressions and regressions or cyclic climatic changes. In the case of the coal measures, periodic marine incursions over peat bogs, marshes, and delta regions are believed to cause the cyclic sedimentation. The incursions could, in principle, be due either to repeated uplifting and subsidence of the coal-forming region or sea-level changes or a combination of both. Such geological changes are not in themselves anomalous, especially where only a few cycles occur. In eastern North America, though, the coal-bearing cyclothems persist over tens of thousands of square miles, with great uniformity, as already noted in X12. Besides being impressed by the scale and uniformity of the phenomenon, one is at a loss in attempting to conceive of a force that can create such a widespread phenomenon in a periodic manner. One would expect to find some other records, from elsewhere in the world, of this strong cyclic signal. (WRC)

X14. Lack of compressing overburden for coal seams. If peat and other vegetable debris are the basic materials of the coal beds, great compressive forces must have been applied to compact each 30 meters of peat into each meter of coal. (The 30:1 ratio is frequently used in the textbooks. R21) Heating due to deep burial is also thought to be required in the making of coal. One estimate requires at least 7500 feet of overburden to generate the necessary pressure for compaction. (R13) Yet, much of America's coal is very near the surface and can be strip-mined. Many mines worldwide are quite shallow. An obvious question is: Where did the 7500 feet of overburden go? Considering the immense areal extent of



An idealized Illinois cyclothem. All ten members are never present in one place. The most common Illinois cyclothem consists of 1, and/or 2, 4, 5, 8, 9, and 10.

the eastern North American coal fields, there is a colossal amount of overburden to account for! Further, where is the evidence of the river systems responsible for this denudation? In view of the scale of denudation required, alternative schemes of coal formation which do not require deep burial should be examined. (WRC)

X15. Intrusive or vein-like coal deposits. Thus far, our discussion of coal anomalies has centered on coal seams that "appear" to be sedimentary, or at least mainly so. Indeed, most commercially mined coal comes from layers of coal which few hesitate to attribute to sedimentation---but appearances might be deceiving, for we know that magmatic intrusions often take the form of large sheets sandwiched between true sedimentary strata.

Coal, for example, is to be found interbedded with lava in several volcanic areas, notably Greenland, near mud volcanos that belch methane. (R20)

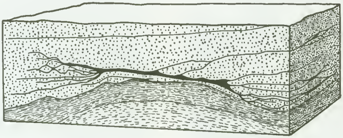
Another curious occurrence is found at Sommerset, Ohio, where coal caps a series of shale crests, both being overlain by sandstone. "But the coal is not truncated by the sandstone as it descends on either side of the crest. The coal seam splits and disappears on either side by interfingering with those 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." (R5) The words "vegetable mud" conjure up a vision of coal---at least some of it---being in liquid form at some stage. (WRC)

The most famous vein-like coal is New Brunswick's Albertite, in Canada. The conclusions of C.H. Hitchcock reveal the peculiar character of this coal, assuming that it really is coal:

"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. This liquid may have been derived from vegetable accumulations, or possibly in part from the abundant ichthic 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



Vein-like coal. (X15)

veins and fissures in the limestones, shales, and 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." (R1)

The examples of coal and carbonaceous materials possessing intrusive properties does not end here. For additional examples, refer to anthraxolite (ESX4), graphite (ESC9), and coal styolites (ESX4).

None of these exotic carbonaceous deposits prove that the great coal measures were in fact once in fluid or vegetable-mud forms. Rather, they emphasize that we should keep our minds open regarding coal formation and not dismiss out-of-hand the possible contributions of carbonaceous liquids and gases. (WRC)

X16. Low mineral content of most coals. W. M. Williams, over a century ago, pointed out that true coal leaves only 0.5-3% ash after complete combustion. He goes on to state:

"I state these figures because they have an important bearing on the interesting question of the origin or formation of coal. They demolish at once the prevailing theory that a coal seam is simply an ancient forest or a woodland marsh that has been submerged and buried where it stood.

"No such forest, no such marshy woodland as we see so prettily displayed in the fancy pictures of the vegetation of the coal period could be formed without soil for the roots of the calamites, the sigilariae, the lepidodendra, the stigmariae, the ferns, &c., to grow in. A single generation of such reeds and trees, if thus buried in situ, would form but a few inches of coal; to produce a seam, many generations piled one above another are required, and each demands a soil. Conifera, such as described, cannot grow on the top of another, nor in the purely vegetable soil formed by the decay of their ancestors.

"The quantity of ash contained in our most abundant coals leaves absolutely nothing to represent the soil. The average amount of incombustible ash contained in the roots, stems, and leaves of forest trees, shrubs, and herbaceous plants is actually in excess of that found in ordinary coal." (R2)

The above facts were not lost on T. Gold, who recently provided similar figures for the mineral content of the great coal measures: "Some coal seams are as much as 100 feet thick, and the mineral content may be as low as 4%. The bulk of the material is just carbon, with a little hydrogen, oxygen and sulphur mixed in various compounds. For a swamp to produce such a seam, it would need to have grown to a depth of 1000 feet, with a mineral content in that volume of less than 1 percent. No such swamps are recognized, and it seems unlikely that they could ever be created or that plants would grow in such circumstances." (R20) Gold, as obvious from ESC13, champions an abiogenic origin for oil and, as implied above, a role for abiogenic carbonaceous material in the creation of coal.

X17. Coal inclusions that bear on its origin. During the centuries that men have hacked away at coal seams, they have found a host of anomalous inclusions. (See the Index under Coal.) Two classes of inclusions may provide hints about coal's formation: (1) concretion-like structures; and (2) boulders and rock fragments.

From the various concretion-like objects found in coal, we single out coal balls and roof balls. The former are ball-like structures containing remarkably well-preserved plant remains. Coal balls range from an inch in diameter to several feet. They are found in the body of the coal seam. (See ESA2 for more details on coal balls.) In the shales that usually cap coal seams, the roof balls are found. These spheroids contain shells and other marine fossils. In addition, roof balls are often found containing vegetable fossils in very poor condition. (R4)

The import of coal and roof balls is in the underscoring the fact of past, very active chemical environments during coal seam formation. Concretions take shape when mineral solutions and slurries are in motion in the deposits. In other words, the coal beds during formation were not simply masses of passive materials. (WRC)

....

Turning next to boulders and rock fragments ---objects obviously foreign to the coal matrix---we first quote J. J. Stevenson:

"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 was masses of several hundred pounds, such as the Ohio blocks, transported several hundreds of miles, the problem becomes serious." (R4) Refer to ESI3, in another volume, for additional information on foreign inclusions in coal.

No widely satisfactory explanation exists for exotic boulders and smaller rock fragments found in coal seams. Transport by floating trees, a simplistic notion once popular, is inadequate to account for ton-sized boulders. Ice-rafting, too, is unlikely given the warm-climate nature of the vegetation apparently associated with the formation of the coal beds. (WRC)

X18. Piercement or polystrate structures in coal beds. An intriguing class of structures in sedimentary geology comprise diapirs, fossil trees, and other objects that penetrate one or more strata while still retaining their integrities. In this Catalog, such structures are collected under ESX. However, in the context of coal's origin, we cannot avoid mentioning the famous polystrate trees found in many coal measures.

One facet of the polystrate tree phenomenon is stated well by D. Ager:

"In the late Carboniferous Coal Measures of Lancashire, a fossil tree has been found, 38 feet high and still standing in its living position. Sedimentation must therefore have been fast enough to bury the tree and solidify before the tree had time to rot." (R22) Catastrophists and scientific creationists always make much of these indications of very rapid deposition. In today's geology, however, occasional rapid deposition is no longer forbidden. Still, it is puzzling how such polystrate trees have survived the rigors of peat formation, marine incursion, compaction, and coalification.

More disturbing is a polystrate tree described by T. Gold:

"Some of the fossils in the coal similarly give indications that temperature was not responsible for the coalification process. It is not uncommon to find lumps of carbonate rock within a coal seam and, on breaking them open, to find fossils containing wood, not black but light in colour, and showing no signs of a coalification process. Similarly, it is reported that in the coal of the Donetz Basin of the Ukraine there are some fossilized tree trunks that span through a coal seam from the carbonate rock above to that below, and those fossils are coalified where they are within the coal seam, but are not coalified where they are in the carbonate. In all these cases the temperature that the fossils suffered must have been the same as that of the coal. Heating a wood fossil in just the same manner as the local coal did not turn it into coal. A circumstance other than heat must be responsible, and it must be a process which can be prevented by another type of rock. The dissociation of fluid hydrocarbons might be such a process." (R20)

Also pertinent is an observation reported by J. J. Stevenson concerning an excavation near Wigan, in England: "The excavation is about 25 feet deep and in a light gray, silty clay very like that at St. Helens and Dukenfield, where the earlier discoveries were made, and the deposit is between two coal beds. In a distance of 50 yards, he found 30 upright trees and some prostrate stems of Sigillaria. They were 2 to 3 feet in diameter, 2 to 12 feet high and filled with silty clay, the bark having been converted into brilliant coal, on fourth of an inch thick. Many Calamites were seen among the trees, 4 to 5 feet high, one to 5 inches in diameter, with a thin coaly crust and filled with the silty clay. Each type occurred in all parts of the deposit from top of the lower seam to bottom of the upper." (R4) Apparently coalification also proceeds outside of coal seams proper.

X19. Lack of coal formation in today's peat bogs. Another fact advanced by catastrophists and creationists is the absence in modern peat bogs of signs of coalification. (R11, R12) Given that modern peat bogs are found primarily in northern climes and at the surface, we obviously have neither the high temperatures nor the high pressures demanded by the mainstream theory of coal formation.

It seems, however, that some peat bogs do produce something close to coal without heat, pressure, and long periods of time, in spite of the widely circulated contrary statement above.

On Beauchene Island, in the Falklands, a remarkable peat bed, some 11-13 meters deep, is obviously lignitic at its base. When this bottom layer of peat is exposed to the air, it turns black and rock-like, even breaking with a conchoidal fracture. Surprisingly---in view of the dominant theory of coal's origin---this lignitic material is dated at a mere 12,500 years, rather than the 1 million years typical of ordinary lignite. R. I. L. Smith and R. S. Clymo, who studied this peat formation, muse:

> "It is not known why the plant matter does not decay as rapidly as it forms. Populations of bacteria, yeasts and other fungi in the peat are high. The temperature is not so low as to restrict decay in general. At the much colder sub-Antarctic South Georgia tussac peat accumulates to several meters in depth yet decomposition of other organic matter proceeds quite rapidly. Why then does peat accumulate on Beauchene Island at all? And why is the rate of input so high at the same time as the decay rate is low?" (R18)

The only answer the authors have is that, "An unusual combination of biological, physical and chemical circumstances may be the cause."

X20. Observation of rapid coalification. That wood can be turned into coal fairly rapidly can be seen both in nature and the laboratory. F. Hitching has given us a historical account:

"During the construction of a railway bridge in Germany in 1882, reports were made on the condition of wooden piles rammed into the ground and compressed by overhead blocks. Their centres had been transformed into a black coal-like substance chemically the same as anthracite. 'From all available evidence it would appear that coal may form in a very short time, geologically speaking, if conditions are favourable,' according to the respected coal authority, E. S. Moore." (R15)

At Argonne National Laboratory, R. Winans et al have, in less than one year, turned lignin into an artificial coal indistinguishable from the real thing:

"The synthetic coal is produced by warming lignins (highly aromatic molecular components of woody tissue) at 150°C for a few months in the presence of twice as much montmorillonite clay, which seems to serve as acid-catalytic role..... The changes that were observed are similar to those that occur in natural coal production." (R19)

That synthetic coal can be created so rapidly raises the possibility that natural coal is formed by a catalytic process in which heat, pressure, and time are not as crucial as generally supposed. (R15, R16)

X21. The existence of extraterrestrial coal-like substances. Carbonaceous meteorites contain materials with coal-like chemistry. See a fuller account in ESC13-X33. (R17) The point here, as in ESC13, is that abiogenic processes can generate complex hydrocarbons. In addition, the earth was very likely born with a substantial carbon inventory.

References

R1. Hitchcock, Charles H.; "The Albert Coal, or Albertite, of New Brunswick," American Journal of Science, 2:39:267, 1865. (X5, X15)
R2. Williams, W. Mattieu; "Bituminous Shales and the Origin of Coal," Knowledge, 9:111, 1886. (X1, X16)
R3. Hopkins, T. C.; "A Short Discussion of the Origin of the Coal Measures Fire Clays," American Geologist, 28:47, 1901. (X6)
R4. Stevenson, John J.; "The Formation of Coal Beds," American Philosophical

Society, Proceedings, 50:1, 50:519, 51: 423, 53:31, 1911-1913. (X10, X17, X18)
R5. Hyde, Jesse E.; "An Occurrence of Coal Which Bears Evidence of Unusual Conditions Accompanying Its Depsoition," Journal of Geology, 20:316, 1912. (X15)
R6. Jeffrey, Edward C.; "Nature of the Substance Known as Mother of Coal and Its Relation to the Process of Coal Formation," Geological Society of America, Bulletin, 24:715, 1913. (X2)
R7. English Mechanic, 117:129, 1923. (X6)
R8. Weir, John; "Recent Studies of Shells of the Coal Measures," Science Progress, 38:445, 1950. (X7)
R9. Velikovsky, Immanuel; Earth in Upheaval, New York, 1965. (X7, X9, X11, X13)
R10. Coffin, Harold G.; "A Paleoecological Misinterpretation," in Scientific Studies Studies in Special Creation, Walter E. Lammerts, ed., Nutley, 1971, p. 165. (X7)
R11. Morris, Henry M.; "Uniformitarianism or Catastrophism," Scientific Creationism, San Diego, 1974, p. 107. (X7, X19)
R12. Daly, Reginald; Earth's Most Challenging Mysteries, Nutley, 1975. (X13, X19)
R13. Walworth, Ralph Franklin; "Gifts of the Ice Ages," Subdue the Earth, New York, 1977, p. 159. (X10, X14)
R14. Cady, Gilbert H.; "Coal," McGraw-Hill Encyclopedia of Science and Technology, 3:238, 1977. (X0, X2)
R15. Hitching, Francis; "How Rapidly Was Coal Formed?" The Neck of the Giraffe, New Haven, 1982. (X11, X18, X19, X20)
R16. "Raking Theory over the Coals," Science News, 124:93, 1983. (X20)
R17. Hayatsu, Ryolchi, et al; "Comparative Structural Study of Meteoritic Polymer with Terrestrial Geopolymers Coal and Kerogen," Meteoritics, 18:310, 1983. (X21)
R18. Smith, R.I. Lewis, and Clymo, R.S.; "An Extraordinary Peat-Forming Community on the Falkland Islands," Nature, 309:617, 1984. (X19)
R19. Larsen, John; "From Lignin to Coal in a Year," Nature, 314:316, 1985. (X20)
R20. Gold, Thomas; "The Origin of Petroleum," Power from the Earth, London, 1987, p. 153. (X3, X4, X5, X8, X15, X16, X18)
R21. Strahler, Arthur N.; "Rapid Formation of Sedimentary Rocks during the Flood," Science and Earth History---The Evolution Creation Controversy, Buffalo, 1987, p. 218. (X0)
R22. Ager, Derek V.; "The Persistence of Facies," The Nature of the Stratigraphic Record, London, 1973, p. 7. (X12, X18)
R23. Weller, J. Marvin; "Cyclothems and Larger Sedimentary Cycles of the Pennsylvanian," Journal of Geology, 66:195, 1958. (X12)
R24. Gresley, W.S.; "The 'Slate Binders' of the 'Pittsburgh' Coal-Bed," American Geologist, 14:356, 1894. (X12)
R25. Jeffrey, E.C.; "Conifers and the Coal Question," Science, 65:356, 1927. (X11)
R26. Skolnick, Herbert; "Observations on Fusain," American Association of Petroleum Geologists, Bulletin, 42:2223, 1958. (X2)

ESC15 Intermittent Outgassing of Radon-222

Description. Enhancements by a factor of two or more of the amount of radon-222 welling up through the earth that cannot be associated with recognized geophysical events, such as earthquakes.

Background. Increases in the flow of gases into and out of the outermost crust and soil are often attributable to changes in atmospheric pressure (blowing caves, weather wells, etc.) and earthquakes (radon enhancements).

Data Evaluation. Radon-222 is a radioactive gas---the only gaseous daughter of uranium-238. Its concentration and flow rate in the soil is measured by buried alpha-particle detectors in the work described in X1. The experimental procedures seem sound, but only a few measurements in a limited area have been carried out. Rating: 2.

Anomaly Evaluation. If all recognized driving forces are eliminated, we are faced with a phenomenon that seems to imply a much more extensive flow of subterranean gases (and liquids) in the soil and earth's crust than generally believed. Rating: 2.

Possible Explanations. Just as we have atmospheric "meteorology" and now recognized the existence of "storms" in the ocean deeps, so may we also have "subterranean weather" with all the vagaries associated with surface weather, but characterized by underground flows of fluids and gases.

Similar and Related Phenomena. Crevicular structure (ETS); blowing caves and weather wells (GHG); earthquake lights, some of which may involve gas releases (GLD8);the origins of oil (ESC13), coal (ESC14) and methane (ESC16).

Examples

X1. New Mexico outgassing measurements. Abstract. "222Rn measurements at 60 cm in the earth show background patterns that can be remarkably reproducible over time. At a site in New Mexico the readings taken at monthly intervals over a 13-month period for a set of 55 positions give different, but nearly constant monthly readings at each position, the typical standard deviation being 22%. Superimposed on that stable pattern have been three periods during which spatially grouped radon readings increased by a factor of 2 or more over their normal values. The simplest description of the source of the increases is sporadic puffs of upflowing gas, originating at as yet unknown depths."

In their search for a possible driving force for the radon enhancements, the investigators, R. L. Fleischer and A. Mogro-Campero, reviewed earthquake records and found no significant correlation. However, in September, 1973, a quake of magnitude 4.6, 35 kilometers from the measurement site, did correlate with the beginning of an unusual 2-month-long radon event. Finally, there was no obvious correlation between radon events and atmospheric pressure. (R1)

References

R1. Fleischer, Robert L., and Mogro-Campero, Antonio; "Radon Enhancements in the Earth: Evidence for Intermittent Upflows?" Geophysical Research Letters, 6:361, 1979. (X1)

ESC16 Anomalies Pertaining to the Origin of Methane

Description. A diverse group of geological and geophysical phenomena, many of which imply that much of the methane in the earth's crust is abiogenic and originates deep in the crust and mantle.

X1. The carbon problem (again)
X2. Carbon-isotope anomalies
X3. Methane rich in helium
X4. Methane inclusions in crystals and magmatic rocks
X5. Extraordinary size of methane hydrate deposits
X6. Methane emissions of mud volcanos
X7. Carbonate rocks and methane around the Siljan Ring
X8. Geographical correlation of methane occurrence and crustal defects
X9. Methane emission during earthquakes
X10. Anomalous animal behavior prior to earthquakes
X11. Properties of tsunamis

Background. The foremost proponent of deep-seated abiogenic methane is T. Gold. Many of the discussions below are based upon his labors. While Gold's thesis has fallen largely upon deaf ears in the United States, Soviet geologists have long entertained the possibility of abiogenic methane and oil. The drilling of a test hole at Sweden's Siljan Ring is proof that some geologists and geophysicists think that Gold's arguments have some merit. Time will tell!

Data Evaluation. Methane, like oil and coal, is an important fuel resource. Its origin and geological occurrence have long been studied in the field and laboratory. Examples X1-X8, below, are considered moderately well-researched by science. Items X9-X11, however, are more speculative. Rating: 2.

Anomaly Evaluation. Virtually all researchers concede that some small proportion of the methane reaching the earth's surface is abiogenic and comes from great depths. The controversy addressed here concerns the proportion: how much of our methane is abiogenic? The scientific consensus holds strongly that the abiogenic fraction is very small, the rest being the product of organic decay. Since the only item of contention is the fraction that is abiogenic, one would not normally accord the phenomena described here a high degree of anomalousness. However, the scientific community is so adamant and vociferous on this matter that we must make an exception. Rating: 1.

Similar and Related Phenomena. Generally, the same as those listed for oil in ESC13. Also: earthquake lights (GLD8); intermittent radon emissions (ESC15); unusual animal behavior prior to earthquakes (GQB1).

Examples

X0. The view of mainstream science on the origin of methane. Mainstream science maintains that the great bulk of methane found in the earth's crust is biogenic and closely related to the origin of petroleum. Thus, the accepted source of methane is buried organic matter, which has been transformed by heat and pressure. The evolution of vast quantities of methane by contemporary decaying vegetation strengthens the mainstream view.

The evidence for abiogenic methane, which is intrinsic in most of the phenomena discussed below, is usually indirect (mud volcanos, gaseous emissions during earthquakes, etc.) and, furthermore, does not distinguish between abiogenic methane and the biogenic methane that we know to be abundant. Yet, even the most conservative geologists acknowledge that some abiogenic methane, derived from the earth's primordial carbon inventory, still seeps upward through the crust. (R4)

X1. The carbon problem (again). As mentioned earlier (ESC9-X4, ESC13, ESC14), the amount of carbon residing in the surface layers of our planet is very large and must have been brought up from the interior by ascending gases and liquids. D. Patterson has placed T. Gold's slant on this fact in an article in the New Scientist:

"The large quantities of unoxidised carbon deposits appear to present a theoretical problem because, assuming they too derived from outgassed carbon dioxide, they must have given up a considerable amount of oxygen. Gold calculates that the unoxidised deposits would have released 20 planetary atmospheres of oxygen during geological time---that is roughly 100 times more oxygen than we presently have in our atmosphere---and this is clearly incompatible with the geological record. His exit from this seeming reductio ad absurdum is characteristically ingenious and plausible. He suggests that carbon dioxide in not the sole outgassing carbon bearing gas---methane should also come up out of the Earth in large quantities and it would have the right chemical properties to 'mop up' the oxygen excesses in the manner of a chemical scavenger." (R2) Manifestly this evidence for large quantities of upwelling methane is indirect.

X2. Carbon-isotope anomalies. T. Gold, in his book Power from the Earth, maintains that the deeper the source of the methane the heavier it is isotopically; that is, more carbon-13 in relation to carbon-12. Since biogenic processes favor carbon-12, Gold suggests that the lighter, near-surface methane contains more biogenic methane than the deeper, heavier methane. This depth effect comes about as the upwelling, heavier, primordial methane mixes with biogenic methane emanating from buried organic material near the surface. (R8) See also ESC13-X4.

Reinforcing the belief that methane found near the surface is mainly biogenic is a study of methane in geothermal systems by D. J. Des Marais et al. They found that the methane in geothermal steam and the steam from fumaroles and hot springs in the western United States is consistently richer in carbon-12 than in the heavier hydrocarbons in the same steam. Conclusion: most methane in geothermal systems comes from the thermal decomposition of organic matter. (R5)

Another carbon-isotope study focussed on the carbon-13 and carbon-14 isotopes: "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." This phenomenon was ascribed to a mixing of petroleum-derived methane with bacterial methane or, possibly, the fractionation of the isotopes as they migrated through the rocks. (R1)

X3. Methane rich in helium-3. Helium is closely associated with sources of oil and methane. (See ESC13-X23.) The most common isotope of helium is helium-4. Some of this isotope is produced steadily by the disintegration of uranium and thorium in the earth's upper crust. The helium-3 detected at the surface, on the other hand, is considered to be almost entirely primordial and outgassing from deep in the crust and mantle. (Note that a very small bit of helium-3 can be created from lithium bombarded by the radiation from uranium.) The consequence of these factors is that most scientists concur that any methane rich in helium-3 comes from deep-seated sources. It seems that there is a goodly quantity of such methane, as pointed out by T. Gold.

"There are many occurrences of methane, both in commercial deposits and in methane seeps, where the associated helium is enriched in helium-3 so as to be identified as primordial and coming from the mantle. The great rift in the Pacific Ocean, called the East Pacific Rise, has been found to emit methane along much of its length, with very hot water, together with decidedly high ratios of helium-3 to helium-4. Expressing these in terms of the atmospheric ratio, the values there are between 7.5 and 9 times as high. The branch of this rift which goes into the Gulf of California, where both methane and petroleum are present, has a helium ratio of 8 in the same terms. In the rift of the Red Sea, where methane emerges with deep hot water (and where oil in commercial quantities occurs nearby), the ratio of the associated helium is 8.6. The continuation of the same rift into Africa has many lakes that have remarkable occurrences of hydrocarbons. Lake Kivu, which has the world record for the quantity of methane dissolved in its waters, shows a total helium content of roughly a thousand times that which surface water would have brought in from the atmosphere, and the helium-3 proportion is 3 times the atmospheric value. The lake water therefore has 3000 times the total amount of helium-3 that it could have obtained from the atmosphere." (R8)

H. Wakita and Y. Sano "observed extraordinarily high $^3He/^4He$ ratios, up to 8.65×10^{-6}, in gases from wells drilled into deep reservoirs in volcaniclastic rock formations, the so-called 'Green Tuff'. These values are almost identical to those of volcanic fumaroles in the Japanese Islands. In contrast, gases in shallower sedimentary rock reservoirs have low $^3He/^4He$ ratios with a minimum value of 0.3×10^{-6}. These low values are similar to those of natural gases originating from biological materials. This suggests that the formation of natural gas reservoirs in the volcaniclastic rock may be attributed to large-scale magmatic activities which occurred in the middle Miocene." (R6)

These same researchers have also found huge helium-3/helium-4 ratios in the gases emanating from the earth in the Kinki region of Japan, where swarms of microseisms are common. (R12)

In 1969, W. B. Clarke and his coworkers found that deep Pacific waters were characterized by helium-3/helium-4 ratios that were higher than the ratio in the earth's atmosphere. (R9, R10) Originally, these results were interpreted to mean that primordial helium-3 was outgassing from the ocean floor. However, later work by S. Ameri and M. Ozima revealed that deep-sea sediments with high helium-3/helium-4 ratios seem to be the consequence of the primordial helium-3 contained in interplanetary dust particles present in quantity in the sediments. (R11) There is thus the possibility that some or all of the excess helium-3 in the deep-ocean waters may be extraterrestrial rather than derived from the earth's interior. (WRC)

X4. Methane inclusions in crystals and magmatic rocks. Even those scientists critical of T. Gold's prediction of abundant primordial methane deep within the earth agree than methane inclusions in crystals and magmatic rocks indicate that at least some abiogenic methane migrates from great depths to the earth's surface. (R4)

Volcanos and hot magmas give off considerable carbon dioxide. Gold suggests that some of the carbon in this carbon dioxide initially rose up from the mantle as methane, but was oxidized within the lava to produce steam and carbon dioxide that are so common in volcanism.

Even so, some lavas manage to retain considerable quantities of methane. Lava flows in Iceland and Hawaii are commonly decorated with small blue flames. So are the magmas expelled by other volcanos; viz., Krakatau in 1920. "There, when for some days there were volcanic discharges underwater, orange-yellow flames were reported as dancing on the surface of the water: 'The entire surface of the water above the crater was like a sea of flames. Seen from a distance of about 200 metres the flames were about 10 metres high'. (The colour of the flames in this case is probably dominated by sodium picked up by the gas in the seawater.) Here there can be no confusion with incandescent cinders. Flames were also observed during the eruptions of Santorini in 1866 and of Pelee in 1902." (R8) Such volcanic methane is doubtless mostly abiogenic and of deep origin. One must add "mostly" in the preceding sentence, because we really do not know how much organic material may reside in the deep crust and mantle. There is always the possibility that the phenomenon of plate subduction may have pulled organic materials down deep into the crust and mantle during the past 200 million years. (WRC)

X5. Extraordinary size of methane hydrate deposits. Soviet geologists have reported the existence of enormous amounts of methane hydrate in the Arctic permafrost and in cold-ocean sediments. So large are these deposits that proponents of abiogenic methane (many of whom are Russian) say that the decay of organic material could not have created all of it. (R7) But the polar regions, especially the Arctic, do contain much buried organic material. The famous Arctic muck, for example, is full of buried trees, mammoths, and other biological debris. It is perhaps premature to say that Arctic methane hydrate cannot be mostly biogenic. (WRC) See also ESC9-X9.

X6. Methane emissions of mud volcanos. "The most spectacular seeps of gas are the 'mud volcanos,' which are hills (if not substantial mountains) built up from sediments by the intermittent and occasionally violent eruptions of gas, sometimes carbon dioxide but most often nearly pure methane. Almost all the mud volcanos are found on or near the major active fault lines and sometimes running parallel to lines of real volcanos." (R3)

Some mud volcanos are truly impressive, being several hundred meters high and several kilometers wide at the base. One mud volcano, near Baku, on the shore of the Caspian Sea, flamed once to a height of two kilometers and then burned at a lesser height for 8 hours. (R8)

T. Gold argues that no natural gas field of biogenic origin would be anywhere near large enough to sustain the prodigious outputs of these mud volcanos over the millions of years they have belched methane. Further, the trace elements (mercury, helium, etc.) and the carbon-isotope ratio all point to an abiogenic origin for the methane. (R8)

X7. Carbonate rocks and methane around the Siljan Ring. Europe's largest meteorite crater, the Siljan Ring, is located on the ancient granite shield of central Sweden. Buried organic matter is rare here, yet cracks in the granite sometimes are filled with tar, and farmers' wells in the area produce combustible gases. All around the Ring are found carbonates that have been created by the oxidization of isotopically light, outgassing methane. Test wells drilled into the granite also record methane. (R7, R8)

The signs of buried hydrocarbons around the Siljan Ring are, in fact, so promising, even if counter to mainstream geology, that the Swedish State Power Authority and other private investors have financed the drilling of a deep well. In mid-1988, at a depth of 22,000 feet, this well brought up some 60 kilograms of very smelly, black sludge. This curious material has the consistency of modeling clay and contains hydrocarbons similar to those found in the surface seeps. Such hydrocarbons are not expected 4 miles down in a granitic body of rock. T. Gold holds that these hydrocarbons are abiogenic and consistent with his theory. Mainstream science, on the other hand, interprets the sludge in terms of contamination from the drilling lubricants and/or the known surface hydrocarbon seeps. Further analysis and drilling will hopefully clear up the picture. (R13, R14)

X8. Geographical correlation of methane occurrence and crustal defects. Methane and petroleum are frequently found together. Petroleum deposits are strongly concentrated along rifts and faults and around salt domes. The basic treatment of this subject in ESC13-X22 also applies here by extension.

Supplementing the oil-methane association is methane's geographical correlation with mud volcanos and, of course, the shattered granite of the Siljan Ring (X7). (R3, R7, R8, R13, R14) Such geographical correlations are consistent with but cannot alone prove the case for deep-origin, abiogenic methane.

X9. Methane emissions during earthquakes. The so-called "earthquake lights", cataloged under GLD8, include phenomena described by witnesses as flames shooting out of the ground. Although some earthquake lights may be of electrical origin, the flame-like phenomena could well be spontaneously ignited methane. Much methane exists in the crust, as detailed in the many cases of spontaneous natural combustion in ESC4. One cannot, of course, determine whether this burning methane is biogenic or abiogenic. Earthquake lights and flames thus constitute only indirect evidence, not very convincing at that, for abiogenic methane. (R7, R8)

Only one seismic event is on record where instrumentation was on hand capable of measuring methane evolution. In this case, gases present in seeps and fumaroles were being monitored at Hot Creek, California. Date of the earthquake: October 4, 1978. Even though the fumaroles in the area spouted steam and gases, methane remained a minor components of the gases being monitored. (R15, R16)

X10. Anomalous animal behavior prior to earthquakes. Observations of strange animal behavior preceding earthquakes are legion. (R7, R8, GQB1) One theory is that precursory stresses in the crust and soil release gases which disturb animals. T. Gold suggests that some of this gas, if that is what really causes the animal agitation, is methane. (R7, R8) Again, we have only weak, indirect evidence for Gold's theory.

X11. Properties of tsunamis. An unusual sort of indirect evidence for the release of large volumes of methane from the deep-ocean bottom has been advanced by T. Gold.

Tsunamis are seismic sea waves conventionally thought to be generated when large slabs of the oceanic crust are suddenly raised or lowered during earthquakes. The dimensions involved are impressive: the vertical displacement should be in the range of a few meters, while the crustal block may be 100 kilometers across. In this conventional view, it turns out that the energy required to displace the large crustal block is tens of thousands of times the amount of energy incorporated in the sea wave. Yet, the total energy of the quake, as determined from seismic data, is only 10-100 times that in the tsunamis. Clearly, the estimated energies are incompatible.

One way out of the energy dilemma is to assume that the mechanism actually generating the tsunamis is not an immensely energetic displacement of a huge slab of the crust, but rather the triggered release of pent up methane. This methane and the stored energy it represents could be released when the crust is ruptured by the earthquake and/or the destabilization of methane hydrate in sediment. The resulting huge methane bubble, or fountain of bubbles, would have the proper characteristics to generate the observed tsunamis. In this way, the energy paradox noted above would be solved. (R3, R8)

References

R1. "Can Rocks Separate Isotopes?" New Scientist, 26:35, 1965. (X2)

R2. Paterson, David; "Methane from the Bowels of the Earth," New Scientist, 78: 896, 1978. (X1, X6, X9-X11)

R3. Gold, Thomas, and Soter, Steven; "The Deep-Earth-Gas Hypothesis," Scientific American, 242:154, June 1980. (X6, X8, X9-X11)

R4. "Abiogenic Methane? Pro & Con," Geotimes, 25:17, November 1980. (X0, X4)

R5. Des Marais, David J., et al; "Molecular Carbon Isotopic Evidence for the Origin

of Geothermal Hydrocarbons," Nature, 292:826, 1981. (X2)
R6. Wakita, Hiroshi, and Sano, Yuji; "$^3He/^4He$ Ratios in CH_4-Rich Natural Gases Suggest Magmatic Origin," Nature, 305:792, 1983. (X3)
R7. Osborne, David; "The Origin of Petroleum," Atlantic Monthly, 257:39, February 1986. (Cr. C.H. Stiles) (X5, X7, X8)
R8. Gold, Thomas; Power from the Earth, London, 1987. (X1-X4, X6, X8-X11)
R9. Clarke, W.B., et al; "Excess ^3He in the Sea: Evidence for Terrestrial Primordial Helium," Earth and Planetary Science Letters, 6:213, 1969. (X3)
R10. "The Ocean Yields up Primordial Helium," New Scientist, 43:320, 1969. (X3)
R11. Amari, Sachiko, and Ozima, Minoru; "Search for the Origin of Exotic Helium in Deep-Sea Sediments," Nature, 317: 520, 1985. (X3)
R12. Wakita, Hiroshi, et al; "High ^3He Emanation and Seismic Swarms Observed in Nonvolcanic, Gorearc Region," Journal of Geophysical Research, 92:12539, 1987.
R13. "Going for Gold," Scientific American, 259:20, August 1988. (X7)
R14. Begley, Sharon, and Lubenow, Gerald C.; "Gushers at 30,000 Feet," Newsweek, p. 53, June 27, 1988. (Cr. C.H. Stiles) (X7)
R15. Aldrich, L.T., and Nier, Alfred O.; "The Occurrence of He^3 in Natural Sources of Helium," Physical Review, 74:1590, 1948. (X3, X4)
R16. Oremland, Ronald S.; "Methane in Association with Seismic Activity," Eos, 64: 410, 1983. (X9)
R17. Gold, Thomas, and Soter, Steven; "Methane and Seismicity: A Reply," Eos, 64:522, 1983. (X9)
R18. Gold, T.; "Ancient Carbon Sources of Atmospheric Methane," Nature, 335:404, 1988. (X1)

ESP ANOMALOUS PHYSICAL PHENOMENA IN GEOLOGY

Key to Phenomena

ESP0 Introduction

The purpose of this chapter is to bring together various physical phenomena occurring in rocks, strata, and sediments. These "physical" phenomena generally involve light, heat (or cold), sound, radioactivity, magnetism, time, and other facets of that scientific discipline we call physics. Like physics itself, the phenomena here are diverse and often unrelated to one another; but at the same time they are fascinating and often accessible to the casual observer of nature.

It is important to remember that this Catalog highlights anomalies. Therefore, the physical phenomena described below are only those selected from a much larger population that poses no problems in explanation.

How anomalous are these physical phenomena? A few are merely curiosities or very minor anomalies, such as flexible rocks and stones that ring like bells. One charming physical phenomenon is that of musical sands, a class including both the common squeaky beach sand and the rarer, stranger booming sand dunes. Mundane phenomena to be sure, but no good explanations of them exist. Most anomalous of all are those phenomena that challenge the geological time scale. Are the earth's rocks mostly millions, even billions of years old? Any data that deny the great antiquity of our planet are very anomalous indeed. Thus, some radiohalos, which geologists usually shrug off as "minor" problems, are really very anomalous. Modern science has much philosophical capital invested in a 5-billion-year-old earth and the constancy of physical constants over that period.

ESP1 Anomalous Radiohalos

Description. Radiohalos with rings that: (1) cannot be associated with alpha particles of any known nuclear disintegration; (2) can be attributed entirely to short-lifetime polonium isotopes (i.e., no uranium rings showing and no uranium in the radiocenters); and (3) are concentric about radiocenters possessing anomalous ratios of uranium, thorium, and/or lead isotopes.

Data Evaluation. Radiohalo data are abundant and have been carefully acquired through modern scientific methods. Ring radii are measured with high accuracy, as are the mass ratios of isotopes in the radiocenters. The great bulk of radiohalo investigation has been carried out by one individual and, on occasion, coworkers. Replication of the more controversial results is therefore desirable. Further, the focus of radiohalo research has been on those existing in very old rocks. Measurements need to be made on more recent rocks. (R35) Rating: 2.

Anomaly Evaluation. The anomalous radiohalos can and have been interpreted as indicating a very young earth. Such an interpretation is an anathema to modern geologists and geophysicists, who maintain that radiohalos constitute only a minor mystery that will one day be explained satisfactorily by today's science. While such may turn out to be the case, the radiohalo phenomenon is potentially very anomalous, and it is rated this way. Rating: 1.

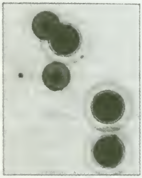
Possible Explanations. An early explanation was in terms of secondary deposition of radioactive isotopes via hydrothermal solutions. Some unrecognized radioactivity or nuclear reaction may be to blame. Scientific creationists, as mentioned above, claim that radiohalos betoken a young earth!

Similar and Related Phenomena. Discordant radiometric data (ESP12); fossils that are time-wise anomalous (ESB11).

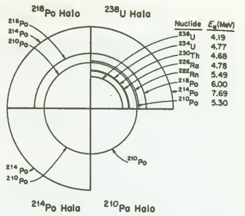
Examples

X0. Background. "When a thin section (very thin slice) of biotite mica is observed at high magnification under a microscope, using transmitted light, there may be seen circular dark-brown patches, all of the same diameter. Surrounding the darkened disk can be seen several concentric rings. Known as pleochroic halos, these circular objects have at the very center a tiny mineral inclusion interpreted as consisting of the daughter products of radioactive uranium or thorium, originally enclosed in the mineral and its associated igneous rock at the time of formation. The halo has been formed by innumerable alpha particles, sent outward in all directions from the radioactive particle and causing dislocations of the atoms of the mineral crystal lattice." (R36)

The pleochroic halos (or radiohalos) were observed as early as 1873 by H. Rosenbusch, but their origin remained obscure until 1907. It was in this year that J. Joly concluded that the halos were the consequence of alpha particles emitted by the bit of radioactive material at the center. (R37) Each halo or ring is associated with an alpha particle of specific energy, as indicated in the diagram for uranium-238. The decay series of uranium-238 is quite complex, producing eight different alphas and their corresponding halos. As the subsequent entries will demonstrate, there are many deviations from the ideal scheme described above. Indeed, the interpretation of radiohalo anomalies has sparked vigorous debate between the scientific community and scientific creationists.



Typical radiohalos as seen through a microscope. (X0)



Uranium-238 series radiohalos (upper right) and isolated polonium halos. (X0, X1) (After R.V. Gentry)

X1. Isolated polonium radiohalos. Research into radiohalos has never been very popular. Perhaps it is because of the long grueling hours required with microscopes. One Canadian scientist, however, G.H. Henderson, assembled a large collection of radiohalo samples. He and F.W. Sparks, in 1939, were apparently the first to discover the famous polonium halos sans uranium halos. In their paper, they simply designated the new halos A, B, C, and D. They wrote:

"Summary. Four types of halos, provisionally designated as A, B, C and D are described, three of them for the first time. These halos have one, two, three and one rings respectively. Measurements of ring radii are given. The mode of occurrence of the halos is described. It is shown that they are probably due to alpha-particles from certain later members of the uranium family, whose lives are exceedingly short on a geological time scale." (R4)

Superficially, nothing seems anomalous here, but Henderson quickly recognized the consequences of polonium halos (as halos A, B, and C turned out to be) without parent uranium in the halo nuclei. R.G. Kazmann summed up the problem nicely:

"The polonium halos, especially those produced by ^{218}Po, are the center of a mystery. The half-life of the isotope is only 3 min. Yet the halos have been found in granitic rocks, at considerable depths below land surface, and in all parts of the world, including Scandinavia, India, Canada, and the United States. The difficulty arises from the observation that there is no identifiable precursor to the polonium; it appears to be primordial polonium. If so, how did the surrounding rocks crystallize rapidly enough so that there were crystals available ready to be imprinted with radiohalos by alpha particles from ^{218}Po? This would imply almost instantaneous cooling and crystallization of these granitic minerals, and we know of no mechanisms that will remove heat so rapidly. The rocks are supposed to have cooled over millennia, if not tens of millennia." (R27)

To explain this anomaly and thus assuage the fears of the geologists, who needed an old earth, Henderson and Sparks proposed that the isolated polonium halos were "secondary" structures, as recounted now by D. York:

"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 or 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 alpha-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." (R28)

More will be said about the value of isolated anomalies in X7. There is little doubt that York, in his discussion above, was reserving the word "absurd" for the interpretation of polonium halos championed by R. V. Gentry. Gentry, a scientist and a Christian, holds that the isolated polonium halos constitute proof of a young earth---an earth merely thousands of years old. Gentry, however, has found considerable experimental evidence to negate the Henderson theory, which, in addition, involves unproven assumptions. Next, we attempt to encapsulate some of the results of Gentry's laboratory work.

R. V. Gentry's experimental approaches. In one study, he employed a technique called the "fossil alpha recoil" method and could find no evidence of past hydrothermal deposition in the neighborhoods of the polonium halos. His closing two paragraphs are useful at this juncture:

"Thus, as far as the experimental analysis is concerned, I cannot confirm Henderson's model for the secondary origin of the polonium halos. To the question of what mode of origin is consistent with the relatively short half-lives of the polonium isotopes (or their beta-decaying precursors), I can say only that other mechanisms are under study.

"Whatever hypothesis is invoked, to explain the origin of the polonium halos, must also explain both the one found by Henderson (due to a combination of isotopes from both the thorium series (^{212}Po and ^{212}Bi) and the uranium series (^{210}Po)) and a halo presumably due to ^{211}Bi from the ^{235}U series. Perhaps most interesting of all is the occurrence of 20,000 to 30,000 ^{218}Po and ^{210}Po halos per cubic centimeter in a Norwegian mica---without the ^{214}Po halos." (R9)
The polonium-halo anomaly is certainly made more profound by the last sentence. (WRC)

Gentry also used ion microprobes to investigate lead isotope ratios near the polonium halo sites. "Radiohaloes associated with decay of several Po alpha emitters have been studied by optical microscopic techniques and more recently by mass spectrometric examination of the halo inclusion using ion microprobe techniques. In such cases a large excess of ^{206}Pb compared with ^{207}Pb was found to be incompatible with the radiogenic decay of ^{238}U and ^{235}U, yet was explainable on the basis of polonium decay independent of uranium. A straightforward attempt to account for the origin of these Po haloes by assuming that Po was incorporated into the halo inclusion at the time of host mineral crystallization meets with severe geological problems; the half-lives of the polonium isotopes ($t_{1/2}$ = 3 min for ^{218}Po) are too short to permit anything but a rapid mineral crystallization, contrary to accepted theories of magmatic cooling rates." (R12) Opponents of Gentry's interpretations do not criticize his experimental work. Further, they usually do not mention his evidence that Henderson's theory of origin is probably incorrect. (WRC)

Apparently the only scientists to seriously question Gentry's identification of the polonium halos were C. Moazed et al. We quote the Abstract from their 1973 Science paper:

> "A study of the sites of so-called polonium radiohalos of various types found in biotite from Bancroft, Ontario, has been carried out. The evidence is consistent with the interpretation that these halos are variants of the standard uranium halos. A review of the literature indicates that there is no firm evidence that polonium halos exist, all evidence being equally consistent with the interpretation that these are uranium halos." (R40)

Gentry replied to Moazed et al in 1974 in a long footnote in a 1974 paper in Science. Here, Gentry explained why the halos examined by Moazed could not be uranium halos. The question of halo identification was never again an issue. (R14)

Another criticism of Gentry's work has involved his use of the word "primordial" in describing the granites in which some of the polonium radiohalos are found. In 1987, J. R. Wakefield demonstrated why many of these granites were probably not primordial. What Wakefield did was to examine the geology of some of the sites from which Gentry obtained his biotite samples. Basically, he found that the supposedly primordial rocks were often just dikes and veins that were formed much later than the earth's oldest rocks. Wakefield commented:

> "This fact alone tells us that the rocks bearing Gentry's halos, even if instantly created, have no bearing on the origin and age of the earth." (R51)

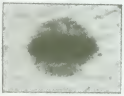
But the fundamental anomaly---the polonium halos without apparent precursors---still survives. Wakefield admitted this: "Still, we must give Gentry his due. Nothing in geology fully explains the apparent occurrence of the polonium halos as described by Gentry. They do remain a minor mystery in the field of physics." (R51)

Today, mainstream scientists still opt for Henderson's explanation despite all of Gentry's lab work. A final excerpt from Gentry's published writings seems in order:

"Abstract. New photographic evidence, data on halo ring sizes, and x-ray fluorescence analyses provide unambiguous evidence that polonium halos exist as a separate and distinct class apart from uranium halos. Because of the short half-lives of the polonium isotopes involved, it is not clear how polonium halos may be explained on the basis of currently accepted cosmological models of Earth formation." (R14)

X2. Radiohalos in coalified wood. R. V. Gentry and his colleagues have found uranium-series halos in coalified wood from the Colorado Plateau. Such halos are termed "secondary", because the uranium is not a constituent of the "primary" wood, but is introduced in solution form during the fossilization process. Normal, round halos are found, as are elliptical halos, created presumably by compaction of the wood matrix. Circular and elliptical halos with the same centers are designated "dual", and are thought to represent wood compaction during fossilization.

The key scientific paper is from Science,



Elliptical radiohalos in coalified wood result when the wood is deformed. Encircling round halos develop later. (X2) (R.V. Gentry) from which we take the 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 far 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." (R19)

Gentry et al begin the paper by noting that while the biological fossil record has been documented extensively, the abundant record of fossil radio halos 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 the 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 therefore be at least as old. The startling part of the evidence presented deals with the 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, very little of the uranium has decayed to lead. The implication is that the coalified wood is much younger than the accepted geological age of the stratum containing it, being perhaps thousands rather than millions of years old.

At the paper's conclusion, Gentry et al mention the existence of coalified wood in the Chattanooga Shale, where embryonic radiohalos have also been found. Here, too, the $^{238}U/^{206}Pb$ ratios are much too high (by more than a factor of 1000) to correlate with the Devonian age of the shale.

Gentry and his colleagues presented their data and conclusions at a 1978 professional meeting on geological and cosmological time measurement. R.G. Kazmann summarized the situation, "Thus ages of the entire stratagraphic column may contain epochs less than 0.01% the duration of those now accepted and found in the literature. The possibility of reducing the 4.5 billion year 'history' of the earth by a factor of 10,000 has not been seriously considered by workers in the field yet." (R27)

At this same meeting D. York stated that Gentry's results represented "a small anomaly" in a large mass of data. The overwhelming bulk of the age data support the 4.5-billion-year age of the earth. This position is still maintained by mainstream science. (WRC)

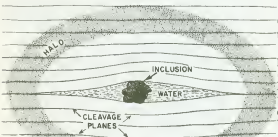
X3. Giant radiohalos. The announcement in 1966 by R. V. Gentry et al (R7) that they had discovered evidence for the existence of superheavy elements in monazite had profound implications. First, the identification of the giant radiohalos, if actually due to the presence of radioactive elements beyond uranium, suggested that some superheavy elements are much more stable than theory permits; or, perhaps more traumatic, that radioactive dating is grossly in error and the monazite deposits are extremely young, and the superheavy elements have not yet decayed away. Neither alternative is attractive in terms of the current world-view of science. Extreme efforts were made to find other, more acceptable explanations of the giant halos.

An abstract from a 1970 paper in Science sets the stage: "A new group of giant radioactive halos has been found with radii in excess of anything previously discovered. Since alternate explanations for these giant halos are inconclusive at present, the possibility is considered that they originate with unknown alpha radioactivity, either from isomers of known elements or from superheavy elements." (R10)

Trying to confirm superheavy elements. In 1976, an experiment was reported at a meeting of the American Physical Society suggesting the existence of element 126, and possibly elements 116, 124, and 127, in mica from Madagascar. The experimenters included R. V. Gentry and scientists from the University of California at Davis and Florida State. Naturally, the scientific community was quite skeptical. (R16)

Nevertheless, several scientists turned their attention to the problem, for the discovery of relict superheavy elements would be little short of remarkable. A. L. Robinson summarized the situation in 1977. After summarizing the problems posed by the findings of Gentry et al, Robinson reported on two experiments that seemed to deny the presence of superheavy elements. First, John Fox and his collaborators at Florida State found that the gamma ray emitted when a praseodymium nucleus relaxes after creation from cerium (common in monazite) has the same energy as the X-ray peak of the supposed element 126. Second, more 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, including Gentry himself, decided that the monazite samples did not contain superheavy elements after all, although they realized that the origin of the giant radiohalos had still not been explained. (R23)

In addition to the lack of direct evidence for superheavy elements, an interesting possible explanation for the giant halos appeared in 1977. "P. H. Fowler and A. R. Lang of the University of Bristol have suggested another simple mechanism to account for the giant haloes. They point out that the giant halos 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



Water in a cleavage plane containing a radioactive impurity can increase the ranges of emitted particles and thus increase halo sizes. (X3)

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." (R24) Although this mechanism is quite reasonable, it would create only a two-dimensional halo. No experimental evidence has been found showing that the giant radiohalos are indeed created in this way; nor do we know if the giant halos are two- or three-dimensional. Further, it would seem that the halos formed in conjunction with water-filled cracks would be fuzzy or smeared over a range of radii. (WRC)

Although giant radiohalos no longer seem a popular research subject, the literature examined so far does not have a definitive explanation, or at least a really convincing explanation, of the giant radiohalos. (WRC)

X4. Dwarf halos and other radiohalos of unknown provenence. In addition to the still enigmatic giant halos (X3), several other mysterious halos appear in the microscope. One class, called "dwarf halos", have been reported frequently in Swedish biotites. They are probably attributable to unknown radioactivity. (R26)

In his extensive radiohalo research, R. V. Gentry has recorded several other halos that cannot be paired with known alpha emissions, as in the following excerpt: "The purpose of this letter is to report that, as a result of extensive research on radioactive halos in biotite from several areas of the world, still another anomalous halo has been discovered. This halo was found in the black Ytterby mica and possesses average ring radii of 13.6μ and 19μ, corresponding to alpha particle energies of 4.5 MeV and 5.4 MeV. These rings are not consistent with the development of either the uranium or thorium halos or any combination thereof.

"Furthermore, fission track analysis of the mica shows no fission tracks in the vicinity of the central inclusion, thus eliminating the presence of any spontaneous fissionable nuclides such as ^{238}U in the central inclusion.

"Whatever the implications, it seems that these halos represent alpha radioactivity of presently unknown origin which at one time existed in the earth's crustal rocks. Just how the evidence of these halos may be reconciled with current theories of nucleosynthesis and crustal formation is treated elsewhere." (R6)

In addition to the dwarf halos, there is a surprisingly large array of "intermediate" halos. R. V. Gentry describes one such group: "Still rarer than the dwarf halos are the X halos first reported by Joly in the micas from Ytterby and Arendal (Norway). Later van der Lingen reported halos of similar dimensions occurred in a granite near Capetown. According to Joly the inside ring of the X halo may be somewhat diffuse and measures about 8.5 to 9.8 μm in radius, corresponding to an E_{alpha} of about 2.9 to 3.2 MeV. The bleached rings extend out to a radius of about 14 to 15 μm, and sometimes an adjacent dark ring is evident at about 17 μm (E_{alpha} = 4.4 to 5.0 MeV). The outer wide band extends to approximately 28 μm corresponding to an E_{alpha} of 6.7 to 6.9 MeV. Despite some similarities with the Th halo there is no known alpha-decay sequence corresponding to these energies." (R39)

Gentry has also reported a halo with rings that seem to be from alpha particles with energies of about 4.4 to 5.4 MeV. G.H. Henderson discovered a so-called D halo with a diffuse radius of 16 um. Still another group of mysterious halos was identified by S. Iimori and J. Yoshimura in 1926. The discoverers named them the Z_1, Z_2, and Z_3 halos and speculated that they were created by alpha-emitters in the actinium series. (R39)

X5. Spectacle halos. Only one "spectacle" halo has been found to date. It actually consists of a spectacle-shaped array of tiny polonium halos; that is, it is a composite of many "ordinary" halos. R. V. Gentry describes the discovery as follows:

"During a routine examination of a mica specimen from the Silver Crater Mine near Faraday Township in Ontario, Canada, I discovered a most unusual pattern of ^{210}Po halos. In the more than 100,000 halos which I had examined under the microscope, none had even faintly resembled the connecting circular patterns observed in this 'spectacle halo'. Incidentally, the shape of this special halo is completely different from any of the known crystallization patterns, all of which yield minerals with straight edges. No mineral crystallizes in circles, yet for some reason the radiocenters of the 'spectacle halo' did." (R34) In addition to the curious pattern formed by the halos, mass analysis of the radiocenters indicated the presence of ^{206}Pb. The mass ratios suggested that the "spectacle halo" originated from ^{210}Po alpha decay and not from uranium or thorium. (R13; R41)

The "spectacle halo" found in mica from the Silver Crater Mine. Magnification: 300×. (X5) (R.V. Gentry)

X6. Variation of halo radius with time. This item is of historical interest only because the phenomenon has never been seen in modern measurements of radiohalos.

In the 1920s, J. Joly's measurements of radiohalos seemed to reveal a remarkable shrinking through geological time. One halo measured 0.0160 mm in Archean mica; 0.0146 in Devonian rock; and 0.0135 in an Eocene sample. Joly commented, "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." (R1) Also of note to historians of science is Joly's best estimate, based on radioactivity and geological measures, for solidification of the earth's crust was 150-200 million years! In reference to the following item, X7, one must admit that concurring data from diverse sources do not always give the right answer. (WRC)

X7. The residue fallacy. First, a preamble by the compiler. In many areas of anomaly research, a single discovery or isolated class of observations stands out boldly against a large, internally consistent backdrop of data that are well-explained by prevailing paradigms. The rather natural attitude of the scientific community is to discount anomalies or, even worse, to dismiss them entirely. Such attitudes are dangerous because, as most scientists will freely admit, anomalous observations often lead to great theoretical advances. Take, for example, continental drift, a linchpin of modern geology and geophysics; even 20 years ago observations supporting this hypothesis were brushed aside. One purpose of the Catalog of Anomalies is to keep discordant data in view until they are properly dealt with.

This said, we turn to general critiques of R. V. Gentry's work. First, a pertinent quotation from S. Dutch's 1983 letter in Physics Today:

"Gentry's halo results are an example of what many science writers call the 'residue fallacy.' The mere fact that items are unexplained does not constitute evidence that a radical revision of science is necessary, and often the 'unexplained' facts turn out to have pretty simple explanations on closer examination. If we can argue that polonium halos show the geologic time scale is wrong, we can far more cogently argue that the evidence for the geologic timetable shows that Gentry's interpretation is in error." (R33)

A similar criticism was offered by D. York in 1979. One paragraph is particularly interesting. It follows a description of the large body of different geological dating schemes, all of which, save for radiohalos, are in good agreement.

"In light of the developments sketched above, it is truly extraordinary then that in the past dozen or so years an American scientist, R. V. Gentry, has chosen to do exactly what Henderson so wisely avoided. That is, Gentry has been trying to promote the idea that the existence in minerals of Po halos means that our presently accepted chronology of the earth's evolution may be grotesquely in error, by many orders of magnitude. Gentry's own observations and measurements of halos, i.e., his recording of high $^{206}Pb/^{207}Pb$ ratios and low U concentrations in Po halo nuclei, add support to Henderson's suggestion that types A, B, and C really are Po halos. They do nothing to detract from Henderson's theory of their mode of origin. Why, then, Gentry takes the position he does, totally ignoring the enormous mass of self-consistent geochronological data and theory, is difficult to understand. He presents no alternative theory and does not even consider why geochronology as presently practiced is so successful." (R28) Anyone who has read X1 realizes that Gentry devoted considerable experimental effort towards demonstrating that Henderson's theory was very likely incorrect. Finally, Gentry does present an alternative; namely, recent creation of the earth. It is perhaps this facet of Gentry's philosophy that is most unpalatable to conventional science! Since theories are not being judged in this Catalog, we can now move on to other anomalies, of which there are a great many. (WRC)

References

R1. Joly, John; "The Age of the Earth," Scientific Monthly, 16:205, 1923. (X6)

R2. "Radioactivity and the Formation of Pleochroic Haloes," Science, 81:sup 6, May 31, 1935. (X1)

R3. "Canadian Scientist Finds Evidence of 'Lost' Elements," Science News Letter, 27:363, 1935. (X1)

R4. Henderson, G.H., and Sparks, F.W.; "A Quantitative Study of Pleochroic Haloes IV. New Types of Haloes," Royal Society, Proceedings, A173:238, 1939. (X1)

R5. Gentry, Robert V.; "Pleochroic Halos and the Age of the Earth," American Journal of Physics, 33:878, 1965. (X1)

R6. Gentry, Robert V.; "Alpha Radioactivity of Unknown Origin and the Discovery of a New Pleochroic Halo," Earth and Planetary Letters, 1:453, 1966. (X4)

R7. Gentry, Robert V.; "Abnormally Long Alpha-Particle Tracks in Biotite (Mica)," Applied Physics Letters, 8:65, 1966. (X3)

R8. Gentry, Robert V.; "Possible Antimatter Shock Halos in Biotite," American Geophysical Union, Transactions, 47:481, 1966. (X3)

R9. Gentry, Robert V.; "Fossil Alpha-Recoil Analysis of Certain Variant Radioactive Halos," Science, 160:1228, 1968. (X1)

R10. Gentry, Robert V.; "Giant Radioactive Halos: Indicators of Unknown Radioactivity?" Science, 169:670, 1970. (X3)

R11. Gentry, Robert V.; "Cosmological Implications of Extinct Radioactivity from Pleochroic Halos," in Why Not Creation? Walter E. Lammerts, ed., Grand Rapids, 1970, p. 106. (X1)

R12. Gentry, Robert V., et al; "Ion Microprobe Confirmation of Pb Isotope Ratios and Search for Isomer Precursors in Polonium Radiohaloes," Nature, 244:282, 1973. (X1)

R13. Gentry, Robert V., et al; "'Spectacle' Array of ^{210}Po Halo Radiocentres in Biotite; a Nuclear Geophysical Enigma," Nature, 252:564, 1974. (X5)
R14. Gentry, Robert V.; "Radiohalos in a Radiochronological and Cosmological Perspective," Science, 184:62, 1974. (X1)
R15. Robinson, Arthur L.; "Nuclear Science: X-Ray Evidence for Superheavy Elements," Science, 193:219, 1976. (X3)
R16. "Mica Giant Halos Suggest Natural Superheavy Elements," Physics Today, 29:11, August 1976. (X3)
R17. Walgate, Robert; "New World beyond Uranium," New Scientist, 70:696, 1976. (X3)
R18. "Doubt over Discovery of Element 126," Science News, 110:357, 1976. (X3)
R19. Gentry, Robert V., et al; "Radiohalos in Coalified Wood: New Evidence Relating to the Time of Uranium Introduction and Coalification," Science, 194:315, 1976. (X2)
R20. Juergens, Ralph E.; "Radiohalos and Earth History, Kronos, 3:3, Fall 1977. (X0, X1)
R21. "Possible Explanation for Giant Haloes," New Scientist, 74:266, 1977. (X3)
R22. Hodgson, P.E.; "Giant Haloes Explained," Nature, 267:581, 1977. (X3)
R23. Robinson, Arthur L.; "Superheavy Elements: Confirmation Fails to Materialize," Science, 195:473, 1977. (X3)
R24. "Giant Haloes in Mica," New Scientist, 76:563, 1977. (X3)
R25. Connor, Steven J.; "Radiohalos in Coalified Wood: New Evidence for a Young Earth," Creation Research Society Quarterly, 14:101, 1977. (X2)
R26. Gentry, R. V.; et al; "Implications on Unknown Radioactivity of Giant and Dwarf Haloes in Scandinavian Rocks," Nature, 274:457, 1978. (X3, X4)
R27. Kazmann, Raphael G.; "Time: In Full Measure," Eos, 60:21, 1979. (X1, X2, X7)
R28. York, Derek; "Polonium Halos and Geochronology," Eos, 60:617, 1979. (X1, X7)
R29. Editors of the Reader's Digest; "Radiohalos: The Glow of Youth," in Mysteries of the Unexplained, Plesantville, 1982, p. 55. (X1)
R30. Gentry, Robert V., et al; "Creationism Discussion Continued," Physics Today, 35:13, October 1982. (X1, X2)
R31. Stakemann, R., et al; "Search for Superheavy Elements in Monazites Using Chemical Enrichment," Nature, 297:136, 1982. (X3)
R32. Raloff, Janet; "They Call It Creation Science News, 121:44, 1982. (X1, X2)
R33. Dutch, Steven; "Creationism Still Again," Physics Today, 36:11, April 1983. (X7)
R34. Gentry, Robert V.; "The Spectacle Halo," Creation's Tiny Mystery, Knoxville, 1986, p. 48. (X5)
R35. "Creation's Tiny Mystery," Origins Research, 10:10, Spring/Summer 1987. (X1, X2)
R36. Strahler, Arthur N.; "Halos Produced by Radioactivity," Science and Earth History---The Creation/Evolution Controversy, Buffalo, 1987, p. 138. (X0, X1)
R37. Joly, J.; "Pleochroic Halos," Philosophical Magazine, 6:13:381, 1907. (X0)
R38. Gentry, Robert V.; "Radiohalos: Some Unique Lead Isotope Ratios and Unknown Alpha Radioactivity," Science, 173:727, 1971. (X4)
R39. Gentry, Robert V.; "Radioactive Halos," Annual Review of Nuclear Science, 23:347, 1973. (X1, X3, X4)
R40. Moazed, Cyrus, et al; "Polonium Radiohalos: An Alternate Interpretation," Science, 180:1272, 1973. (X1)
R41. Fremlin, J.H., and Gentry, Robert V.; "Spectacle Halos," Nature, 258:269, 1975. (X5)
R42. Gentry, R.V., et al; "Evidence for Primordial Superheavy Elements," Physical Review Letters, 37:11, 1976. (X3)
R43. Damon, Paul E., et al; "Time: Measured Responses," Eos, 60:474, 1979. (X1)
R44. Gentry, Robert V.; "Polonium Halos," Eos, 61:514, 1980. (X1)
R45. Ellis, Harry W., and Gentry, Robert V.; "Creationism Discussion Continues," Physics Today, 35:13, October 1982. (X1, X2)
R46. Matthews, Jaymie, and Gentry, Robert V.; "Galactic Red Shifts," Physics Today, 36:124, November 1983. (X1)
R47. Wyckoff, Robert C., and Gentry, Robert V.; "Polonium Halos," Physics Today, 37:108, April 1984. (X1)
R48. Ellenberger, C. Leroy, and Gentry, Robert V.; Physics Today, 37:92, December 1984. (X1, X3)
R49. Ellenberger, C. Leroy; "Absolute Dating," Physics Today, 39:152, March 1986. (X1)
R50. Wakefield, J. Richard; "Gentry's Tiny Mystery---Unsupported by Geology," Creation/Evolution, 22:13, Winter 1987/1988. (X1)

ESP2 Flexible Rock

Description. Various types of rock which, when cut into strips, exhibit unusual flexibility. Thin strips can often be bent into a complete circle; thicker slabs sag noticeably under their own weight. Most flexible rock is readily classified as sandstone, limestone, marble, or coal; although normal rocks of these types are not flexible. Somehow, flexible sandstone, limestone, and marble are different from the ordinary varieties of these common rocks. Moisture seems to be a factor promoting flexibility.

Data Evaluation. Flexible sandstone and paper coal are well-known curiosities. The other flexible rock varieties have received little scientific attention. Rating: 2.

Anomaly Evaluation. It cannot be denied that flexible rock has a certain popular appeal, but it is merely a curiosity to science, not a serious anomaly. Even though the precise mechanism that allows normally stiff rock to bend easily is not well-understood, flexible rock is only a minor challenge to geology. Rating: 3.

Possible Explanations. Scientists who have studied flexible rock through the microscope claim to see "gear-like" or "elbow-like" connections between adjacent grains. This is all rather vague; one would think the cement or matrix would have to be elastic, too. On the other hand the flexibility of paper coal can be understood in terms of its matted-plant character.

Similar and Related Phenomena. Normal rock is elastic to a small degree.

Examples

X1. Flexible marble. Evidently this is a rare substance, for only two reports on it have been found.

Massachusetts. "Some account of this marble was given to the public by Dr. Meade, in Bruce's Mineralogical Journal. A considerable quantity of this substance has since been found, and a notice of some large slabs of it was published a few years since by Dr. Mitchill. Til lately it has been found chiefly in West Stockbridge and Lanesborough. It is now found in New Ashford in a quarry extensively wrought. I have procured three fine specimens of it, in slabs from five to six feet in length, and seven inches in width. Its flexibility and elasticity may be shown as it stands upon one end, by applying a moderate force to the middle of the other end. Its flexibility is seen too by supporting the ends of it in a horizontal position upon blocks.

"This marble has various colours---nearly white, with a reddish tinge, gray, and dove-coloured. Some of it has a fine grain; other specimens are coarsely granular, and have a loose texture. It is not uncommon for one side of a large block to be flexible, while the other part is destitute of this property. It takes a good polish, and appears to be carbonate of lime, and not a magnesian carbonate." The flexibility of the Massachusetts marble is partially lost when it is dried. (R1)

Virginia. A letter published in Scientific American: "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. Holiday 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 along the minute crystals which compose the mineral, or it may be due to molecular motion alone; I cannot tell." (R2)

X2. Flexible sandstone or itacolumite. This is the most common type of flexible rock.

North Carolina. "A variety of sandstone with grains so loosely bound that a strip of it like those illustrated (not reproduced), 21 inches long, 1 1/2 inches wide, and about 1/4 inch thick, will bend without breaking into an arc whose curve is 3 inches out of a straight line, is a specimen that interests everyone, whether a mineralogist or not. 'Wigglestone, you will agree, is a good name for this 'flabby' or 'limber' geological formation, as you hold it loosely by one end and watch the other end wave back and forth in the air.

.....

"The reason for the flexibility of this sand-rock has been the subject of much conjecture and some investigation. It is nearly pure quartz, with an admixture of tiny mica plates. Some mineralogists have thought that the mica might cause flexibility by allowing the grains to move backward and forward with a gliding motion. But this does not seem to be the case. According to the position of the rock in the geologic column, it is of Cambrian age, and represents an ancient beach or delta deposit. But its grains have been much altered in shape since its deposition, due to the removal of silica from the outside of the quartz grains, and its deposition in new positions in the pore spaces between them. Dr. Clarence S. Ross, of the U.S. Geological Survey, who has made a microscopic investigation of thin sections of the flexible sandstone, reports that there seems to be a sort of ball-and-socket arrangement of the grains against the material surrounding them. Thus the movement might be likened to that of the knee or elbow." The sandstone mentioned occurs in western Stokes County, North Carolina. Material of even greater flexibility may be found in India. (R6)

Some general observations. "Itacolumite, alias flexible sandstone, is probably the only rock able to be bent noticeably. Thin slabs of this unique material can carefully be bent up to about 6 inches in either direction and will even sag under their own weight.

.....

"In recent years, itacolumite has been the source of discussion as to whether it is sedimentary or metamorphic in origin. A large portion of it is now thought to be quartzite, a metamorphic rock, other than sandstone, which is sedimentary.

"Generally, itacolumite consists of minute quartz crystals, with a sprinkling of chlorite, talc and mica. Some impurities are present, which do much to determine the color and strength of the rock. These minerals roughly interlock, much like gears, and turn against each other; thus, the elasticity." Itacolumite occurs throughout the southern Appalachians, in the Urals, and at a few spots in India. (R11) It is not easy to understand just how individual grains, which are usually considered to be rounded, can interlock like "gears" or "elbow joints". (WRC)

X3. Mountain leather. "One of the oddest of minerals is mountain leather (a variety of amphibole) which occurs on the joint faces of many limestones. It may occur as minutely thin sheets (mountain paper) and grade up into thick masses resembling a poor grade of asbestos. Sometimes the mineral is so flexible that it can be pulled off the rock in large, thin sheets. It is white, gray or brownish in color.

"It is when wet that the mineral shows its oddest character. Loose sheets are often found on the floor of a quarry which are so wet, crumpled, ragged and encrusted with sand as to lose all semblence to a mineral and appear to be old cardboard or discarded thin pieces of leather. Not until the sheet is washed, smoothed out and dried, does it begin to look like a mineral." (R5)

X4. Paper coal. The major deposits of this odd form of coal are found in Indiana and the Moscow Basin.

Indiana. "The term 'paper coal' has been used to describe a deposit, consisting chiefly of stem and twig cuticles of lepidodendralean affinity, occurring 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 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." (R7)

Russia. "The discovery of a cuticular coal in Indiana prompted the reinvestigation of the famous Russian paper coal. Since 1860, when Auerbach and Trautschold reported its existence, misconceptions have grown around the Russian Papierkohle.

"Although the Moscow Basin covers an area of more than 30,000 sq. km, the coal seams are discontinuous, lenticular deposits and thus do not underlie the entire area. Only one seam, a lignite coal, is mined extensively. This coal is composed chiefly of durain, is extremely high in ash, is relatively high in volatile matter, and contains pockets of cannel coal. Local concentrations of plant cuticles in the upper layers of this seam form the famous Hautkohle or Papierkohle. The writer found that only four exposures of such papery layers were cited---at Milenino, where Jeremejev discovered them in 1853, and at Ssatinka, Malovka, and Tovarkova. Although the thickness of the entire coal seam may reach 3.5 m, the reported thickness of the papery layers ranges from 1.2 to 8.0 cm." (R10)

X5. Flexible limestone. The only flexible limestone noted so far appears in an isolated rock, called the Marsdon Rock, near the entrance to the Tyne, in England. A letter to the editor of the English Mechanic described one experience with this sandy, magnesian limestone.

England. When some years since I resided in Newcastle-on-Tyne, I frequently randown 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 say, that 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 in 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." (R4)

References

R1. Dewey, C.; "Notice of the Flexible or Elastic Marble of Berkshire County," American Journal of Science, 1:9:241, 1825. (X1)

R2. Hay, George; "The Wonderful Curiosity ---The Flexible Marble of Wheeling, Va.," Scientific American, 26:148, 1872. (X1)

R3. "Flexible Sandstone," English Mechanic, 32:212, 1880. (X2)

R4. "Flexible Sandstone," English Mechanic, 40:319, 1884. (X5)

R5. "Mineral Oddities," Rocks and Minerals, 17:241, 1942. (X3)

R6. Hawkins, A.C.; "The Charmed Circle," Rocks and Minerals, 17:279, 1942. (X2)

R7. Neavel, Richard C., and Guennel, G.K.; "Occurrence of Paper Coal in Indiana," Geological Society of America, Bulletin, 69:1622, 1958. (X4)

R8. Guennel, G.K., and Neavel, Richard C.; "Paper Coal in Indiana," Science, 129:1671, 1959. (X4)

R9. Neavel, Richard C., and Guennel, G.K.; "Indiana Paper Coal: Composition and Deposition," Journal of Sedimentary Petrology, 30:241, 1960. (X4)

R10. Guennel, G.K.; "Re-Evaluation of the Russian Paper Coal," Geological Society of America, Bulletin, 71:1875, 1960. (X4)

R11. Hodges, Kip; "Itacolumite: The Flexible Rock," Rocks and Minerals, 47:419, 1972. (X2)

ESP3 Unusually Colored Rocks

Description. Rocks, including ice, possessing colors that cannot be readily accounted for by impurities, microscopic structure, or crystalline form. Note that most rocks and many minerals come in wide ranges of colors, most of which are easily attributable to impurities.

Data Evaluation. The data are skimpy here---just a few odd items picked up in the searches of general-science publications. Journals specializing in mineralogy and polar research (in the case of colored icebergs) probably have more to say about the phenomena mentioned below. Thus, this entry in the Catalog must be considered incomplete. Rating: 3.

Anomaly Evaluation. Colored icebergs and iridescent coal, the only examples interesting enough to include, pose no serious problems for science. As with other colored minerals, impurities and mineral structure will almost certainly provide answers to the color problems. Perhaps most puzzling, and hardly anomalous at that, is the complex, sharply defined structure of the bottle-green bergs' color patterns. Rating: 3.

Possible Explanations. As mentioned above; included foreign matter, mineral crystal struture, and surface films.

Similar and Related Phenomena. Glacier ice is often discolored by impurities, especially dust and rocky debris. High density glacial ice is often a beautiful blue. Iridescence is common in nature; viz., opals and butterfly wings.

Examples

X1. Colored icebergs. Generally icebergs are white due to trapped air bubbles, and some high-density glacial ice is normally blue. Bottle-green bergs, however, constitute a puzzle.

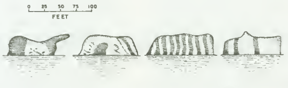
Antarctic waters. "Bergs of dark colour, called for convenience black and white bergs, have been observed with some frequency off the mouth of the Weddell Sea. When opportunity occurred for close examination it was found that these bergs are of two distinct varieties: one of them is the truly morainic berg, in which the dark portion is quite black and opaque and consists of mud and stones which are often clearly visible; while in the other variety the dark part proves on closer approach to be translucent and of a very deep green colour, resembling that of some kinds of glass used in bottle making, and mud and stones appear to be absent. We can speak then of black and white bergs falling into two subdivisions, the morainic and the bottle-green bergs. At a distance the two kinds resemble each other very closely, and it has been found that they have some features in common. In both of them as seen by us the dark part is always smoothly rounded by water action, and in both, with few exceptions, the junction between the white and dark parts is a perfectly straight clean-cut plane.

.....

"From the observations made it seems certain that black and white bergs are not all formed the same way. In the one examined in 1915 the evidence points to an origin from wind-borne detritus. We think therefore that minute specks of wind-borne dust might possibly account for the appearance of the unexplained bottle-green bergs, which on their dark portions sometimes have a faceted or even honeycombed surface. On this point however we feel that further speculation is idle until actual specimens have been collected." (R1)

The bottle-green bergs are all the more curious because of their complex banding, as observed from the R.R.S. JohnBiscoe.

"22nd March 1971. Between 1200 and 1915 GMT, while the vessel was 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;



Black-and-white icebergs observed in the Southern Ocean. (X1) 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° to the position in which they were originally formed and the layers of ice were therefore vertical or near vertical." (R3)

X2. Iridescent or Peacock coal. So-called Peacock coal is found in Pennsylvania and perhaps elsewhere, too. Usually it is an anthracite, but here a bituminous variety is described. The scene is a quarry near Ligoner, Pennsylvania.

"But behind the quarry now being worked there is an abandoned quarry. Wandering around the same recently the writer noticed some large lumps of weathered coal lying about. Tapping one idly he noticed that it was full of beautiful colors and very fragile. .... Further inspection showed that in the wall of the quarry there is a vein of this iridescent coal about one foot in thickness and several hundred feet long." (R2)

X3. The curiosities of sodalite. "In the year 1806 a mineralogist named Giesecke, passing near an outcrop among the bony hills of Greenland, collected a few samples of some lustrous, greasy-looking rocks which, when broken open, revealed a beautiful translucent pink interior. To his surprise, within a few hours the fractured pieces had turned green wherever the light had struck them. This was pink sodalite, the same remarkable mineral described by a later writer who, while collecting bright blue sodalite specimens among the hills of Rujputana, India, found others that were transparent and colorless. Kept in the dark for a fortnight, these assumed a pink color which quickly faded in bright daylight and almost instantaneously in sunlight.

"'The phenomenon is especially brilliant,' he said, 'when the rock is first broken in the field. The large blocks of elacolite (nephelite), some of which are over a yard wide, appear, on fracture, as suffused with blood.'

"This strangely pulsing color of pink sodalite gained it a reputation as one of the most temperamental of minerals. Ultraviolet's arrival brought discovery that sodalite from Bancroft, Ontario, where particularly fine specimens of pink sodalite were given the name of hackmanite, possesses still more remarkable properties. Long-wave UV produces an orange glow, and under exposure to short-wave UV for a minute or so, an amazing change can be seen in the daylight The specimen is splashed with broad patches and streaks of a rich raspberry-red hue quite unlike the original pink color, which is still visible on unexposed surfaces. Held close to a strong electric lamp, or exposed to daylight, the hackmanite rapidly loses its deep color. This entire process can be repeated again and again." (R12) See ESP15.

References.

R1. Wordie, J.M., and Kemp, Stanley; "Observations on Certain Antarctic Icebergs," Geographical Journal, 81:428, 1933. (X1)

R2. Lisle, T. Orchard; "Coal of Many Colors," Rocks and Minerals, 20:423, 1945. (X2)

R3. Cole, M.J.; "Black and White Icebergs," Marine Observer, 42:15, 1972. (X1)

R4. Gleason, Sterling; "Searching for New Keys to Fluorescence," Ultraviolet Guide to Minerals, San Gabriel, 1972, p. 230. (Cr. R. Calais) (X3)

ESP4 Noncrushing of Fossils in Sediment Compaction

Description. The lack of noticeable crushing of shells and other fragile fossils in carbonate sediment subjected to high compaction pressures.

Background. Geological dogma holds that limestones exhibiting uncrushed fossils were never compacted under high pressures. Unfortunately, this assumption leads to serious problems in explaining the cementation of uncompacted carbonate sediments, as detailed in X0 below.

Data Evaluation. Only a single experiment in sediment compaction has been found. Replication is thus desirable, especially in the light of the fact that the results seem contrary to common sense. Rating: 3.

Anomaly Evaluation. Superficial thinking suggests that fragile fossils should be severely damaged when sediments are highly compressed. Since this expectation has shaped the hypotheses of many sedimentologists, its experimental refutation represents a modest anomaly. Happily, if the experimental findings are confirmed, and the prevailing dogma is removed; this Catalog entry becomes academic and, further, the origin of some limestones becomes much easier to explain. Rating: 3.

Possible Explanations. None needed.

Similar and Related Phenomena. Deformed and shattered pebbles in strata (ESI12) prove that powerful stresses do occur in some strata, although not necessarily during the compaction process.

Examples

X0. Background. Before describing their experiment on sediment compaction, E. A. Shinn et al summarize the "limestone compaction enigma".

"In the supposed absence of compaction, cementation of fine-grained sediment has for years been the perplexing problem of limestone formation. The problem is nowhere better stated than by Bathurst in a chapter dealing with cementation:

'Two petrographic facts make the problem of the source of the $CaCO_3$ outstandingly difficult. The first is that limestones normally show scant evidence of compaction. Exceptions, such as part of the Chalk of northern Europe, seem to be rare. The second is the known high porosity of unconsolidated Recent carbonate sediments, ranging commonly from 40 to 70%. We must therefore infer: (1) that cementation begins early, before compaction, and (2) that about half the volume of $CaCO_3$ in many limestones has been carried into the sediment from outside. Redistribution of carbonate by dissolution of aragonite and reprecipitation of calcite is, by itself, inadequate to fill the pores: it is accompanied only by an 8% increase in volume of $CaCO_3$. Thus initial porosities of 60% and 40% in pure aragonite sediment would be reduced only to 56.8% and 36.4% if all the dissolved aragonite were reprecipitated locally as calcite. The problem before us is twofold. How were such large quantities of cement delivered, and from what equally great repository of $CaCO_3$ were they derived?'

"Bathurst's statement of the problem applies to lithified carbonate grainstones in which the initial porosity and the volume and type of porosity-reducing cements can generally be determined. But in carbonate mudstones the problems become even more difficult, because any cement would be extremely fine grained and virtually indistinguishable from the fine-grained matrix, plus the very low permeability presents almost insurmountable problems of carbonate-rich fluid transmission through very small interstices. The cement in ancient carbonate muds cannot be isolated and generally are simply assumed to be present.

"The purpose of this paper is to describe a simple experiment, the results of which indicate that dogma concerning compaction of some carbonate sediments---long perpetuated by carbonate sedimentologists (including ourselves)---is in error. We have long assumed that an apparent lack of fossil breakage in ancient micritic limestones is evidence against compaction." (R1)

X1. A compaction experiment.

"Abstract. Compression of an undisturbed carbonate sediment core under a pressure of 556 kg/cm^2 produced a 'rock' with sedimentary structures similar to typical ancient fine-grained limestones. Surprisingly, shells, foraminifera, and other fossils were not noticeably crushed, which indicates that absence of crushed fossils in ancient limestones can no longer be considered evidence that limestones do not compact." (R1, R2)

References

R1. Shinn, Eugene A., et al; "Limestone Compaction: An Enigma," Geology, 5:21, 1977. (X0, X1)

R2. Chanda, S.K., et al; "Limestone Compaction: An Enigma: Comment and Reply," Geology, 6:198, 1978. (X1)

ESP5 Some Rather Remarkable Polished Rocks

Description. Occurrences of highly polished rocks of great areal extent and/or of uncertain origin.

Background. Polished areas on rocks are common in regions thought to have been glaciated; so common, in fact, that rock polish is almost automatically taken as proof of ice action. In this connection, it should be realized that ice is softer than most rocks, so that polishing requires a glacier to carry along a very fine abrasive agent---something finer than sand or gravel. Motion of rocks along a fault plane also smooths and shines rock surfaces, producing the familiar "slickensides." Running water, too, and the wind can add polish to rock surfaces. This sort of polishing is generally omitted from the Catalog.

Data Evaluation. Polished rocks are hardly a popular research topic; and few articles have been found in the literature. Undoubtedly, geological surveys and works on other topics do mention them, but such allusions are rarely caught by our searching methods. In this sense, our data are woefully incomplete. Rating: 3.

Anomaly Evaluation. Unmysterious polishing mechanisms probably account for the examples of polished rocks described below, remarkable though they may be. Aside from curiosity value, the only profundity that intrudes is the fact that the presence of polished rocks does not necessarily mean that a region has been glaciated. Rating: 4.

Possible Explanations. Glacial polishing; water erosion; wind action; fault-plane motion; surface chemical reactions; animal scratching.

Similar and Related Phenomena. Pebbles facetted by the wind; glacial striae; slickensides.

Examples

X1. Rochester, New York. Although the Rochester polished limestone is in country covered by the postulated ice sheets, its great extent requires mention here. It is just possible that some other mechanism may have been at work.

"Only a partial notice has been given of this limestone, found in and about this city. The upper surface of the transition limestone through which the Genesee river here passes, is in many places found polished at various depths under the diluvial deposit and soil. A small surface of natural polish might pass unregarded; but a surface of many acres, and over a space miles in length and breadth, is no ordinary fact, and one not admitting of the most ready explanation. The fact has been merely mentioned in the geological reports of this State. Beginning three miles west of the Genesee in the town of Gates, the railroad is cut through the polished limestone for more than a hundred rods in width; the stone being covered with earth from two to eight feet deep. The polished layer is commonly at this place three or four inches thick, bituminous strongly, rather brittle, breaking into irregular fragments. The polish is often so fine as to show faintly, objects by reflection of the light. It would be a beautiful article for window sills, if it could be obtained readily of the proper dimensions, as it is already smoothed for this use. Half a mile north, the polished rock was struck in digging a well, and half a mile east of this in digging a cellar, and half a mile farther east in digging a well, and afforded beautiful specimens; this was seven feet below the surface. More than a mile farther east, about half a mile west of the Genesee, it was struck at the depot of the railroad, nineteen feet below the surface. Half a mile south of this, the Genesee valley canal is dug through this rock for thirty rods; the upper layer being a foot or more thick, and four or five feet underground. Though the polished surface ceases at each extremity, the rock continues at nearly the same level; it may be that the direction is oblique to the line of the canal. In another place, however, we are able to trace the edge of the polish, and can see no reason why the polished surface should not continue, unless it is a slight depression of the surface. The Erie canal is cut through this polished rock for many rods, near the Bethel church. These are the chief localities on the west side of the Genesee, till we ascend a mile and a half southwards to the rapids.

.....

"The surface of this polished rock is often marked with grooves, as if a rough and heavy body had moved over it and left deep traces. These are nearly parallel with each other, and on the west side of the river are found to lie nearly from N. E. to S. W. in the rock at the rapids." (R1)

From the style of writing and the mention of "diluvial" deposits, it is quickly realized that this article was prepared well over a century ago. In fact, it precedes the ascendancy of the glacial hypothesis in America. While the grooves and location of the deposit tempt one to blame glacial action for the polishing, there are three curious aspects: (1) the great horizontal extent of the polished surface; (2) the high quality of the polish (mirror-like!); and (3) the sharp demarcation of polished and unpolished areas sans any geological reason ascribable to ice-sheet action. In the following examples, we shall see polished, grooved rock surfaces in regions where glacier action was unlikely. (WRC)

X2. The Barvarian Alps. Polished rocks in glaciated areas are not always the work of glaciers.

"In relation to the erratic phenomena and their connexion with ancient glaciers, I propose to add a few remarks upon the polished and striated rocks, which have been considered, I think in some instances with too little hesitation, as general evidences of the presence of ancient glaciers.

"There can be no doubt whatever, that the glaciers have the faculty of extensively producing by their movement polished and striated rock-surfaces on their borders. These interesting phenomena can be traced sometimes at very great distances from the present glaciers. They are seen very well developed in the environs of the glaciers of Macugnaga and of Gorner, especially on the lower termination of Gorner glacier.

"But there are still many other agencies which can produce similar phenomena in a very deceptive way. I will not dwell on the polished and striated rocks produced by land-slips, so very common in the Alps; or on the striae resulting from a small amount of sliding of sedimentary strata one along the other, which I clearly observed in several quarries: but I will merely call the attention of the Society to the fact that the gneiss as well as the granite of the Alps very often shows a concentric exfoliation; and that all these concentric laminae, having very different dimensions and various degrees of curvature, offer on their surfaces a fine polish and fine parallel striae, which are not limited to the superficial surface, but are repeated on all the laminae in the interior of the rock." (R2)

X3. The Rodadero; Cuzco, Peru. A strange formation of polished rock near Inca ruins.

"The unusual feature of the Rodadero and the one which gives it its name (Spanish, rodada, a rut), is the remarkable series of polished grooves which ornament the entire surface of the irregular knob. An area exceeding an acre is occupied by grooves whose width varies from a few inches to four or five feet, and whose depth varies between a fraction of an inch and four feet. Smaller flutings and delicate striae traverse the troughs and crests of the larger depressions in a longtitudinal direction. Microscopic abrasion lines have smoothed and polished the channels and ridges to such a degree that one may slide down the inclines without damage to clothing---an amusement indulged in by natives and tourists alike; and, if tradition is to be accepted, by the Inca rulers themselves. The larger and smaller grooves are continuous and parallel for 100 to 300 feet, and at one locality thirty-two parallel channels with a combined width of fifty feet were traced for a distance of 180 feet."

The Rodadero stands at an altitude of 11,700 feet; there are no signs of glaciation at this elevation. Furthermore, when slabs of the Rodadero are pried apart, they are found to be striated on both top and bottom. The author attributes the polish and striae to faulting; i. e., the polish is slickensides. (R3)

X4. Texas and New Mexico. Peculiar polish-areas on granitic porphyries.

"Recently, while engaged in making geological observations in the Hueco and Cornudas Mountains of western Texas and New Mexico, I became aware of the repeated occurrence of large highly polished patches of rock which had escaped my notice before this. The Huecos and Cornudas, like other granitic intrusive masses, upon weathering have developed large open fractures, niches and even sizable caves, many of which have openings at the level of the ground. There was observed at the entrance to one of these small crevice caves a highly polished rock surface on the hanging-wall side. The footwall, however, showed the same rough weathered appearance as the inner and outer surface about the polished area. Subsequently it was found that at practically all other slanting cavernous openings, the polished surface, if present, appeared on the hanging-wall side. I do not recall having seen polished surfaces upon rocks which were high above the ground surface or upon the tops of rocks.

"Later I was surprised to see the same type of polished surface on the sides of large outlying boulders, some fifteen to twenty feet in diameter, which had broken loose from the high cliffs and had tumbled out onto the surrounding apron of detrital wash. My recollection is that most of these polished areas are on the south side of the boulders and near their edges or corners. It was noted that all the patches are similar in size and position. They begin at a point about two feet off the ground, often extending to a height of seven to nine feet and seldom cover a space more than five to ten feet wide, whether at the entrance to openings or on isolated boulders." The author ventured that these polished areas might have been the rubbing posts of prehistoric animals! (R4) Further study reinforced his belief. (R5)

The same area was visited by C. Grant, who saw things a bit differently. First, he found no boulders broken loose from the high cliffs. Second, he found one polished area that extended right down to the ground. Lastly, he located a polished area on the underside of a ledge with polishing that "could have been done only by the back-scratching of an animal the size of a pig." Since the polished areas seemed correlated with the course of an ancient river, Grant suggested that water scoured the polished areas in times past. (R6)

Actually, none of the proposed polishing mechanisms seem satisfactory. (WRC)

References

R1. Dewey, Chester; "On the Polished Limestone of Rochester," American Journal of Science, 1:37:240, 1839. (X1)
R2. Schlaginweit, Adolphe; "On the Geological Structure of Part of the Barvarian Alps," Geological Society of London, Quarterly Journal, 10:356, 1854. (X2)
R3. Gregory, Herbert E.; "The Rodadero (Cuzco, Peru), ---A Fault Plane of Unusal Aspect," American Journal of Science, 4:37:289, 1914. (X3)
R4. Lang, Walter B.; "Polished Areas on Granitic Porphyries of the Hueco and Cornudas Mountains of Texas and New Mexico, Science, 94:390, 1941. (X4)
R5. Lang, Walter B.; "The Polished Rocks of Cornudas Mountain, New Mexico," Science, 105:65, 1947. (X4)
R6. Grant, Chapman; "The 'Polished Rocks' of Cornudas Mountain, New Mexico," Science, 107:191, 1948. (X4)

ESP6 Puzzling Features of Sonorous or "Ringing" Rocks

Description. Properties of ringing rocks that seem to be incompatible with physical theory, such as: (1) some rocks ring while seemingly identical rocks nearby do not; (2) fragments of some ringing rocks emit the same frequency as the parent rock; (3) some ringing rocks emit different frequencies depending upon where they are struck; and (4) different sizes of rocks produce the same frequencies.

Background. Since such elastic materials as glass and metal can be made into bells and other shapes that ring, it is really not surprising to discover that some rocks, which are also elastic, can be made to ring, too. Perhaps the most surprising thing about ringing rocks is the apparent lack of relationship between the frequency emitted and rock size and shape; the size of a metal bell certainly affects its tone, but not so with ringing rocks. The ringing rocks are also remarkable in the purity and loudness of their emissions, even when the rocks are ponderous and badly shaped.

Data Evaluation. Casual accounts of ringing rocks and rock gongs are rather common; but scientific analysis of this phenomenon are essentially nonexistent. In fact, some of the anomalous aspects claimed above for ringing rocks may not be verified in a careful scientific study. Rating: 3.

Anomaly Evaluation. That rocks ring is not really anomalous, as pointed out above. What *is* mildly anomalous is the observation that size and shape seem to have little effect on the frequencies heard by observers. We are also not certain why some rocks ring and others just as likely do not. Fascinating though ringing rocks may be, their anomalies will probably disappear under thorough scrutiny. Rating: 3.

Possible Explanations. None offered.

Similar and Related Phenomena. Musical sand (ESP14); other natural musical sounds (GSM).

Examples

X1. French chalk deposits---flints. "Among the flint stones that are met with in the chalk formation there are some that when struck with another flint emit sounds of great purity. The tones that are thus obtained with different musical flints are out of all proportion to the bulk and weight of the stone. This is a very curious phenomenon, the explanation of which is not furnished by the fundamental laws of acoustics, and which surely merits being studied by physicists.

"As long ago as 1873, I spoke of musical stones as a curiosity worthy of attracting attention. I then promised to return to this interesting subject, but the years passed by, and the singing stones were forgotten. Upon recently visiting the new electric lighting of the Grevin Museum, however, they were casually brought to mind again. After examining this interesting installation, I was walking through the great hall of the museum, looking at the wax figures mounted therein, when I heard some delightful music that attracted my attention. Approaching the spot where these harmonious and pure sounds were being produced, I saw a musician, who, holding two flints, was playing upon a stone piano with wonderful agility, by striking other flints of all shapes suspended by two wires at a few fractions of an inch above a sounding board. I at once made the acquaintance of the player, who was Mr. H. Baudre, a distinguished musician, and a zealous collector of musical stones.

"'How do you procure these flints that render so delightful sounds, and from which you get so remarkable music?' said I.

"'Ah, sir, it required much time and many trips to collect the 26 stones which you see before you, and which form two chromatic octaves. It took me more than thirty years (from 1852 to 1883), to search for them in the chalk beds of Haute-Marne, Perigord, Eure, and the Paris basin.'

"'Are such flints found in all chalk formations?' 'I believe not; the innumerable quantities of English flint have yielded nothing acceptable.' 'Are there any works that treat of this interesting subject of singing stones?' 'I do not know; but I have letters from numerous scientists, who have been pleased to congratulate me, or to give me their opinion.'" (R2) The contents of some of these letters are mentioned in X2 and X11. Some English flints found in the chalk *are* musical. See X7.

X2. Ethiopia---flint chimes. "Mr. Cartailhac, director of the Toulouse Museum, reports that three musical flints were once noticed by a missionary in the village of Chaffa, in the center of the plain of Thumazana, Abyssinia. These stones were hung by threads from a horizontal wooden rod, and were used for calling the faithful to prayers or to battle. They were struck with another flint, and their sounds, which were very intense, were heard from some distance." (R2) B. Fagg, writing in an archeological journal, infers that suspended rock chimes are frequent in Ethiopian Christian churches. (R16)

X3. England---"mountain limestone". "When roaming over the hills and rocks in the neighbourhood of Kendal, which are composed chiefly of mountain limestone, I have often found what we call here 'musical stones.' They are generally thin flat weather-beaten stones, of different sizes and peculiar shapes, which when struck with a piece of iron or another stone, produce a distinct musical tone, instead of the dull heavy leaden sound of any ordinary stone. The sound of these stones is, in general, very much alike, but I know of gentlemen who possess sets of eight stones which are said to produce, when struck, a distinct octave." (R1)

X4. France---amphibole. "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 recognize 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.

.....

"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 soft wood. The sound, as far as a hurried examination allowed us to judge, corresponds to mi. 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, when 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 other two 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 their 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 two kinds of rock." (R3; R4, R11)

X5. Pennsylvania and New Jersey---diabase. Boulder fields are rather common in Pennsylvania and adjacent states. They are, in fact, so interesting that a separate category has been assigned to them (ESM5). Here, however, we focus on the few rocks, in a few out of the many boulder fields, that ring when struck. These are the so-called "ringing rocks" mentioned in the Fortean literature. They have been recognized for many years, as the first quotation demonstrates:

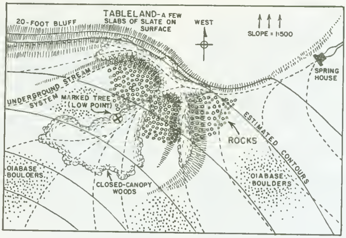
"'Ringing Rocks Park' is a wild and beautiful place about three miles north of Pottstown (Pennsylvania). The Ringing Rocks, a great natural curiosity, are a great mass of weather-beaten gray rocks, heaped together in wild confusion, and covering two acres of ground. Scientists are not wholly agreed as to their origin, but they state that it is certain they are related to some vast volcanic disturbances which agitated the earth hundreds of thousands of years ago. The rocks which give forth the best and clearest sound are found near the middle of the great mass, and when struck with a hammer or any other metallic substance give a distinct musical note. All the notes of several musical octaves may be produced from these stones. There is a group of selected stones behind the pavilion so arranged that they form an octave. Any musician can play airs upon them by means of a hammer. The Rocks are in a very picturesque location, being surrounded by a grove of fine trees. I inclose the best photograph (not reproduced) of the Rocks that I can procure. In addition to this large group of which I send the photograph, there is in the East Park a very interesting smaller group called 'Little Ringers.' They possess the same musical qualities as the larger group, though not in such a marked degree. There are also in the East Park Haystack Rock, Bullfrog Rock, and many other geological curiosities scattered here and there amid fragrant cedar trees." (R5)

In the late 1960s, J. Gibbons and S. Schlossman organized an investigation of the famous Ringing Rocks. First, their description of the rocks: "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."

Gibbons and Schlossman examined some of the ringing rocks in the laboratory and concluded that those that rang were different because they possessed internal stresses. Chemical weathering was changing pyroxene into montmorillonite and producing a volume change in consequence. Internal tensions raised the resonant frequency of the rocks to the ringing frequencies heard by people down the centuries. Rocks that did not ring had weathered sufficiently to relieve the internal strains. (R13) The forgoing theory does not seem to explain the many other types of rocks in other parts of the world, some of which ring when close associates do not. (WRC)

The Gibbons-Schlossman theory was attacked in the pages of Pursuit. The unidentified author (probably I. T. Sanderson) pointed out several errors in the Gibbons-Schlossman account: "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



Upper Black Eddy rock field in Pennsylvania. Contour lines are 10 feet apart and descending from the west. (X5)

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 these 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 given 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." (R14)

X6. Ch'ufu, China---limestone. A. Tingle has described and photographed sounding stones in temples and other spots around Ch'ufu. Here is his account of one found in the great Confucian temple: "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." (R6)

X7. English chalk---flints. "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." (R7)

X8. Wolf Rock, England---phonolite. The phonolite deposit nine miles south of Land's End has musical properties. (R7) Phonolite is a volcanic rock composed largely of alkali feldspar, feldspathoids, and mafic minerals. Its name apparently has nothing to do with its sonorous properties. (WRC)

X9. Portland, England---limestone. Workmen quarrying this limestone judge its quality upon the clearness of its metallic ring. (R7)

X10. African east coast---limestone. "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." (R8)

X11. Nigeria---granite. Rock gongs or "pierres sonnantes" are widely employed in rituals in Nigeria. The two reports we have found on this subject are little concerned with the geology involved, stating merely that the stones used are found in the boulder debris of a granite outcropping. (R10, R12)

X12. Cougnac, France---stalactites. A large variety of musical notes may be obtained by tapping stalactites with pebbles. At the cave of Cougnac, there exists evidence that ancient man used stalactites for ritual purposes. (R11) Actually, "musical" stalactites are not uncommon. (WRC)

X13. Carnac, France. Some of the horizontal rock slabs among the megalithic remains have a bell-like sound when struck. (R11)

X14. Wales. Rock gongs of unspecified composition have been found in Wales. They were located at the foot of the Prescelly Mountains at Maenclochog ("ringing rocks"). (R11)

X15. Amusing cases of "naturally rung" ringing rocks. Items X1-X14 deal with stones and rocks that ring when struck by the hand of man. Sometimes, though, nature rings her stones for us!

"Singing stones of a third category are found in various parts of the world. Fraas, journeying from the Red Sea to the Nile, saw a round, thin fragment an inch in diameter, resembling a shell, split off, with a peculiar sound, from a flint which lay baking in the hot sun at his feet. This observation is very remarkable and perhaps unique, for flints split gradually as a rule, but the violent and noisy rupture of the last bond under the influence of the sun's rays and in the presence of an observer does not seem impossible. Broken flints are common in the desert. Many persons have heard the noise caused by similar fractures of hard rocks and have seen the fragments roll down mountain slopes. Behm writes of the basalt columns of the Bamangwato hills, in South Africa: 'In the evening, after a hot day, it was not unusual to hear the basalt crack and fall with a peculiar ringing sound, from which the natives inferred that the rock contained much iron.'.... Jollois, Devilliers, and the younger Champollion often heard ringing, cracking sounds issuing from the huge granite blocks of the great temple at Karnak. Similar sounds have been heard in the temple at Philae and in the granite quarries at Assuan." (R9) Loud explosive or cracking sounds are often heard in mines, but of course these are not musical in any sense. (WRC)

X16. General observations. G. Tissandier remarked on two difficulties in explaining ringing rocks in his 1885 paper: (1) some ringing rocks emit different frequencies when struck in different spots; and (2) there is little correlation between the frequency of sound emitted and the size of the rock. Small rocks may emit the same notes as much larger ones. The upshot is that rocks arranged to emit the notes of the scale show no progressive change in size. (R2)

X17. Montana---mafic monzonite. "The Ringing Rocks stock, at the south end of Dry Mountain in secs. 4 and 9, T. 2 N., R. 5 W., is roughly circular and is about half a mile in diameter. Pink medium-grained quartz monzonite, which makes up the center of the stock, is partly enclosed in a crescent-shaped body of coarse-grained mafic monzonite. At the south end of the stock the mafic monzonite has weathered to a heap of irregular rusty-brown extremely tough blocks 3-12 feet across that have vibrant bell-like sounds when struck; hence their local name, Ringing Rocks." (R16)

References

R1. Nelson, Richard J.; "Musical Stones," Nature, 8:46, 1873. (X3)
R2. Tissandier, G.; "Baudre's Silex Piano," Scientific American, 53:55, 1885. (X1, X2, X16)
R3. "The Sounding Rocks of Guildo," English Mechanic, 49:191, 1889. (X4)
R4. "The Sounding Rocks of Guildo," Scientific American Supplement, 27:11076, 1889. (X4)
R5. Jewell, Helen Stetson; "The Musical and 'Ringing Rocks'," St. Nicholas, 29:1039, 1902. (X5)
R6. Tingle, Alfred; "Sounding Stones at Ch'ufu, Shantung," Nature, 73:222, 1906. (X6)
R7. Carus-Wilson, Cecil; "Sounding Stones," Nature, 73:246, 1906. (X7-X9)
R8. Crossland, Cyril; "Sounding Stones," Nature, 73:297, 1906. (X10)
R9. Rosenfeld, Georg; "Singing and Speaking Stones," Scientific American Supplement, 66:395, 1908.
R10. Ettlinger, E.; "Rock Gongs," Man, 56:75, 1956. (X11)
R11. Fagg, Bernard; "Rock Gongs and Rock Slides," Man, 57:30, 1957. (X2, X4, X12-X14)
R12. Conant, Francis P.; "Rocks that Ring: Their Ritual Setting in Northern Nigeria," New York Academy of Sciences, Transactions, 2:23:155, 1960. (X11)
R13. Gibbons, John, and Schlossman, Steven; "Rock Music," Natural History, 79:36, December 1970. (X5)
R14. "Why the Rocks Ring," Pursuit, 4:38, April 1971. (X5)
R15. Fagg, Bernard; "The Discovery of Multiple Rock Gongs in Nigeria," Man, 56:17, 1956. (X11)
R16. Prostka, Harold J.; "Igneous Geology of the Dry Mountain Quadrangle Jefferson County, Montana," U.S. Geological Survey Bulletin 1221-F, 1966. (X17)

ESP7 Small-Scale Magnetic Anomalies

Description. Unusual, erratic, or inexplicable magnetization of rocks or strata on a local basis. Included here are field observations of self-reversal, coexisting normal and reversed remanent magnetization (NRM), and sundry magnetic oddities. Paleomagnetism, in general, as a large-scale phenomenon is treated in category EZ in another volume.

Data Evaluation. The data vary in quality from inferences (X1) and amateur experiments (X2) to professional observations with modern instruments. A composite rating: 2.

Anomaly Evaluation. Many of the phenomena described below indicate variability and an erratic nature for some paleomagnetic phenomena. These anomalies and curiosities are usually thought to be of a minor nature and not influencing the great mass of self-consistent paleomagnetic studies. However, we rate potential impact here; and the whole of paleomagnetism would be adversely affected if, say, the effects of self-reversal are seriously underestimated. Rating: 1.

Possible Explanations. Lightning strikes probably account for some erratically magnetized rocks and strata. Magnetic self-reversal is a well-known physical phenomenon and certainly occurs in nature as well as the lab. We don't know for certain how important it really is in paleomagnetic surveys.

Similar and Related Phenomena. The phenomena below are obviously related to the popular discipline of paleomagnetism (EZ), especially as employed in supporting the hypothesis of continental drift (plate tectonics). Also related are the fossils of magnetic bacteria (B), which may contribute substantially to the magnetism of deep-sea sediments.

Examples

X1. Magnetic boreholes. "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 magnetized 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 borehole. 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 the 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 carelessly been 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 borehole, as well as the magnetized 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." (R1) It would be very interesting to learn the magnetic state of the rocks penetrated by this borehole. (WRC)

X2. Magnetite deposit anomalies. "About 10 miles north of Peekskill, N.Y., is a group of abandoned magnetite mines known as the Sunk Mines. One of these, the Canada Mine, consists of a series of pits sunk in the vein that parallels the adjacent Seven Mile Road. At one point in this mine (in what is now Fahnstock Park) the remnants of the vein outcropping consists of massive lodestone but not of strong quality. When hammered, the lodestone powders up and attaches itself to the hammer as small bunches of fuzzy magnetic strings. The hammer soon becomes magnetized so that it can later pick up tacks, small nails, etc.

"Even though the outcropping lodestone was weak, the deposit was of considerable interest as it represented the first occurrence actually found in place by the writer. The strike of this particular vein is approximately east and west and its dip is about

50^o south. The occurrence allowed the writer to settle the question---how does its north-seeking pole lie in reference to the magnetic north?

"If this was to be determined, the lodestone had to be marked and taken out carefully so that its position when in the ground could always be determined later. At least 12 specimens from various parts of the vein were chosen and before extracting an arrow pointing north was marked on each. However, the lodestone crumbled so easily that only five samples could be used as representative.

"These five samples were later carefully suspended by fine thread and allowed to come to rest (suspended all night). The specimens were hanging in a room where no iron, etc., was present to act upon them and they were suspended at some distance apart from each other and each about an inch above a table on which was fastened a sheet of paper bearing an arrow pointing north (Magnetic North). But not even in one instance did an arrow marked on a specimen coincide with the arrow on the paper underneath! Two arrows on specimens pointed due south; one southeast; another southwest; and the last, due west.

"Something was radically wrong! Why didn't they point north? Tests were then made on a compass and again results were unsatisfactory. The arrow-pointed ends of each lodestone not only attracted the north-seeking pole of the compass but the south as well---yet parts of the lodestone would repel the needle. Some point on the lodestone had to be the north-seeking pole but where was it? It was finally found but it was not a point. The entire surface that had been exposed to the air in the vein formed the north-seeking pole while its opposite face which had been embedded in the rock formed the south-seeking pole! This is all the more remarkable when the fact is brought out that though the samples were rather thin slabs, 3 or 4 inches long and about 1/2 inch thick, the faces of each slab formed the poles." (R2) See Catalog entry AYE7-X1 for the Bondoc meteorite, which possessed more than 90 each positive and negative (N and S) poles. (WRC)

X3. Coexistence of normal and reverse natural remanent magnetization.

Japan. "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. It was once understood that the NRM was due to a reversed geomagnetic field at the time the lava 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." (R3)

Switzerland. "Abstract. Stable remanent magnetization in a granite-aplite dyke from the Bergell massif (Switzerland) forms stripes of normal and reversed polarity. Phenomenonological evidence suggests that the different polarities are caused by self-reversal of ilmenohematite, the carrier of stable remanence." (R7)

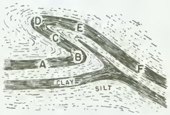
X4. Erratic magnetization.

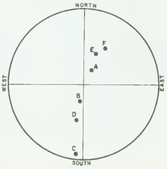
Oklahoma. "Summary. The 1320 My Spavinaw granite from north-eastern Oklahoma is strongly magnetized, averaging about 10^{-2} emu cm^{-3}. The NRM directions are randomly oriented: steep and shallow, positive and negative inclinations are equally represented. Although very fine grained titanomagnetite and haematite are primary Fe-Ti oxides, demagnetization generally produces no change from the initial NRM directions whether up to 660^oC or in 1400 Oe peak A.F. This tends to rule out large amounts of secondary magnetization and self-reversal, particularly as there are no apparent compositional variations throughout the granite. We discount lightning because the same magnetic features are shown by samples from all surface exposures, as well as by subsurface samples from deep wells." A few possible explanations: multiple reversals of the Precambrian field during cooling; motion in the crystal mush below 600^oC; the acquisition of stable viscous components. (R4)

Arizona. "Abstract. Anomalous remanent magnetization of sandstone attributed to lightning 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 and in a dike by Graham.

"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... 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." (R5)

Massachusetts. Samples taken from a folded varve in a lake near Chicopee, Massachusetts, showed that remagnetization of the folded material did not occur after deformation and that the original remanence was locked in. (see illustration) In view of this, the paleomagnetic signature from a deformed zone can be misinterpreted as evidence for globally coherent fluctuations in the earth's magnetic field. (R6)





Wyoming. "Abstract. A paleomagnetic investigation of in-situ and exploration drill core samples of the Wilkins Peak Member of the Eocene Green River Formation in the Green River Basin of Wyoming yielded poor and unreliable paleomagnetic results." In reviewing previous measurements in the same area, the authors state, "Both studies also report seemingly anomalous Eocene paleomagnetic directions. Strangway and McMahon report a mean field direction 90° west of the expected direction. Richardson and Noltimier show nine very thin reversed zones in a section of normal polarity that represents about 5 x 10^5 years or more; this zoning is peculiar with respect to the Eocene geomagnetic polarity time scale of Ness et al." (R10) See X3 for other examples of coexisting normal and reversed magnetizations.

Hawaii. "Abstract. A study designed to examine the basic theory of thermoremanent magnetization acquisition parallel to the earth's ambient magnetic field upon cooling and to evaluate intra-flow variations of very young basalt flows has yielded some startling initial results. Two extensively sampled flows, the 1950 flow of Mauna Loa and the 1972 flow from Mauna Ulu, Kilauea, have been found to have paleomagnetic directions statistically different from the present geomagnetic field direction (PFD) in Hawaii. The 1950 flow shows very consistent, but shallow directions throughout the flow, with a mean inclination 6° shallower than the PFD. Directions from the 1972 flow vary from site to site both along the length of the unit and within vertical sections. Relative between site consistency is low, with all sites but one having paleomagnetic directions distinct from the PFD, however, the mean inclination for this flow, 33.4°, is only about 3° shallower than expected. The source of such anomalous behavior in the recording of ambient field directions is yet unknown, although several possible causes are examined." (R12; R13)

X5. Self reversal. Below, we present just two recorded instances of self-reversal in specific instances.

France. The Olby lava flow (Auvergne, France) displays complete self-reversal during thermal demagnetization. Some samples show partial self-reversal of NRM at room temperature. (R8)

Columbia. Excerpt from the Abstract. "Andesitic pumice, which was hurled several kilometres during the disastrous 1985 eruption of the Nevado del Ruiz volcano (Columbia), carries a stable but reversed NRM with southerly declination and negative inclination. Heating experiments show that this magnetisation is due to a self-reversal mechanism which also induces a reversed thermoremanent magnetization (TRM) in the laboratory field." (R9)

General observations. The two examples above and, indeed, most other examples of self reversal in nature involve lavas. Self reversal in lava seems to be due primarily to titanohematites. The problem is that no one knows how widespread the titanohematites are, especially those from eroded lavas now residing in sedimenary deposits. Hopefully, the quantity of titanohematites is small so that paleomagnetism is not compromised. (R11) See Category EZ, in a future volume. for paleomagnetic anomalies.

References

R1. Millar, Albert; "Magnetic Boreholes," Nature, 113:14, 1924. (X1)
R2. Zodac, Peter; "A Secret of the Lodestone Exposed," Rocks and Minerals, 17:286, 1942. (X2)
R3. Domen, Haruo; "On the Unstable Natural Remanent Magnetization of Rocks as a Paleomagnetic 'Fossil'," Eos, 50:130, 1969. (X3)
R4. Spall, Henry, and Noltimier, H. C.; "Some Curious Magnetic Results from a Precambrian Granite," Geophysical Journal, 28:237, 1972. (X4)
R5. Purucker, Michael; "Magnetic Record of Lightning Strikes in Sandstone," Eos, 55:1112, 1974. (X4)
R6. Verosub, Kenneth L.; "Paleomagnetic Excursions as Magnetostratigraphic Horizons: A Cautionary Tale," Science, 190: 48, 1975. (X4)
R7. Heller, F., and Egloff, R.; "Self-Reversal of Magnetization in a Granite-Aplite Dyke," Eos, 56:237, 1975. (X3)
R8. Heller, Friedrich; "Self-Reversal of Natural Remanent Magnetisation in the Olby-Laschamp Lavas," Nature, 284: 334, 1980. (X5)
R9. Heller, Friedrich, et al; "Reversed Magnetization in Pyroclastics from the 1985 Eruption of Nevado del Ruiz, Colombia," Nature, 324:241, 1986. (X5)
R10. Sheriff, Steven D., and Shive, Peter N.; "Unreliable Paleomagnetic Results from the Wilkins Peak Member of the Eocene Green River Formation, Wyoming," Geophysical Research Letters, 9:723, 1982. (X4)
R11. Weisburd, Stefi; "Self-Reversing Minerals Make a Comeback," Science News, 127:234, 1985. (X5)
R12. Castro, Joyce, and Brown, Laurie; "Shallow Paleomagnetic Directions from Historic Lava Flows, Hawaii," Geophysical Research Letters, 14:1203, 1987. (X4)
R13. "Last Time I Looked, North Was That Way," Science News, 133:41, 1988. (X4)

ESP8 Frazil Ice, Anchor Ice, Ground Ice

Description. Ice that forms on the beds of streams and underwater obstructions rather than on the surface. Such ice often rises to the surface, accumulates, and poses hazards for water intakes and bridge supports.

Background. Two centuries ago, scientists were most perplexed by the easily observed fact that ice sometimes forms on the beds of streams, when it should, by virtue of its density, form on the surface of the water. Two theories were advanced many years ago: (1) Anchor ice is simply frazil ice (ice platelets formed in slightly supercooled water) that aggregates on stones and other obstructions in river beds; and (2) Anchor ice forms because radiation cooling makes the stream bed colder that the surface water. The dispute seems to revolve around the question of whether frazil ice and anchor ice are one and the same.

Data Evaluation. Most of the reports amassed so far are anecdotal in nature and, also, somewhat ancient! Only a few recent scientific investigations have been found, although these are of good quality. Rating: 2.

Anomaly Evaluation. The radiation-cooling hypothesis seems definitely to have been disposed of, but there remains the question of whether anchor ice is an aggregation of frazil ice or whether it forms directly on the bottom (see X5 and X6). Even though technically interesting, the anchor-ice phenomenon does not constitute a serious anomaly. Rating: 3.

Possible Explanations. See above.

Similar and Related Phenomena. Ice caves (ESP18); the sudden disappearance of ice from lakes (GHC8).

Examples

X1. Observations of ground or anchor ice in the St. Lawrence. The engineering problems posed by anchor ice and an interesting anecdote.

"In this paper the author described the two principal modes of growth of ice, in still water and in running water. In still or slowly moving water the ice forms itself as a crust on the surface, because, as the water cools from about 40°F. down to the freezing point, it expands, and therefore becomes lighter, and remains floating at the surface, and then, on freezing there, it expands still further, and therefore still more tends to float. In rapidly-moving river water, on the contrary, and especially at the foot of rapids, ice is often found to grow attaching itself to the rocks or stones forming the bed of the river, as a spongy or porous mass, which, seen in the aggregate and not examined minutely, presents a general appearance not unlike the spawn of frogs. In large rivers in cold climates, as, for instance, in the St. Lawrence, immense quantities of this ice, called ground or anchor ice, are found to accumulate with astonishing rapidity. These accumulations of ice, by damming up the water, cause great floods, and by yielding to the force of the water, and moving down with the current, especially after they have become jammed and heaped up with other ice formed on the surface, act in producing very striking geological effects in disturbing the bottom and banks of the river, and in shoving along huge boulders which otherwise would remain immovable. The ground- and surface-ice, also, by their shoving action, introduce formidable difficulties and dangers in the construction of bridges or other engineering works requiring to be founded on the beds of rivers in cold climates." The author goes on to detail problems associated with the building of the Great Victoria Bridge at Montreal. (R3)

The anecdote. "On the 17th of January, this year (1884), I had occasion to cross the River St. Lawrence in one of the small Indian ferry-boats which ply between the Indian village of Caughnawaga, on the south shore, and Lachine, on the Island of Montreal. The current of the river at this point flows at the rate of four or five miles an hour, I think, and never freezes over. The day was quite stormy, the thermometer indicated about 12° or 15° F.; and the river was pretty thickly covered with cakes and masses of porous or very snowy ice. But the most peculiar phenomenon was the sudden and almost incessant rising of dark, muddy ice from the bottom of the river. The formation of this ice so far below the surface of the water is supposed to take place in very cold weather, when large masses of snow, descending the river, become saturated with water, and are carried by the current to the bottom, where they stick to the rocks and stones, clinging more firmly and becoming more compact as long as cold weather continues. At least, this is the theory that the Indians advanced. The ice may be seen six or eight feet under water, and often accumulates until it forms miniature islands. When it rises, it often lifts considerable quantities of small stones and gravel to the surface.

"Another peculiar circumstance is, that this rising of the ice from the bed of the river always occurs a day or two before the approach of mild weather; and the Indians regard this phenomenon as an infallible presage of milder weather within forty-eight hours." (R6) The origin of anchor ice suggested above is not considered correct by scientists today. (WRC)

X2. Stones clinging to the underside of ice along the Susquehanna. "When the severe cold weather came upon us so suddenly in November last, my attention was called to a curious phenomenon in the Susquehanna River here. Upon Thanksgiving Day, not far below the dam which crosses the river here, I noticed a large number of stones clinging to the under side of the ice. The river there was two or three feet deep, the ice at that time was about three inches thick. The stones were the rounded river stones, and evidently came from the bottom of the river. They were of all sizes, up to those weighing probably two pounds." It is noted later in the report that stones of up to eight pounds have been observed clinging to ice in the Thames. (R5)

X3. Anchor ice formed in deep, calm water. A letter to Scientific American in 1852. Your correspondent's remarks about anchor ice being found only in swift shallow places of water, is clearly a mistake, as I should be able to show him if he were at this place; it is quite common, in drawing my fish in the morning, after their being sunk in twenty feet of water, and that too where it does not move at the rate of half a mile an hour, to find them almost a solid mass of anchor or bed ice, and sometimes other fish are found encrusted and fastened in the mass, which leads me to the conclusion that it forms in almost any depth of water and at a very rapid rate, the cause of which, to my mind, has never been satisfactorily explained. The rising or rather the letting go of the bottom, is equally rapid; I have known it to be a foot thick all over the bed of the river, or as far as we could ascertain, and from some cause yet unknown, would entirely disappear in less than an hour." (R1) The sudden disappearance of anchor ice resembles the equally remarkable disappearance of ice from lakes in the spring. See GHC8 in another volume of the Catalog. (WRC)

X4. Direct observation of anchor ice formation. "The streams best suited for exhibiting the phenomenon of ground ice are those which drain open exposed tracts of country with few trees or tile-drains. From 10 to 12 miles north of Liverpool, at Altcar, there is a flat country of this character; the land is drained by a series of open slow-running ditches; a portion of the water of these ditches is carried by a stream, locally known by the name of the Brook, into the river Alt. The velocity of the water varies from 2 to 3 miles per hour, depth 2 feet. On the 11th and 12th of February 1853, the district was visited by a severe frost, temperature 21°, with a sharp wind; on the morning of the 13th I examined the locality, when I found the bed abundantly covered with ground ice. The temperature of the water was 31°.9, air 35°. The ice consisted of small thin plates interwoven with one another in every possible manner; where the water was not more than 2 feet deep, and the current ran at 2 1/2 miles an hour, the ice spread over the bed of the stream to a depth of from 2 to 4 inches. At the edges on the surface there was not much ice; in thickness it was about 3/4 of an inch at the edge, and thinning off quickly to a shell edge within 1 foot from the side of the bank. On the ditches in the neighbourhood the ice was about 1 inch thick, which at once broke when an attempt was made to stand upon it. In the forenoon of the 13th, the sun shone with considerable power; this had the effect of producing a sufficient increment of temperature to detach the ice from the bed of the stream, and when I left the Broon the ground ice had begun to rise rapidly. I have observed that changes of this kind are very sudden; in half an hour a large portion of the ground ice will often disappear; it rises to the surface and floats away with the current." (R2)

Another observation. May 1888, at Karzok, altitude 15,000 feet. "The night had been a cold one, and in the morning, while the ground was still hard with frost, I noticed that the water in the irrigation channel had risen and overflowed its banks; as this water was derived from the melting of snow on the hills, it should have been at its lowest in the early morning, and the rise of the water during the night made me look for the cause of so unexpected an occurrence. I found that a sheet of semi-opaque, whitish ground-ice had formed on the bottom of the channel and so raised the level of the water, and that the ice was still growing. As the depth of the channel was under a foot, the process was an easy one to observe, and I was able to notice that the water was full of minute crystals of ice, which were swept along by the current, and, coming into contact with the surface of the ice on the bottom, became entangled in the irregularly disposed crystals of which it was composed and frozen into one solid mass with them." (R7) The minute crystals mixed with water conform to the definition of frazil ice. (WRC)

X5. Altberg's experiments. The Russian physicist, W.J. Altberg, came to somewhat different conclusions than Oldham (X4 above). Altberg's work tended to discredit the theory of Barnes, which was widely accepted in the 1920s, and attributed the formation of anchor ice to radiation cooling of the bed of the rivers.

"Altberg has conducted very careful and exhaustive observations and experiments both in rivers and in the laboratory, which have left him in no doubt as to the real explanation of anchor ice. He had been offered special facilities for research in consequence of a very unusual and serious case, in December 1914, of freezing of the Neva. The bed of the river, at a depth of 20 metres, was covered with a continuous sheet of loose ice 0.76 metre thick, which by enveloping and blocking the apertures of the receiving pipes interrupted the water-supply of Petrograd. He concludes, from a careful study of the distribution of temperature in rivers, and from laboratory experiments in which the phenomenon was produced under conditions absolutely precluding the possibility of any such radiation effect as Barnes postulates, or the introduction of ice to the bottom from the surface of the water (which according to Aitken's view may effect ground freezing), that anchor ice in rivers is a phenomenon due to the joint effect of supercooling and mixing. Water is commonly in a slightly super-cooled condition, and if the current in a stream is such that the heat generated by incipient congelation is carried away by mixing at a suitable rate from the bottom to the surface layers the formation of ground ice may proceed unhindered. Or, put in the author's own words: 'The mechanical intermixture of the layers thus maintains an energetic interchange of heat between the bottom and the surface, and affords the means for a continuous supercooling, and therefore for an uninterrupted process of crystallization. In this circumstance lies the whole root of the matter.'" (R8)

Altberg summarized his findings as follows: "The artificial reproduction of the process of the formation of a primary layer of anchor-ice under conditions fully excluding the access of ice from the surface and any share that might be taken in the phenomenon by the radiation of heat from the bottom, thus emphatically indicates the direction in which the cause of the phenomenon is to be sought. And in rivers the mechanism of the formation of the primary layer on the bottom is obviously the same as in the artificial reproduction of it; its further growth would proceed in either or both of the following ways:

1. By means of the immediate growth of the crystalline elements at the expense of the supply of cold continuously furnished by the flowing supercooled water, which would then carry away with it the heat produced by crystallization (as has been proved by experiments artificially reproducing the formation of anchor-ice).

2. By means of an extensive accumulation and adhesion (due to regelation) of fine particles of ice always found in water. The accumulation of ice by this last means is also unconditionally admitted by Barnes and other investigators." (R10)

X6. More recent general observations. An exchange of comments in the Transactions of the American Geophysical Union tells us that there is still no unanimity of opinion as to the formation of anchor ice and other underwater accumulations of ice.

R. W. Gerdel first chides V. J. Schaefer for implying that radiation cooling of river beds (the old theory of H. T. Barnes) was still a viable hypothesis, especially after the work of Altberg. In Gerdel's view, anchor ice and frazil ice are identical.

V. J. Schaefer's reply stated that he did not mean to imply that radiation cooling was important but, apparently, he still feels that there is some difference between underwater ice formations: "If anchor ice is to be used to describe underwater accumulations of frazil ice, then a new term should be devised to describe the formations which I illustrated, such as are found firmly attached to underwater objects which have provided the nucleation sites. I would prefer to call the underwater accumulations of tiny, plate-like crystals frazil ice since it is my understanding that this word was originally coined to describe the floes of underwater frazil ice which look like cinder.

"I am quite in agreement with Gerdel that more basic research in this interesting field is needed since a number of fascinating problems remain to be asnwered. With the increase of interest in using the St. Lawrence River and other northern streams for power purposes, it is important in my opinion that scientists interested in the various states of H_2O become interested in solving these problems." (R9)

X7. Anchor ice in shallow seas. "Abstract. Diving investigations confirm previous circumstantial evidence of seafloor freezing and anchor ice accretion during freeze-up storms in the Alaskan Beaufort Sea. These related bottom types were found to be continuous from shore to 2-m depth and spotty to 4.5-m depth. Spotty anchor ice occurred as pillow-shaped crystal aggregates on buried slabs of frozen sand surrounded by unfrozen sand. Considerations of required conditions for ice bonding and anchor ice growth allows regional extrapolation and suggests the possibility of anchor ice growth out to 20-m depth, the estimated maximum depth of supercooling during fall storms. Anchor ice and seabed freezing apparently do not develop during a calm freeze-up. Because of the abrupt growth of anchor ice during a freezing storm and its release soon after formation of a surface ice cover, this ice type has not been documented before." This type of anchor ice lifts coarse material off the bottom and incorporates it into the ice canopy, thereby contributing to the transportation of seabed sediments. (R15) It had been thought that anchor ice was confined to rivers.

References

R1. "Anchor Ice," Scientific American, 7:174, 1852. (X3)
R2. Adie, Richard; "On Ground Ice Found in the Beds of Running Streams," Philosophical Magazine, 4:5:340, 1853. (X4)
R3. Thomson, James; "On Ground-Ice, or Anchor Ice, in Rivers," Philosophical Magazine, 4:24:241, 1862. (X1)
R4. "Anchor Ice," Scientific American, 12:54, 1865.
R5. Philips, G.M.; "Stones Clinging to the Under Side of Ice," Scientific American, 44:97, 1881. (X2)
R6. "Formation of Anchor-Ice," Science, 3:303, 1884. (X1)
R7. Oldham, R.D.; "Notes on Ground Ice," Natural Science, 4:450, 1894. (X4)
R8. "Anchor Ice," Geographical Journal, 62:238, 1923. (X5)
R9. Gerdel, R.W., and Schaefer, Vincent J.; "The Formation of Frazil and Anchor Ice in Cold Water," American Geophysical Union, Transactions, 33:127, 1952. (X6)
R10. Altberg, W.J.; "On the Cause of the Formation of Ice at the Bottom of Rivers and Lakes," Royal Meteorological Society, Quarterly Journal, 49:54, 1923. (X5)
R11. Parsons, Walter J., Jr.; "Ice in the Northern Streams of the United States," American Geophysical Union, Transactions, 21:970, 1940. (X6)
R12. Devik, Olaf; "Freezing Water and Supercooling," Journal of Glaciology, 1:307, 1949. (X6)
R13. Osterkamp, T.E.; "Frazil-Ice Nucleation by Mass-Exchange Processes at the Air-Water Interface," Journal of Glaciology, 19:619, 1977. (X6)
R14. Hanley, Thomas O'D.; "Frazil Ice Nucleation Mechanisms," Journal of Glaciology, 21:581, 1978. (X6)
R15. Reimnitz, Erk, et al; "Anchor Ice, Seabed Freezing, and Sediment Dynamics in Shallow Arctic Seas," Journal of Geophysical Research, 92:14671, 1987. (X7)

ESP9 Unusual, Long Range Fine Structure in Strata

Description. Enigmatic, laminar, foliated, or ribbon-like structure in rocks, including ice; often continuous over large areas, but apparently not associated with ordinary bedding phenomena.

Data Evaluation. Modern glaciologists have at last begun to attack the problem of glacier foliation, although studies are still few in number. We have found no recent work on coal lamination in our literature searching to date. Rating: 2.

Anomaly Evaluation. The laminar and foliated structures dominating this phenomenon are probably associated in some way with the accumulation of the material forming the strata and subsequent stresses applied. Still, the precise origins of the structures are obscure. Even so, no important geological paradigms are threatened. Rating: 3.

Possible Explanations. Glacier foliation, as described in X1 below, may be the consequence of the pressure deformation of impurities collected in the ice.

Similar and Related Phenomena. Jointing (ESP10); varves, coal layering, and Schlieren layering in igneous rocks.

Examples

X1. Vertical ribboned structures in glaciers.

The Aar Glacier, in the Alps. Observations of a party of three scientists, including L. Agassiz. "It was fully three hours' good walking on the ice or moraine from the lower extremity of the glacier to the huge block of stone, under whose friendly shelter we were to encamp; and in the course of this walk (a distance of eight or nine miles, on a moderate computation, allowing for the roughness of the way) on the first day I noticed, in some parts of the ice, an appearance which I cannot more accurately describe, than by calling it a ribboned structure, formed by thin and delicate blue and bluish white bands or strata, which appeared to traverse the ice in a vertical direction, or rather which, by their apposition, formed the entire mass of the ice. The direction of these bands was parallel to the length of the glacier, and, of course, being vertical, they cropped out at the surface, and wherever that surface was intersected and smoothed by superficial water-courses, their structure appeared with the beauty and sharpness of a delicately veined chalcedony. I was surprised, on remarking it to Mr Agassiz as a thing which must be familiar to him, to find that he had not distinctly noticed it before, at least if he had, that he had considered it as a superficial phenomenon, wholly unconnected with the general structure of the ice. But we had not completed our walk before my suspicion that it was a permanent and deeply-seated structure was fully confirmed. Not only did we trace it down the walls of the crevasses by which the glacier is intersected, as far as we could distinctly see, but, coming to a great excavation in the ice, at least 20 feet deep, formed by running water, we found the vertical strata or bands perfectly well-defined throughout the whole mass of ice to that depth..... Where the plane of vertical section was eroded by the action of water, the harder seams of blue ice stood protuberant; whilst the intermediate ones, partaking of a whitish-green colour and granular structure, were washed out. We did not sleep that night until we had traced the structure in all directions, even far above the position of our cabin, and quite from side to side across the spacious glacier of the Finster Aar." The ribboned structure was found to penetrate the ice to great depths, with a course parallel to the glacier's length." (R1)

In the modern literature, the term "foliation" is employed to describe the phenomenon observed above. It is not uncommon and has long perplexed glaciologists. R. LeB. Hooke and P.J. Hudleston have reviewed the phenomenon: "Most glacier ice displays a planar or layered structure, developed during deformation and defined by variations in bubble or dirt content. Crystal size, texture and orientation may also vary from layer to layer but such changes are usually less obvious."

The same authors outline the complexity of the foliation. For example: "In valley glaciers, foliation may form longitudinally with steep to vertical dips throughout the length and breadth of the glacier, but with the most dense development normally near the margins.... In general it seems that foliation is most strongly developed near the base and towards the margins of glaciers, and is usually parallel to the base or valley sides as these are approached. It may be folded in these locations." Hooke and Hudleston theorize that foliation is derived from inhomogeneities in dirt and bubble content accumulated during the glacier's formation. The high strain existing within glacier ice then flattens and stretches out these inhomogeneities until they assume a foliated appearance. (R4; R5)

X2. Coal laminae. Coal being formed from plants, it is not surprising to find a fine structure that may be attributed mostly to compressed and modified plant remains. Included are rod-like bodies, obvious stems, fibers, and the like. The so-called "coal laminae", however, are a bit more mysterious. Two different opinions are at hand.

W.S. Gresley. "The literature of coal-formation, so far as I know it, is most unsatisfactory relative to the probable or supposed nature and vegetable structure of the pitch-coal layers or laminae, that give coal its 'grain' or stratified aspect (so-called). How exceedingly variable in size and shape these black lines or plates are, all observers of coal-beds know. Looking up the opinions of authors as to the meaning of these laminae, I find that hardly any two agree, though most seem to favor a woody origin of some kind, rather than that they represent patches or streaks of residual products having little or no organic structure. I have given much attention of late to these black laminations, both in bituminous coals and in anthracites; and, strange as it may seem, the latter have afforded the most favorable materials developing anatomical structures. Some of these tissues, etc., I purpose publishing in the near future. Now, these black laminae are by no means all black, nor uniform in lustre, or in possessing clearly defined and flat exterior surfaces, terminals, etc. The edges of some are wavy, ragged, spiny, etc.; the upper and lower plates or layers of some consist of closely compacted rods, straight or twisted; or dense black in one layer while the parallel one is composed of rods. Other laminae consist wholly or largely of wavy vertical rows of alternating black and gray streaks or spots; others are of black layers interlaminated with gray dull-lustrous material, in which latter material a macrospore occasionally peeps out. There are numerous laminae wholly made up of flattened fibrous tubes, filled with as well as surrounded by gray granular material; the aspect of lines, etc., differing in all these cases with the fracture of the specimen, its obliquity and so on. Another lamina will show a somewhat open cellular upper and lower rind with a dense black central plate. Still another may consist of connected patches or expansion-like processes on either surface of a ? blade or ? midrib-like center. Then we have them apparently composed entirely of one kind of cell:---of rows or a cluster of seed-cases attached or detached from stalk-like connections:---masses of cells gray in color, apparently perforated in a regular manner, by holes. And this necessarily crude list might be lengthened, making it evident that if future investigation shall show that none of these structures observed are new to coal---or to known coal-plant anatomy, these laminae cannot in future be said to be so devoid of internal organization as to prevent identification being some day possible." (R2) This rather muddy paragraph simply denotes that the laminae are highly diverse. (WRC)

T. E. Savage. "In explaining the origin of the bright and dull laminae, Dawson maintained that it is the outer bark of flattened tree trunks that alone formed the shining coal. In a recent paper on the origin of bright laminae of coal, Pringle, of the Geological Survey of Great Britain, reaffirms Dawson's view.

"The serious objection to this view is the fact that the bright and dull laminae of the coal beds are so nearly parallel and are often continuous for long distances. Trees that are overturned in swamps fall in various directions, and their trunks lie across one another at various angles. If the cortical portion of the tree trunks formed the bright laminae of coal, these bright laminae would not be continuous for long distances, and the dull laminae would be broken at short intervals by small areas of bright coal representing the cross-sections and oblique sections of the cortical portions of tree trunks that lay at different angles and at different levels from those that formed the bright bands in any exposure. The distribution of the bright and dull laminae is not consistent with this explanation." Savage's view is that the laminae are continuous over such wide areas that their formation must therefore involve agencies that were repeatedly active over the entire coal-bed-to-be. His only suggestion involved the change of water level. (R3)

References

R1. Forbes, James D.; "On a Remarkable Structure Observed by the Author in the Ice of Glaciers," Edinburgh New Philosophical Journal, 32:84, 1842. (X1)

R2. Gresley, W. S.; "Side-Light upon Coal Formation," American Geologist, 23: 69; 1899. (X2)

R3. Savage, T. E.; "On the Conditions under Which the Vegetable Matter of the Illinois Coal Beds Accumulated," Journal of Geology, 22:754, 1914. (X2)

R4. Hooke, Roger LeB., and Hudleston, Peter J.; "Origin of Foliation in Glaciers," Journal of Glaciology, 20:285, 1978. (X1)

R5. Hambrey, M. J.; "Origin of Foliation in Glaciers," Journal of Glaciology, 22:556, 1979. (X1)

ESP10 Jointing, Cleat, Crack Patterns

Description. The frequent tendency of rocks of many types, including ice, to fracture or split into geometric shapes or some otherwise regular manner. These planes of weakness sometimes persist over distances of tens of miles or more. Regular jointing is one of the most obvious phenomena of geology. The salient features of the phenomenon are: (1) geometrical regularity; and (2) organization over large distances.

Data Evaluation. Columnar jointing and the "cleat" in coal measures have received considerable attention in the literature; other varieties of jointing and cracking seem to be neglected. Further, many of our references are rather cursory in nature. Rating: 3.

Anomaly Evaluation. The major forces that contribute to jointing and cracking are well-known: thermal contraction, desiccation contraction, volume changes due to chemical reactions, tectonic forces, and weather. The anomalies reside not in the forces but rather in the nature of the effects: geometrical and/or long-range order. As with surface mud cracks and desiccation polygons (ETP3), the fundamental question is why planes of weakness of long range and high geometrical order form in ostensibly homogeneous materials. Answers, when given, tend to be superficial or do not stand up to scrutiny; viz., the minimum action principle or "thermal contraction" or "desiccation contraction". Such problems in explanation are not weighty as geological anomalies go, but they seem to be sloughed off too quickly. Rating: 2.

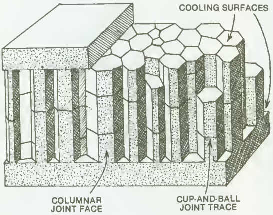
Possible Explanations. Stresses, as enumerated above, cause rocks to fracture; but these do not come to grips with the phenomenon. The time-worn appeal to the least-action principle (R2) has fallen out of favor today. In the case of columnar jointing, hexagonal convection cells set up during lava cooling have been proposed. This sort of explanation does not apply, of course, to sedimentary jointing that has not been subjected to heating.

Similar and Related Phenomena. Patterned ground (ETP1); block fields (ETP2); desiccation polygons (ETP3); the crystalline forms of most minerals.

Examples

X1. Columnar or prismatic jointing. Prismatic jointing, exemplified by the famous Giant's Causeway, in Ireland, is perhaps the most spectacular and intriguing type of jointing. Over a century ago, R. Mallet explained the common hexagonal prism form in terms of "least action." This sort of explanation still dominates geological discussions of prismatic jointing, as in the encyclopedia quotation that follows. It should be noted at the beginning, however, that this phenomenon is more complex than it appears on the surface, and that grave doubts now exist as to the "least action" or "least energy" theory.

General observations in an encyclopedia. "Columnar joints occur in sheetlike or pluglike intrusive and extrusive igneous rock bodies. They also may be found on occasion in sedimentary rocks that have been heated adjacent to igneous intrusions. Individual columns ordinarily are five- or six-sided but may have from three to eight sides in some examples. The columns range from a



Columnar jointing. (X1)

few inches to several feet in diameter and from a few feet to many tens of feet in length. Dish-shaped cross joints (cup-and-ball joints) divide the columns into segments.

"Columnar joints invariably are oriented normal to cooling surfaces and result from the contraction of the igneous rock on cooling. The columnar structure is what may be expected if the strain energy generated by contraction of the rock is to be dissipated by the least amount of work." (R26)

The widespread occurrence of columnar structure. An 1876 survey: "It is almost needless to remark that though columnar structure appears to be most frequent in basalt, it is not confined to that rock; I have myself seen it in trachyte (district of Mont Dor, Auvergne), pitchstone (Arran), felstone (Cader Idris, &c.), phonolite (Roche Sanadoire &c., Auvergne). Nor is it confined to igneous rock. I have observed it in volcanic mud (beneath a bed of basalt in Tideswell Dale, Derbyshire), in coal at contact with basalt from Ayrshire (Geological Museum of Edinburgh) and from Yorkshire (Woodwardian Museum, Cambridge), in hematite iron-ore (ib.; the columns are about 1/8 inch in diameter), and, though rather imperfect, in palagonite tuff (Iceland), and in a large quartz vein (Svolvaer, Lofoten Islands). Ice, also, when kept for some time very near a temperature of 32° Fahrenheit, as it is during a slow thaw or in those singular caverns termed glacières, in the Alps, also exhibits a beautifully regular columnar structure, which I can only attribute to a contraction of the mass, probably as it passes from the point of minimum density to the melting point.

"Occasionally one set of parallel divisional planes is more strongly marked than the others, so that, while the majority of the columns retain the hexagonal type, an oblong form dominates, and a somewhat platy or bedded aspect is given to the rock mass. I remember observing this especially in a trachyte in the ravine of the cascade of the Dore, on the Pic de Sancy; and it is very conspicuous in the great mass of felsite which rises above Llyn-y-Gader (Cader Idris)." (R3)

The Bombay columnar basalts. We begin our sketches of a few more interesting examples with the large Andheri columns. "Well developed hexagonal prisms about 3 feet across and attaining heights of over 100 feet occur at Andheri, a suburb of Bombay. No geological work has so far been done on these basalts. The columns comprise coarse-grained basalt which, in thin sections, does not show any variation of mineralogical characteristics from the centre to the side. Polished sections reveal irregular ore mineral grains but there is no observable pattern of variation across the column." The authors of this paragraph report a study of the magnetic grains in this basalt because, as they state, "the origin of many features of the columnar basalts is still controversial." (R21)

Prismatic sandstone. Sedimentary rocks do on rare occasions show a prismatic structure, as illustrated in this example. The locale is a quarry near Knob Lick, Madison County, Missouri. "The country rock here is the Cambrian sandstone which overlies the granite, as is beautifully illustrated at the quarry nearby. 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 nearby 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

Prismatic sandstone from Missouri. The prisms are about an inch wide. (X1) 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.

"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 water-worn, 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 adjacent granite is claimed to be much older than the sandstone and thus could have played no part in the formation of the prisms. (R4) See X5 below for an occurrence of "sand crystals" and section ESX4 for instances where sandstone is an instrusive rock. (WRC)

The Giant's Causeway. This is perhaps the most famous of all columnar basalt formations. Quoting the Encyclopedia Americana: County Antrim, Northern Ireland. "The causeway, part of an overlying mass of basalt, 300 to 500 feet thick, which covers much of County Antrim, extends about three miles along the coast and forms a promontory into the sea. It is of volcanic origin and is believed to have been caused by the cooling of a lava flow from the earth which split into thousands of prismatic columns, mostly hexagonal in shape, with some pentagonals, and a few with an irregular number of sides. There are approximately 40,000 vertical columns, 15 to 20 inches in diameter and of varying heights to 20 feet; from a distance the effect is one of an uneven platform."

Other well-known columnar basalts include the Devil's Postpile, eastern California; a Pleistocene basalt flow near Dunsmuir, California; and the Mt. Rodeix basalt flow, in the Auvergne region of France.

Banding in columnar jointing. A clue to the mode of formation of columnar jointing may lie in the frequent "banded"structure on the columns. A. V. G. James described these bands in 1920, although he called them "chiselings". He also mentioned that when these bands, which circumscribe the columns, are deepened by erosion a "Dutch cheese" structure results, as in the Organ Pipes at Sydenham, Australia. (R30)

More recently, J.M. DeGraff and A. Aydin theorized about how banding helps us understand how columnar jointing develops: "Columnar joints in basaltic lava flows display conspicuous bands oriented normal to column axes. New observations show that each band contains a single plumrose structure and thus represents an individual crack, or joint segment, formed during a discrete growth event. Analysis of plumrose structure and intersections of cracks leads to a new kinematic model of columnar jointing, and provides the first direct proof that columnar joints grow incrementally from exterior to interior regions of solidifying magma bodies. Columnar joints form by nucleation and growth of new cracks on the edges of older cracks. Each new crack begins at a point and propagates mostly normal to column axes and along the leading edge of a developing column face, where thermal stress is concentrated." (R35)

Theoretical studies. R. Mallet made one of the first theoretical attacks on the problem of prism formation. He came to the conclusion that it could be explained as a consequence of the Principle of Least Action. (R2) As mentioned earlier, this approach has long been popular.

However, more recently, analyses of different basalt flows, the Giant's Causeway, in particular, cast doubt on Mallet's approach. I.J. Smalley, for example, finds that pentagonal prisms predominate in many flows. Even in the Giant's Causeway, 35% of the columns are pentagonal, while 51% are hexagonal; the rest are 4-, 7-, and 8-sided. Obviously, the ideal hexagonal prisms are not heavily favored, as Mallet's theory would suggest. Smalley has his own theory, as his abstract demonstrates: "The traditional concept of contraction crack formation is based on a model having a regular arrangement of stress centres. A more realistic result is produced if the model consists of a close random packing of stress circles; this gives a crack configuration very close to that observed in real basalt flows." (R19)

D. Weaire and C. O'Carroll, on the other hand, like neither Mallet's approach nor that of Smalley. They say, "Mallet's calculations are, if examined in detail, difficult to analyse or accept, even if his approach is based on the now accepted mechanism of crack formation due to cooling on contraction." Smalley's model "lacks a convincing physical basis and achieves, according to Getis and Boots, only a vague resemblance to the observed structure."

Weaire and O'Carroll then question the whole idea of horizontal crack propagation, based on data from the Giant's Causeway. "The crack network displays a remarkable homogeneity, balance and consistency throughout, which seems incompatible with formation by the horizontal propagation and bifurcation of cracks. One would expect that the more or less accidental confluence of cracks would generate a lot of mistakes even if they emanated from a single centre. The resulting structure would be inhomogeneous, due to the mismatch of propagating cracks in some areas." The authors' approach has a model in which vertical crack propagation has an essential role. (R28) Thus, the theoretical situation is far from settled for this very common type of jointing. (WRC)

X2. Spheroidal structures. Ordinarily, one would dismiss spheroidal jointing or cracking in rock masses are unlikely. The phenomenon does seem to be rather uncommon in comparison to other varieties of jointing, but it does exist.

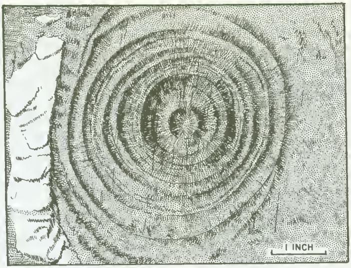
General observations. "Spheroidal structure has been observed in plaster on a wall. A very fine example of it in bedded shale is figured by Mr. Jukes in his 'Manual of Geology'. I have seen it well developed (of an ellipsoidal form) in a lenticular fragment of shale caught up in a basalt on the Fifeshire coast, near Elie. A very fine instance of it may be seen in volcanic ash near the village of Santa Lucia (Valle de Cordevole, Italian Tyrol). Here it is so conspicuous that the rock at a short distance might be readily mistaken for a decomposing basalt. Instances of it can also be found in the agglomeratic ash of the Binns, Berntisland (Fife).

.....

"But I can produce yet stronger cases. A few kilometers from Le Puy on the route de Brioude, close to where the road turns off to Polignac, is a mass of columnar basalt rather decomposed, part of which exhibits very well the spheroidal structure. Here spheroids may be seen, one above the other, enclosed three or four at a time in a columnar shell without any dividing cross joints, so that they are just like Dutch cheeses packed in hexagonal cases (the interstices being filled up). The lid of the box has more or less fallen away, and exposed the contained spheroids." (R3) Note that these spheroids are not concretions, or geodes, or other spherical aggregations covered in ESA. Erosion plays a role in forming the Dutch cheese and spheroidal forms, as illustrated below. (WRC)

Bird's-Eye coal. Spheroidal cracking in coal. "Abstract. Excellent examples of bird's-eye coal from the Tertiary bituminous coal measures of Greymouth, New Zealand, are described. The 'eyes' consist of concentric rings, each ring a miniature ridge with slope directed radially in opposite directions from the crest line of the ridge. They are believed to be the product of conoidal shearing induced in material of suitable physical character by tec-

"Dutch cheese" structure observed in eroded columnar jointing. On occasion, stacked spheres result. (X2)



Structure of "bird's eye" coal from New Zealand. (X2)

tonic stresses." (R14) This interesting form of fracturing may be compared to the percussion cones of X6. (WRC)

X3. Jointing or cleat in coal beds. The remarkable feature of large-scale jointing in coal beds is its great uniformity over wide areas and independence of jointing in adjacent strata.

The coal beds of Ohio. "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 appears 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."

The author believes cleat is the consequence of tectonic forces rather than contraction due to loss of gases and liquids. Shrinkage, he thinks, would produce jointing in all directions. (R13) One would think, however, that tectonic forces would produce similar jointing or cracking patterns in adjacent strata. The next example indicates that this does not always occur. (WRC)

English coal beds. Quoting J. Phillips: "'In the northern coal districts of England, and in other tracts, there exists, besides the lamination parallel to the bounding surfaces of the beds, a series of approximate, often nearly vertical divisional surfaces along which the coal admits of easy fissility. This structure is called cleat, and it is of the greatest importance in coal working, since parallel to it the headways are driven in the post-and-stall workings of Northumberland and Durham, and parallel to it the banks are wrought in the long wall and bord-and-end systems of Yorkshire and Derbyshire. Cleat is little affected by fractures or undulations of the strata. It has usually one persistent course across a large district,---the same direction often obtains in neighboring districts, and even prevails over the whole of a great Carboniferous region. Thus in Northumberland and Durham the cleat runs most generally to the northwest (true); and its strike is in that direction. The most general strike of the beds is to N.N.E. The same direction of cleat is prevalent in Yorkshire and Derbyshire, and this whether the beds strike eastward, as near Leeds and Sheffield, or southward, as near Huddersfield and Chesterfield. The same direction prevails in Lancashire.'

.....

"The particular aspect of the subject to which I wish now to apply myself is the absolute independence of the cleat in coal-seams, not only to the lie of the rocks, but also to the jointing of the measures in immediate association with them. This relation is not explicitly indicated by Phillips, though it is perhaps implied by his statement that the direction of the cleat maintains its constancy despite diametric changes of dip.

.....

"Why does the jointing in the coal take a course absolutely unrelated to that of the enclosing measures? The first proposition I would advance is the obvious one that the two sets were produced by forces operating in different directions and at different times. The cleat would, I imagine, be produced first---otherwise it is difficult to understand why a fragile substance like coal should have escaped shattering by the force that jointed the other rocks, whereas if it had already acquired a cleat it might yield to later strains or stresses without the production of a fresh system of fractures." (R6) But why does coal, which is created from huge masses of tangled vegetation, tend to fracture so easily along such perfect patterns over large areas? (WRC)

X4. Coal partings. Coal beds are often composed of distinctly different bands of coal separated by thin layers of clay, shale, pyrites, fusain, or other mineral matter called "partings". Of these, fusain is perhaps the least understood. Fusain is also called mineral charcoal and mother-of-coal. It is covered in more detail in ESC8. Here, it is of interest because it contributes so commonly to the formation of separation planes. T. E. Savage describes the situation thus:

"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." (R7) One of the theories of origin for mineral charcoal or fusain invokes huge forest fires. The large areal extents of fusain partings cast doubt on this hypothesis. (WRC) See X12.

X5. Polyhedral jointing. Prismatic or columnar jointing (X1) is essentially a two-dimensional phenomenon. In this entry, we describe a three-dimensional variety of jointing, which expresses itself in the form of cubes, properly pointed prisms, and various polyhedra. Of course, the mode of origin may be the same as in columnar jointing.

Sand crystals. Snake Buttes, Pine Ridge Indian Reservation, South Dakota. "Snake Buttes are unique in that they are beds for the famous sand crystal formations reportedly found in only two areas of the world---on these buttes and in a certain area in Australia. On the buttes they are found strewn about the surface and deep down in the moist sand beds hemmed in by huge strata of hard rock lining the edges of the summits of the buttes.

"These strange sand crystals are all hexagon shaped, more or less pointed at both ends, and range in length from less than an inch to six inches or even longer. They are rough and gritty to the touch, and sparkle in the sunlight.

"The sand crystals strewn about over the surface of the buttes are hard and do not break easily, as they have been exposed to the sunshine and the elements. Those dug from the moist sand beds, however, are moist, soft, crumbly, and break quite easily. They are a very interesting study. Some dug up are not yet fully formed but still in the process of 'growing.'

"Sand crystals grown together in clusters, in the form of open lattice work, are a very beautiful sight to behold. Twenty years and longer ago, many huge, beautiful crystal clusters could be seen on display in many business places and museums, especially in the Black Hills, Badlands, and Indian reservation areas, as well as on Indian graves in cemeteries." Many of the sand crystals are so perfectly formed that "they look like they have been manufactured in molds." (R15) See also X1 for "prismatic sandstone". If the sand crystals are the consequence of shrinkage due to drying, one wonders how such perfect three-dimensional shrinking can occur. (WRC)

Polyhedral cracking in granite. "Polyhedral 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 or 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 boulders 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." (R8)

X6. Pyramidal and conical fracturing. The Editor of Scientific American received from a reader, in 1938, a concial stone thought to be a fossil. In actuality, the specimen seems to be a percussion cone and representative of a certain type of fracturing in rock.

"'The fossil of which this is a photograph was found in Devonian limestone in an old quarry at Kelley's Island, Ohio. It is a three-sided pyramid 10 inches in altitude. The sides are smooth but the bottom is uneven, as though, after the flesh of the creature that once occupied the shell had decayed, the base had been filled with different material from that which later filled the remaining space, and which is limestone containing small fossils common to the middle Devonian period. The actual shell has been dissolved. The space surrounding the cast once was occupied by the shell.'

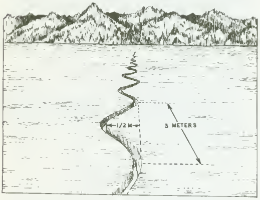
The Editor of Scientific American submitted the material to a scientist specializing in Devonian fossils, who replied that the object was not a fossil but rather a percussion cone, such as are often found in quarries where there has been blasting. (R9) Percussion cones are easily made by shooting BBs at plate glass. However, the object under discussion is actually pyramidal. (WRC)

Tepee structure. "Abstract. Distinctive peritidal tepee antiform structures, buckled margins of saucer-like megapolygons are common in marine vadose fenestral and pisolitic limestones and or dolomites of carbonite platform sequences and occur in intertidal and supratidal carbonates ranging in age from Silurian to Holocene. These megapolygons commonly form and are sometimes truncated before the deposition of the next sedimentary layer. The megapolygons result from the expansion of surface sediments by as much as 15%." (R34)

X7. Sinusoidal fracturing of ice. The regularity of this phenomenon is difficult-to-understand.

Lake Bohinj, Yugoslavia. "In January of this year (1935), 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.

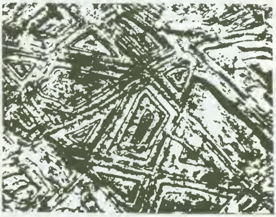
"On January 4, Mr. F. Avcin noticed a peculiar crack in the ice. It extended across the entire lake and was about one kilometre in length. Near the southern shore its course was curved and then followed a straight line to the opposite shore. The crack itself, however, was in the form of an almost perfect sine curve. 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." One speculation was that stress waves created by the normal cracking created a sine wave crack! (R10) Across the lake, there were over 300 near-perfect sine waves, according to simple arithmetic. (WRC)



One of the sine-wave cracks observed in the ice of Lake Bohinj, Yugoslavia, in 1935. (X7)

X8. Geometrical patterns on weathered sandstone. We have next to nothing on this phenomenon.

Carpet rocks. In Petit Jean State Park, Arkansas, geometrical patterns appear in relief on sandstone slabs. "The design is carried out with startling regularity in many places where the rocks have been exposed to the weather." See the accompanying photo. (R11) Presumably, the patterns are caused by differential weathering; but why are there geometrical zones of weakness? Are these patterns related to the sandstone prisms (X1) and the sand crystals (X5)? (WRC)



The Carpet Rocks, Petit Jean State Park, Arkansas. The patterns appear where sandstone has been exposed to weathering. (X8)

Polygonal weathering of sandstone. "At several points near Chapel Hill, North Carolina, in an arkosic sandstone of Newark age, the writer has observed what seems to be a rather peculiar type of weathering. This sandstone, where outcropping in two widely separated points, is broken into polygons, many of which are definitely hexagonal. At least one writer in his work on the Upper Triassic of North Carolina, has referred to this arkose and pointed out its well developed 'sun-cracks,' supposing that the cracks were formed during Triassic time, when the material was as yet unconsolidated." (R30)

X9. Crystal alignment in sea ice. Contrary to expectations, some sea ice has directional properties---a phenomenon which seems to fit well in this section.

"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."

The equipment that first detected this effect consisted of a sledge-borne radar. The primary purpose was the radar measurement of ice thickness. It was noticed, however, that when the linearly polarized antenna was rotated about a vertical axis, the echo strength varied strongly.

"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 stopped and changed the ice was rougher and composed of rotated and re-frozen plates. Multiyear ice, too, often exhibited the anisotropy, but less consistently."

An ice core revealed that individual ice crystals were in a sub-parallel alignment with tidal currents in the region. This was also the direction of minimum radar echo. It is not known whether the alignment is due to the currents directly, to their large-scale stressing of the ice, or some other factor. (R23)

X10. Sheeting fractures in granite. Directional structures are common in granite. For example, tabular lenses, banding, and parallel arrangement of inclusions are common. The sheeting fracture patterns are of particular interest to this discussion.

"A special type of joint known as sheeting fracture divides the granite into huge slabs or sheets, resting one above the other. Normally these fractures form parallel to the Earth's surface presumably due to expansion and release of confining pressure as erosion strips away the thick overburden." (R25) The other "directional structures" found in granite are, in contrast, associated with the direction of flow of the molten rock.

X11. Megapolygons in subsurface strata. This phenomenon is the subsurface analog of ETP3, "Giant Expansion and Contraction Polygons", in the Catalog volume dealing with topography (CAROLINA BAYS, etc.). Except, possibly, for the final example, all polygonal features mentioned below developed below the surface, although the forces involved (contraction due to desiccation and/or cooling, expansion due to chemical changes) are the same as with the giant surface polygons.

Triassic salt of Cheshire, England. "The Triassic salt in Cheshire, England, has large polygonal patterns on bedding surfaces. The polygons are bounded by deep V-shaped fissures. The fissures have a banded internal structure made up of individual units of pure secondary salt and clastic-rich halite. The salt was deposited from shallow brines in an arid environment. A thermal contraction model is proposed here for the formation of the polygons." (R27) The salt polygons are up to 14 meters wide. Similar patterns are found in many salt deposits around the world.

Jurassic dolostone, England. "Megapolygons with thrusted margins occur within the lowermost dolostone of the Kimmeridge Clay Formation (Upper Jurassic), at the type locality in southern England. Unlike similar features previously described, these structures did not develop at, or near, the sediment surface but at a considerable depth of burial. They formed at a time when the adjacent shales were already compacted but prior to tectonic jointing and faulting. Features distinguishing them from similar near-surface structures include sigmoidal thrust planes, complete lack of penecontemporaneous erosion, absence of internal sediments and association with localized deformation of surrounding compacted sediments. Diagenetic growth of dolomite is proposed as the mechanism that gave rise to expansion." (R24)

Triassic limestone, southern Alps. Megapolygons in the Ladinian limestones, 1-2 meters in diameter, have been reported. They are thought to be the consequence of either desiccation contraction, cementation expansion, or both. (R20)

Jurassic sandstone, Utah. On the southwest flank of the Boundary Butte anticline (San Juan County, Utah), the Carmel Formation crops out "as a series of large, bedded, polygonal rock forms which resemble man-made stone corrals." The walls of these polygons are 1 1/2 to 2 feet high and a maximum of 3 feet wide. The author hypothesizes that they "were formed by eolian infilling of mudcracks with sand, followed by lithification and partial removal of the easily eroded siltstone 'mold.'" (R17) This entry is the same as ETP3-R6-X3, reflecting classification difficulties. (WRC)

X12. Large-scale regular jointing, cracking, and cleavage. "Large-scale" here means kilometer-scale or regional.

Polygonal patterns in Missouri. "The geotectonic location of the polygonal patterns of Missouri is that of intersection points of two fault systems.... This main fault line strikes almost exactly E-W and has its small angle deviations and occasionally parallel sets of faults." Various polygonal features occur along this "almost continental break in the shield of the Middle West". Near St. Genevieve, the fault splits into a roughly trapezoidal pattern. In south central Missouri one finds the polygonal Crooked Creek Structure. (R18)

Regular cracks in thick sea ice. "Long cracks spaced at reasonably regular intervals have been observed in thick ice sheets in the Arctic." (R22) This is all we have on this most interesting phenomenon.

Slaty cleavage. Coal partings, described in X4, represent an example of the more general phenomenon of slaty cleavage. This type of cleavage is often mentioned in textbooks, but seldom do writers address the problem of its persistence over great areas. In fact, the best description of the phenomenon is almost 150 years old.

In slaty cleavage "we have cleavage planes perfectly parallel, almost indefinitely extending with unaltered features over vast surfaces of the most rugged country, changing neither direction, dip, nor interval, with hill or valley, cliff or scarp, and passing alike through strata whose planes of stratification, horizonal, elevated, undulating, or contorted, offer no obstacle or modification to the omnipotent energy which has rearranged every particle in the mass subsequent to deposition. The supposition of Professor Sedgwick, who has minutely described and considered this geological puzzle, that 'crystalline or polar forces acted on the whole mass simultaneously in given directions, and with adequate power,' can hardly be considered as a solution of the difficulty, until it is shown that the forces in question have so acted, and can so act." (R1)

X13. Cylindrical jointing. One would not expect circular joint geometry, but it does exist.

Beartooth Mountains, Montana. "Abstract. Cylindrical joints are well displayed in two Precambrian mafic dikes that cut granitic gneiss in the central Beartooth Mountains, Mont. The dikes are vertical and about 23 m (75 ft) and 23 to 46 m (75-150 ft) thick, respectively. The cylindrical joints are perpendicular to the dike walls, and the cylinders defined by the joints are as much as 5 m (16 ft) in diameter. No petrographic, textural, or other features related to or possibly responsible for the joints are recognized. The dikes are chemically and petrographically similar to quartz dolerite dikes found throughout the Beartooth Mountains. Some of these dikes show typical polygonal columnar joints; a few others have cylindrical jointing, but in most dikes neither kind of jointing was observed. The orientation of the cylindrical joints normal to the walls of the dikes indicates that they probably formed by thermal contraction during post-crustallization cooling of the dikes and are thus genetically related to the much more common polygonal jointing. However, the model proposed to explain the cylindrical joints suggests that their origin is partly dependent on the geometric relation between the orientation of the dikes and that of the predike fracture pattern in the host rock." (R33)

References

R1. Forbes, James D.; "On a Remarkable Structure Observed by the Author in the Ice of Glaciers," Edinburgh New Philosophical Journal, 32:84, 1842. (X12)
R2. Mallet, Robert; "On the Origin and Mechanism of Production of the Prismatic (or Columnar) Structure of Basalt," Philosophical Magazine, 4:50:122, 1875. (X1)
R3. Bonney, T.G.; "On Columnar, Fissile, and Spheroidal Structure," Geological Society of London, Quarterly Journal, 32:140, 1876. (X1, X2)
R4. Haworth, Erasmus; "Prismatic Sandstone from Missouri," Science, 19:34, 1892. (X1)
R5. Gresley, W.S.; "Theory for 'Cleat' in Coal-Seams," Geological Magazine, 29:523, 1892. (X3)
R6. Kendall, Percy F.; "On the 'Cleat' in Coal Seams," Geological Magazine, 51:49, 1914. (X3)
R7. Savage, T.E.; "On the Conditions under Which the Vegetable Matter of the Illinois Coal Beds Accumulated," Journal of Geology, 22:754, 1914. (X4)
R8. Leonard, R.J.; "Polygonal Cracking in

Granite," American Journal of Science, 218:487, 1929. (X5)
R9. "A Puzzle Solved, and How," Scientific American, 158:229, 1938. (X6)
R10. Groselj, Pavel; "A Sine Curve Crack in Natural Ice," Nature, 135:877, 1935. (X7)
R11. "Odd Rocks in the Ozarks," Nature Magazine, 31:224, 1938. (X8)
R12. Dix, Emily; "Some Minor Structures in the Anthracite Coal Seams of South Wales," Geological Association, Proceedings, 52:227, 1941. (X3)
R13. Ver Steeg, Karl; "Jointing in the Coal Beds of Ohio," Science, 96:83, 1942. (X3)
R14. Gage, M., and Bartrum, J. A.; "Bird's-Eye Coal from Greymouth, New Zealand," Journal of Geology, 51:320, 1943. (X2)
R15. Spindler, Will; "Unique Sand Crystals Harder to Locate Now," Rocks and Minerals, 27:589, 1952. (X5)
R16. Kelly, Allan O., and Dachille, Frank; "The Waters Mould the Earth," Target: Earth, Carlsbad, 1953, p. 127. (X1)
R17. Tompkins, J. Q.; "Polygonal Sandstone Features in Boundary Butte Anticline Area, San Juan County, Utah; "Geological Society of America, Bulletin, 76: 1075, 1965. (X11)
R18. Amstutz, G. C.; "Tectonic and Petrographic Observations on Polygonal Structures in Missouri," New York Academy of Sciences, Annals, 123:876, 1965. (X12)
R19. Smalley, I. J.; "Contraction Crack Networks in Basalt Flows," GeologicalMagazine, 103:110, 1966. (X1)
R20. Assereto, Riccardo L., and Kendall, Christopher G. St. C.; "Megapolygons in Ladinian Limestones of Triassic of Southern Alps: Evidence of Deformation by Penecontemporaneous Desiccation and Cementation," Journal of Sedimentary Petrology, 41:715, 1971. (X11)
R21. Radhakrishnamurty, C., et al; "Magnetic Grains in Bombay Columnar Basalts," Nature (Physical Science), 234: 33, 1971. (X1)
R22. Mukherji, B.; "Crack Propagation in Sea Ice---'A Finite Element Approach'," Eos, 53:1009, 1972. (X12)
R23. "Why Does Sea Ice Have Its Crystals Aligned?" New Scientist, 65:191, 1975. (X9)
R24. Bellamy, Jon; "Subsurface Expansion Megapolygons in Upper Jurassic Dolostone (Kimmeridge, UK)," Journal of Sedimentary Petrology, 47:973, 1977. (X11)
R25. Wyllie, Peter J.; "Granite," McGraw-Hill Encyclopedia of Science and Technology, 6:279, 1977. (X10)
R26. Hodgson, Robert A.; "Joint (geology)," McGraw-Hill Encyclopedia of Science and Technology, 7:350, 1977. (X1)
R27. Tucker, Roger M.; "Giant Polygons in the Triassic Salt of Cheshire, England: A Thermal Contraction Model for Their Origin," Journal of Sedimentary Petrology, 51:779, 1981. (X11)
R28. Weaire, D., and O'Carroll, C.; "A New Model for the Giant's Causeway," Nature, 302:240, 1983. (X1)
R29. James, Albert V. G.; "Factors Producing Columnar Structure in Lavas and Its Occurrence near Melbourne, Australia," Journal of Geology, 28:458, 1920. (X1)
R30. Johnston, C. Stuart; "Polygonal Weathering in Igneous and Sedimentary Rocks," American Journal of Science, 213:440, 1927. (X8)
R31. Beard, C. Noble; "Quantitative Study of Columnar Jointing," Geological Society of America, Bulletin, 70:359, 1959. (X1)
R32. Spry, Alan; "The Origin of Columnar Jointing, Particularly in Basalt Flows," Geological Society of Australia, Journal, 8:191. 1962. (X1)
R33. Armbrustmacher, Theodore J., and Simons, Frank S.; "Cylindrical Jointing in Mafic Dikes, Central Beartooth Mountains, Montana," U. S. Geological Survey, Journal of Research, 3:213, 1975. (Cr. R. Calais) (X13)
R34. Assereto, Riccardo L. A. M., and Kendall, Christopher G. St. C.; "Nature, Origin and Classification of Peritidal Tepee Structures and Related Breccias," Sedimentology, 24:153, 1977. (X6)
R35. DeGraff, James M., and Aydin, Atilla; "Surface Morphology of Columnar Joints and Its Significance to Mechanics and Direction of Joint Growth," Geological Society of America, Bulletin, 99:605, 1987. (X1)
R36. Aydin, Atilla, and DeGraff, James M.; "Evolution of Polygonal Fracture Patterns in Lava Flows," Science, 239:471, 1988. (X1)

ESP11 Shocked Mineral Grains at Geological Boundaries

Description. Mechanically shocked grains of quartz, feldspar, and other minerals occurring in strata located at major transition points in geological history, in particular the Cretaceous-Tertiary (K-T) boundary. The shocked grains are usually found in conjunction with iridium spikes and other possible evidence of catastrophism.

Background. Actually, the observables here are sets of planar features in the grains, which are associated with the crystal axes. Such features are strong evidence that the grains were subjected to powerful mechanical shock waves.

Data Evaluation. Shocked mineral grains have been found at the K-T boundary at several widely separated locations, as well as at bona fide impact craters and around the sites of nuclear detonations. More controversial is the evidence for shock mosaicism on mineral grains found around volcanos. (See X7 below.) Are the planar features found on grains at the K-T boundary equivalent to the so-called shock mosaicism of grains around volcanos? Opinions vary. Rating: 2.

Anomaly Evaluation. The best-established facts are consistent with the hypothesis that the K-T boundary event was the impact of an asteroid or comet. Although such astronomical catastrophism was rejected by science until just a couple decades ago, it is now widely accepted. In this intellectual environment, the presence of shocked mineral grains is not anomalous at all. This assessment would have to be changed if the proponents of volcanism were able to make a strong case for shocked grains around volcanos. Rating: 4.

Possible Explanations. The impact of an asteroid or comet created the shocked mineral grains at the K-T boundary. The minority viewpoint is that the K-T events were caused by volcanism.

Similar and Related Phenomena. Iridium anomalies (ESC1); biological extinctions (ESB1); widespread soot layers (ESD9).

Examples

X0. Overview. Shocked minerals, especially quartz, have been found in many locations around our planet---too many to cover in detail. We itemize here five specific sites and supplement them with a recent worldwide survey. The final entry, X7, concerns the nature of shocked minerals and the various theories as to their origin(s).

X1. Brownie Butte, Montana. Here, one finds a thin claystone layer at the Cretaceous-Tertiary boundary containing an anomalously high amount of iridium and quartz grains with planar features. "These planar features are related to specific crystallographic directions in the quartz lattice. The shocked quartz grains also exhibit asterism and have lowered refractive indices. All these mineralogical features are characteristic of shock metamorphism and are compelling evidence that the shocked grains are the product of a high velocity impact between a large extraterrestrial body and the earth. The shocked minerals represent the silicic target material injected into the stratosphere by the impact of the projectile." (R3; R1, R2, R6)

Noting the relatively large sizes of the Montana quartz grains (50-100 μm), B.M. French proposed that the impact crater is probably to be found on the North American continent. He suggested two sites: the Sierra Madera structure, in Texas, and the Manson structure in Iowa. (R4) See ETC3 for details on these structures.

X2. Raton Basin, New Mexico. G.A. Izett and C.L. Pillmore "found shocked quartz and feldspar grains in the Raton (N.M.) Basin. These grains have been fractured along their crystal axes in the same way that quartz grains found near craters and nuclear explosion sites have been fractured when the shock waves from such events ripped through the crust." The presence of shocked feldspar grains favors a continental impact site, because this mineral is rare in oceanic rocks. (R5)

X3. Gosau Basin, Austria. The Cretaceous-Tertiary boundary here consists of an "undisturbed 2-mm thick boundary clay in the palaeomagnetic G^- zone (differing) from the surrounding sediments in having significant colour, no biogenic calcite and different contents of rare-earth and siderophile elements, carbon and magnetic minerals. The clay also contains shocked quartz and plagioclase particles, and indicates a dramatic change in sedimentation caused by a short-lived event." (R7)

X4. Teapot Dome, Wyoming. "Rocks of the Cretaceous Lance and Paleocene Fort Union Formations are well exposed along Salt Creek a few kilometers east of Teapot Dome. The upper 170 m of the Lance (as previously mapped) lacks dinosaur remains but contains Paleocene leaves and numerous thin coal beds. Ten centimeters below a 20-cm-thick coal bed, the stratigraphically lowest coal bed in the area, excavation revealed a 2-cm-thick claystone directly overlain by another claystone about 6 mm thick. This couplet of kalinitic claystone beds that marks the K-T boundary is similar to the so-called 'K-T boundary claystone' and 'K-T boundary impact layer' in the Raton basin of Colorado and New Mexico, at Lance Creek, Wyo., and Brownie Butte, Mont. At Teapot Dome, the impact layer contains less that 1% shock-metamorphosed mineral grains chiefly consisting of quartz, metaquartzite and quartzite. Rare shocked grains are as large as 0.5 mm long, but the mean size of 300 shock metamorphosed grains (is) 0.14 ± 0.04 mm. The large size and abundance of shocked mineral grains relative to that in K-T boundary rocks outside North America suggest that the K-T boundary asteroid or comet struck the North American continent." (R12)

X5. Caravaca, Spain. The Cretaceous-Tertiary (K-T) boundary layer at this site consists of three layers or units: "a light gray Cretaceous marl, a 1-to-3-mm-thick ferruginous clay called the 'K-T boundary impact layer' because of its content of shock-metamorphosed quartz grains, and an overlying greenish-gray clay." An important feature of the impact layer is the presence of spherules. The author's conclusion, however, is that these spherules are not altered microtektites or melt droplets resulting from the postulated impact. (R13) See ESI11 for a discussion of spherules in strata.

X6. Survey of K-T boundary sites displaying shocked quartz grains. In addition to the North American sites mentioned above, shocked quartz has been found in New Zealand, in a core (GPC-3) taken from the North Pacific Ocean, and five European localities (Nye Kiøv, Stevns Klint, Caravaca, Petriccio, and Pontedazzo). "In summary, this study confirms the presence of shocked quartz at several widely separated K-T boundary sites around the world. It shows that the association of shock-metamorphic effects in quartz grains with strong iridium anomalies in K-T boundary clays is not unique to the original discovery site in Montana but is to be expected at this event horizon wherever it may be found worldwide. The Alvarez hypothesis of an earth-girdling dust cloud of ejecta from the impact of a large extraterrestrial body is strongly supported by these data." (R10) This demonstration of global distribution is important to the extraterrestrial-object theory, as opposed to a volcanic, purely terrestrial K-T event, because it is thought that the impact of a large body would be more apt to loft debris to higher altitudes and thus effect a wider geographical distribution. As we shall see below, differences of opinion exist. See ESC1 for material on the K-T iridium spike.

X7. General observations and discussion of theories. When shocked quartz grains were first found at the Cretaceous-Tertiary boundary site in Montana (X1), researchers felt certain they had proof that the K-T boundary event was an extraterrestrial impact. After all, no one had ever found shocked quartz grains around volcanos, the only reasonable terrestrial sources of global catastrophism. However, no one had really looked very hard around volcanos.

1984. The "smoking gun". In analyzing the

K-T boundary layer at Brownie Butte, the last step in removing the clay from the sample involved treatment with hydrofluoric acid. This left the quartz grains etched with a distinctive pattern of intersecting, parallel grooves oriented according to the quartz's crystal structure. These features were proof positive of an event that created powerful shock waves.

"The only way known to produce such features in quartz grains is by a high-velocity impact. The shock of the impact---producing in this case over 150,000 atmospheres---disorganizes the crystalline quartz and produces amorphous glass, but only on planes having particular orientations with respect to the crystalline structure. High-velocity shock experiments in the laboratory have produced these planar features and their grooves, as have nuclear explosions. Such features are also found in the debris from known impact craters on Earth, but they have never been found in volcanic ash." Basically, volcanically generated pressures are just too weak. (R1)

Some proponents of volcanism, though, deny these contentions. N. Carter, C. Officer, and others have examined the debris from the Toba eruption in Sumatra for signs of high shock pressures. "Carter believes he has found such evidence, primarily in the mottled appearance, called a mosaic texture, of quartz and feldspar grains." Other investigators, however, believe that the resemblance is only superficial, and that the mottled appearance of the Toba grains probably results from other geological processes. (R9)

In 1988, M.R. Owen and M.H. Anders described their cathodoluminescence study of shocked quartz from the K-T boundary from southeastern Colorado. This quartz displayed a diversity of luminescence colors not present in the quartz from known volcanic ejecta. This research therefore supports the impact origin of shocked quartz. (R18)

Summary of the volcanism position by A. Hallam. "What appears on the face of it to be especially impressive evidence is the discovery at several K/T boundary localities around the world of so-called shocked quartz, with multiple laminar features held to be uniquely characteristic of impact deformation; the largest grains and highest proportions occur in the western United States, and a single impact event is favored. Shock mosaicism has been recognized, however, in plagioclase and biotite phenocrysts from the Toba caldera, Sumatra. Multiple laminar features are not likely to be found in volcanic minerals because of annealing at high temperatures, but might be expected to occur in country rock surrounding sites of highly explosive volcanicity. The question naturally arises as to whether explosive volcanicity can generate pressures of the extremely high order apparently required (a minimum of 90 kbar). Theoretical modeling based on the Mount St. Helens eruption suggests that this is indeed possible." Hallam also points out that the shocked quartz implies a continental impact, and that no plausible impact crater has been found. (R11)

X8. Vredefort Dome, South Africa. The quartz grains from this site have anomalous features which suggest that the region received two separate, distinct shocks. Since two large impacts at the same site are unlikely, to say the least, some scientists believe that this structure must have had a volcanic origin. This position is backed by independent research indicating two separate episodes of pseudotachylite formation. However, scientists belonging to the "impact school" argue that the anomalous quartz could have been created after impact when temperatures were high enough to anneal out some of the defects, thus producing the anomalous character of the Vredefort quartz grains. (R14)

X9. Manson Structure, Iowa. This structure under the city of Manson, Iowa, is considered by some as the most promising candidate for the elusive K-T asteroid/comet crater.

"Further evidence that the Manson crater was contemporaneous comes from shards of quartz known as shock mineral grains. Under an electron microscope, grains created by a spectacular impact such as a falling comet exhibit a unique lamellar pattern with features of a few microns in size. These are found just above the K/T layer of clay. The grains in the western US are 1000 times as abundant and about three times as large as those found in the K/T layer elsewhere in the world. Because shock grains fall more heavily near the site of impact the Manson crater is the logical source." (R16; R17)

References

R1. Kerr, Richard A.; "An Impact but No Volcano," Science, 224:858, 1984. (X1, X7)
R2. Simon, C.; "New Findings Establish Impact Occurred," Science News, 125: 197, 1984. (X1)
R3. Bohor, B. F., et al; "Mineralogical Evidence for an Impact Event at the Cretaceous-Tertiary Boundary," Science, 224:867, 1984. (X1)
R4. French, Bevan M.; "Impact Event at the Cretaceous-Tertiary Boundary: A Possible Site," Science, 226:353, 1984. (X1)
R5. Weisburd, Stefi; "Search for Impact Clues: Amino Acids and Shocked Mineral Grains," Science News, 128:300, 1985. (X2)
R6. Weisburd, Stefi; "Volcanos and Extinctions: Erupting of the Impact Idea?" Science News, 127:172, 1985. (X1)
R7. Preisinger, A., et al; "The Cretaceous/Tertiary Boundary in the Gosau Basin, Austria," Nature, 322:794, 1986. (X3)
R8. Weisburd, Stefi; "Volcanoes and Extinctions: Round Two," Science News, 131:248, 1987. (X7)
R9. Kerr, Richard A.; "Asteroid Impact Gets More Support," Science, 236:666, 1987. (X7)
R10. Bohor, Bruce F., et al; "Shocked Quartz in the Cretaceous-Tertiary Boundary Clays: Evidence for a Global Distribution," Science, 236:705, 1987. (X6)
R11. Hallam, Anthony; "End-Cretaceous Mass Extinction Event:Argument for Terrestrial Causation," Science, 238: 1237, 1987. (X7)
R12. Wolfe, J. A., and Izett, G. A.; "A New Cretaceous-Tertiary Boundary Section near Teapot Dome, Western Powder River Basin, Wyoming," Eos, 68:1344, 1987. (X4)
R13. Izett, Glen A.; "Authigenic 'Spherules' in K-T Boundary Sediments at Caravaca, Spain, and Raton Basin, Colorado and New Mexico, May Not Be Impact Derived," Geological Society of America, Bulletin, 99:78, 1987. (X5)
R14. Boslough, Mark B.; "Quartz Grains Shape New Impact Theories," Geotimes, 32:31, June 1987. (X8)
R15. Loper, D. E., and McCartney, K.; "Catastrophic Volcanism As a Cause of Iridium and Shocked Quartz Found at the K/T Boundary," Eos, 69:302, 1988. (X7)
R16. Joyce, Christopher; "Fragmentary Theory of Dinosaur Extinctions," New Scientist, p. 27, February 11, 1988. (X9)
R17. Hecht, Jeff; "Meteor in the Midwest Blamed for Extinctions," New Scientist, p. 38, September 8, 1988. (X9)
R18. Owen, Michael R., and Anders, Mark H.; "Evidence from Cathodoluminescence for Non-Volcanic Origin of Shocked Quartz at the Cretaceous/Tertiary Boundary," Nature, 334:145, 1988. (X7)

ESP12 Radiometric Dating Discordances

Description. Substantial differences between radiometrically determined ages of rocks compared to values estimated from geological considerations, magnetic dating, archeology, and other radiometric methods. "Substantial" here means deviations of 20% and more.

Data Evaluation. Several hundred discordant radiometric dates have been reported in the scientific literature. Many of these have been measured recently using the best modern techniques. Rating: 1.

Anomaly Evaluation. Discordant radiometric dates are not necessarily anomalous since there are often reasonable explanations. Radiometric dates can be grossly distorted by the addition or removal of the radioactive parent isotope and/or the stable daughter, through weathering, chemical alteration, and thermal effects. In fact, there exist so many potential explanations that almost any discordance can be explained away---and this is what is almost always done! The consequence of this "plasticity" of radiometric dating is that one cannot tell whether a radiometric discordance represents a "real" geological anomaly or whether the age difference is merely "apparent" and due to the lack of a "closed system." In view of this highly unsatisfactory situation, it is wise to be conservative and rate the anomalousness of radiometric discordances rather low. Rating: 3.

Possible Explanations. Radiometric discordances may be the consequence of the "open systems" prevailing in most geological situations. It is possible, however, that some discordances may indicate "true" geological anomalies; i.e., rocks that are chronologically out-of-place; but there seems to be no way to pinpoint this kind of discordance.

Similar and Related Phenomena. Radiohalos and their possible implications (ESP1); carbon-14 dating in archeology (Series M Catalogs, to be published).

Examples

X0. Introduction. In its simplest form, radiometric dating involves measuring the ratio of the amount of a radioisotope in a sample to the amount of its stable daughter product. Then, if the half-life of the decay reaction is known, the age of the sample can be calculated. However, the assumptions that must be made complicate the situation:

1. The half-life of the parent radioisotope was constant over the time period measured.
2. The sample has remained a "closed system" following its formation as, say, in the solidification of basalt. This means: (a) that no new supplies of the parent radioisotope were supplied and that none leaked from the sample; (b) ditto for the stable daughter; and (c) that no radiation capable of transmuting the parent or daughter passed through the sample.
3. The sample originally contained none of the stable daughter or, if it did, the amount can be accurately estimated.

We shall see in the following pages that all of these assumptions can and have been challenged. In particular, the assumption of a closed system is very often difficult to justify. In fact, when radiometric dates do not conform to expectations, an open system is claimed, in which compromising material has leaked into or out of the sample. Radiometric dating is, in this sense, a bit plastic. Discordant results can always be explained as the consequence of open systems, thus deflecting any serious criticism of radiometric dating itself. This line of thought leads directly to the claim, which is a key feature of the geochronological paradigm, that radiometric dating not only contains methods that insure its own integrity but also that its results are always consistent with dates from other dating methods, such as geomagnetism, geological considerations (varve counting), tree ring counting, fossil content, and archeological results. The geochronological edifice is generally considered to be a triumph of modern science. Certainly, our geological and astronomical outlooks depend heavily upon it.

In the examples that follow, which are categorized according to the several radiometric systems in vogue, our focus (as usual) is on anomalies; that is, radiometric dates that do not match expectations. The points to consider are:

1. How many and how serious are the discordances?
2. How reasonable are the explanations of the discordances? In other words, is the plasticity of radiometric dating ---that consequence of open systems ---overworked to make dates come out "right"?
3. Are assumptions 1 and 3 (above) violated seriously?
4. Are too many grossly discordant radiometric dates discarded as "wild points" and thus left out of the age calculations? Obviously, there is little in the literature on this point!

X1. Radiocarbon (C^{14}) dating. Radiocarbon dating, because the half-life of C^{14} is short (about 5730 years), is applicable only to geological situations a few tens of thousands of years old. The accuracy of radiocarbon dates is affected by the amount of C^{14} in the atmosphere, a value that varies with cosmic-ray intensity and nuclear weapons tests, to name two factors requiring corrections.

Discordant radiocarbon dates are rather easy to find in the literature. Here, we describe a few that have either interesting geological consequences or that demonstrate science's ways of dealing with discordant dates.

Modern snail shells. "Abstract. Carbon-14 contents as low as 3.3 ± 0.2 percent modern (apparent age, 27,000 years) measured from the shells of snails Melanoides tuberculatus living in artesian springs in southern Nevada are attributed to fixation of dissolved HCO_3^- with which the shells are in carbon isotope equilibrium." (R46) Modern shellfish often possess old radiocarbon dates. With little difficulty, geochronologists can find reasonable explanations in terms of environmental conditions.

The australite fall. "A gross inconsistency exists between the age of australite glass arrived at by K/Ar analysis (also fission-track counting) and the age of fall indicated by stratigraphic studies made so far." The australites are tektites, which are radiometrically dated at about 700,000 years. But radiocarbon dates for charcoal accompanying the australites in situ are only 4830 to 5700 years before the present. (R35)

Age of Soviet glaciers. The glaciers of the Soviet Union are generally believed to date from the Ice Ages; i.e., they are more than 10,000 years old. However a Soviet glaciologist named Grossvald "claims to have shown that there were no glaciers in the European sector of the Soviet Arctic 1000 years ago. He found tree trunks under the ice, which radio-carbon methods showed to date from this time. On the basis of this information, Professor Tushinsky believes that the glaciers of the Arctic and mountainous regions of the Soviet Union spread and developed in the cold winters of the late fifteenth century." (R10)

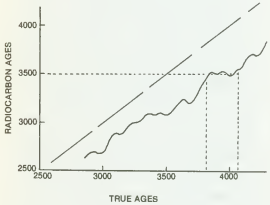
Age of the Antarctic ice cap. "Carbon 14 dating has shown that Antarctica's ice is less than 6000 years old. Holmes writes that 'Algal remains, dated at 6000 B.P. have been found on the latest terminal moraines' (Principles of Physical Geology, p. 718). This shows that Antarctica must have been sufficiently free from ice for green algae to grow, 6000 years ago." (R34) The reference above is to Arthur Holmes. For other evidence for a recent, relatively ice-free Antarctic, see ESD5.

Radiocarbon dating of a core taken from the Chukchi Sea off Alaska. The purpose of this item is to demonstrate what happens to grossly discordant data! "Six radiocarbon ages have been determined for organic carbon throughout the core. These ages, which range from 4,390 ± 210 to 15,500 ± 800 years B.P., are so disarranged that no consecutive dates are juxtaposed, and the oldest age determination is from the 2.88-to-3.40 meter interval. This disarrangement of radiocarbon ages suggests that the delta sediments are to some degree composed of recycled sediment. By disregarding the 15,500 ± 800-year age as being inconsistent with the other radiocarbon ages, and by assuming that contamination has made the remaining dates too old by about the same amount that the radiocarbon age (4,390 ± 210 years B.P.) near the top of the core exceeds usual surface sediment dates, Creager and McManus conclude that the delta was formed about 12,000 years ago." (R11)

Apparent radiocarbon ages of recent marine shells. "The mean apparent radiocarbon ages of marine shells, collected alive before the initiation of atomic bomb testing, and also before the main input of dead carbon derived from fossil fuels, are found to be 440 yr for the coast of Norway, 510 yr for Spitzbergen, and 750 yr for Ellesmere Island, Arctic Canada." These discrepant dates are explained in terms of the circulation of carbon isotopes in nature---seawater in this instance. (R33) Such examples do not show that radiocarbon dating is worthless, only that corrections can be subtle and complex. (WRC)

Archeological dating in the Near East. Detractors of radiocarbon dating often cite C. A. Reed's frustrations with this technique during his research in Iraq. "A last difficulty, and at the moment one of the most frustrating, is the failure of the radiocarbon (C^{14}) technique to yield dates of certain dependability. Although it was hailed as the answer to the prehistorian's prayer when it was first announced, there has been increasing disillusion with the method because of the chronological uncertainties (in some cases, absurdities) that would follow a strict adherence to published C^{14} dates. This is not to question the physical laws underlying the principle used, or the accuracy of the counters now in operation around the world; the unsolved problem, instead, seems to lie in the difficulty of securing samples completely free from either older or younger adherent carbon. At least to the present, no kind or degree of chemical cleaning can guarantee one-age carbon, typical only of the time of the site from which it was excavated. What bids to become a classic example of C^{14} irresponsibility is the 6,000-year spread of 11 determinations for Jarmo, a prehistoric village in northeastern Iraq, which, on the basis of all archeological evidence, was not occupied for more than 500 consecutive years." (R8)

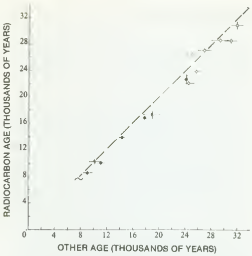
Answers to creationist attacks on carbon-14 dating. An article with this title, by C.G. Weber appeared in the journal Creation/Evolution. (R43) Most of the "answers" appear quite reasonable; some are less satisfying, viz. the young age of old oil (R65). "Question: A sample that is more than fifty thousand years old shouldn't have any measurable C-14. Coal, oil, and natural gas are supposed to be millions of years old; yet creationists say that some of them contain measurable amounts of C-14, enough to give them C-14 ages in the tens of thousands of years. How do you explain this? Answer: Very simply. Radiocarbon dating doesn't work well on objects much older than twenty thousand years, because such objects have so little C-14 left that their beta radiation is swamped out by the background radiation of cosmic rays and potassium-40 (K-40) decay." (R43) The radiocarbon dating of oil, for example, is the work of noncreationists. (R65) They have found enough carbon-14 to measure Gulf of Mexico oil ages, even after the passing of thousands of half-lives. Obviously, the original "question" was not answered. Why is there any measurable carbon-14 in the oil at all? (WRC)



Most carbon-14 calibration curves have variations that allow multiple ages for a single sample. (X1)

Complaints from noncreationists. Abstract. "A detailed comparison of conventional radiocarbon years with calendar years covering the past four centuries is given. Relatively large atmospheric ^{14}C changes are encountered over this time, and even very precise ^{14}C dating cannot entirely solve the problems of age calibration. By matching radiocarbon ages with ages derived from $^{230}Th/^{234}U$, thermoluminescence and magnetic dating, the ^{14}C timescale is shown to deviate by a maximum of 2,000 years over the 9,000-32,000 year BP interval." (R62)

J.G. Ogden, III, director of a radiocarbon dating laboratory despaired, as late as 1977,



A comparison of carbon-14 ages with ages determined by other methods. These include: thorium/uranium dates on lake sediments (○); thermoluminescence dates of basalt (X); and magnetic dates (●). (X1)

as follows: "It may come as shock to some, but fewer that 50 percent of the radiocarbon dates from geological and archaeological samples in northeastern North America have been adopted as 'acceptable' by investigators." Prior to this statement, Ogden had listed several reasons for radiocarbon's disappointing track record. The varying amount of C^{14} in the atmosphere led the list, followed by the discrimination of biological systems between carbon isotopes, the huge quantities of "dead" carbon dumped into the environment since the beginning of the Industrial Revolution, the deficiency of C^{14} in some waters metabolized by organisms, and so on. (R61) Of course, there have been technical improvements and "recalibrations" of the radiocarbon scale since the above papers were written. Still, one must take radiocarbon dates with some degree of skepticism. (WRC)

X2. Potassium-argon (K-Ar) dating. The K-Ar dating method has generated the great majority of discordant radiometric dates in geology.

The standard "open-system" explanation of dating anomalies. From the abstract: "Potassium-argon determinations on 23 muscovite-biotite pairs from the Upper East Alpine Altkristallin of the Eastern Alps yield apparent ages ranging between 79 and 107 m.y. for the muscovite and between 78 and 430 m.y. for the coexisting biotite. The micas appear to be of the same generation and neither differential leaching of potassium nor abnormal blocking temperature relationships are able to explain this discordance. It is concluded that excess radiogenic ^{40}Ar entered the micas in a zone at least 1 1/2 km thick and 200 km^2 in area." The excess argon-40 was thought to have been acquired between 65 and 80 million years ago, when the partial pressure of argon-40 was high. (R16) Here, an outgassing event has been conceived to account for the discordant dates.

Old dates for recent lavas. "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." These lavas were thought to have "inherited" radiogenic argon and helium, which distorted the ages. (R12)

Sea-floor-dating anomalies. Despite the above admonishment, K-Ar dating is often applied to studies of sea-floor spreading, sometimes with anomalous results. "Abstract. Potassium-argon determinations of age from whole-rock samples of tholeiitic basalts, dredged from the crest of the East Pacific Rise and from the flanks of three seamounts at varying distances from the crest, show that the crest is younger than 1 million years and that age does not correlate with distance from the crest. Our data, however, do not necessarily oppose the general concept of spreading of the ocean floor." The authors claim to have observed large amounts of excess argon-40 in some rocks, but that their report "is limited to data that we feel give valid K:Ar ages and that are therefore appropriate to discussion of spreading of the sea floor." (R14) Even with data "selection", the concept of sea-floor spreading is challenged.

Possible underestimation of the earth's age. Although many geologists subscribe to the 4.5 billion-year age for the earth, a Soviet scientific team, headed by E.K. Gerling, claims to have found 6-billion-year-old rocks.

"Professor Gerling and his team used the potassium-40-argon-40 method of radioactive dating on samples of Pre-Cambrian rocks that had been formed at great depths below the Earth's surface. Geologists at the Laboratory have been mapping parts of the so-called Baltic Shield---an old stable region of the crust that covers large areas of Scandanavia, Karelia and the Kola Peninsula. They have recognized in these older rocks some 14 major cycles of geological activity, each culminating in a mountain building phase. Specimens from the most ancient of these formations are responsible for the new result.

"One explanation put forward by the Soviet workers to account for the age discrepancy is that earlier maximum Earth ages were derived from potassium-bearing minerals ---notably mica---occurring at higher levels in the Earth's crust. Their new figure comes from deeper-seated rocks with different minerals for which they had to perfect more sensitive methods of assessing the appropriate isotopes. Thus it may be that the older rocks of the crust are some 2,000 million years younger than those underlying them." (R9) No confirmation or refutation of the 6.5-billion-year figure for the earth's age has been found. (WRC)

Effects of sample purity. "Abstract. The K-Ar dating of more than one mineral from a single rock sample has often revealed widely discordant ages. Where these minerals are mutual contaminants in mineral separates, as in the system biotite-hornblende, mixed ages will result, and these will always tend toward apparent concordance. The 'true' ages of the pure end-member of such mixtures may be very different from the mixed ages. It is not uncommon to find situations where purity levels of 95% or more do not suffice to give geologically meaningful ages. The effects of sample purity on discordant mineral ages can be evaluated and limits determined for the ages of the theoretical mineral components." (R58)

Dating Skull 1470. Skull 1470 was found in association with the so-called KBS-tuff in Kenya. Dating of this tuff has proven very difficult and controversial.

"The fossil skull known as 1470 was found by Richard Leakey in 1972 in Kenya. It has proved a difficult skull to date. When Leakey made his find, he believed the skull was about 2.6 million years old. So he sent samples of the rock in which 1470 was found to Cambridge, England, for dating. Tests on these first samples gave an average age not of 2.6 million years, but of an incredible

221 million years! This was more than 218 million years too great!

"Scientists who did the dating decided the rock they had tested must have been contaminated. So Leakey sent more samples. From these the scientists chose crystals that seemed fresher than others, and they came up with an age of 2.4 million years. (They later adjusted this to 2.6 million years, plus or minus 260,000 years, which agreed well with Leakey's belief before dating tests began.) (How convenient! WRC)

"But dating work on the rock did not stop there. More samples were taken. More tests were done. Results this time ranged from 290,000 years up to 19.5 million years! Trying to bring some sense to the results, paleomagnetic determinations were begun. Leakey's 1470 fossil was then given an age of three million years. But this drew opposition from paleontologists who said it conflicted with the age of animal fossils from the region. Then Dr. Garniss Curtis, from the University of California at Berkeley, said his potassium/argon tests dated the rock at 1.8 million years." (R48) R48, a creationist publication, took the facts in this item from John Reader, Missing Links, London, 1981.

Attitudes toward discordant K-Ar dates. "In conventional interpretations of K-Ar age data, it is common to discard ages which are substantially too high or too low compared with the rest of the group or with other available data, such as the geological time scale. The discrepancies between the rejected and the accepted are arbitrarily attributed to excess or loss of argon." (In R39, quoting Hayatsu, A.; "K-Ar Isochron Age of the North Mountain Basalt, Nova Scotia," Canadian Journal of Earth Sciences, 16:974, 1979.)

X3. Rubidium-Strontium (Rb-Sr) dating. Although no mobile gases are involved here, as in the K-Ar method, many situations being dated are manifestly "open".

Rb-Sr dating of volcanic rocks. Once again, recent volcanic rocks are dated radiometrically as ancient. "An important but commonly overlooked isotopic property of volcanic rocks 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." What the authors propose is that magma rising through ancient rocks pick up constituents which give the volcanic rocks falsely ancient ages. In a sense, age is chemically transferable! (R37)

Complex scenarios are sometimes required to explain discordant ages. Abstract. "Major isotopic age discordances are found at the eastern margin of a terrane in SW Montana which underwent metamorphism 1.6 AE ago (1 AE = 10^9 years). In Portal Creek, a one-mile portion of a traverse across this margin yields: (1) discordant whole rock Rb-Sr ages which approximate 2.8 AE; (2) seven biotite Rb-Sr ages concordant at 1.68 AE; (3) fifteen biotite K-Ar ages which are highly discordant and range from 1.63 to 3.25 AE; (4) ten generally concordant hornblende K-Ar ages at 1.9 AE. It is concluded that there was a major resetting event for the hornblendes at 1.9 AE ago. This was followed by a milder (?) event at 1.6 AE when the biotites became open systems while the hornblendes did not. During this time, the biotites lost all their radiogenic ^{87}Sr, but actually gained radiogenic ^{40}Ar in amounts up to 16 x 10^{-4} scc Ar/g biotite. There is clear evidence of the incorporation of ^{87}Sr into minor amphibolitic layers which occur occasionally in these generally quartzofeldspathic rocks." (R23) While not suggesting that this scenario is incorrect, it does seem that geological systems are so open that a wide variety of radiometric dates can be accounted for. (WRC)

X4. Uranium-lead dating.

Overview of uranium-lead dating problems. "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 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., less than 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."

This report goes on to show how lead removal from the rocks, perhaps through thermal metamorphism, might account for the discordant dates in many instances. (R2)

G. A. Kerkut, in his influential book Implications of Evolution, pointed out some of the problems involved with using the uranium-lead and thorium-lead methods of radiometric dating in attaching age markers to fossil-bearing rocks. Radiometric methods have improved since Kerkut's book was published in 1960, but the problems have not all disappeared:

> "...when the radiogenic methods are applied to more recent rocks, especially those bearing fossils, two serious handicaps arise. The first is that this method can of course only be applied to rocks that contain radiogenic lead; that is, lead derived from uranium or thorium. These rocks are usually pegmatites, i.e. rocks formed from the residues after granite has crystallised out from the liquid mass. This implies that the material at some stage or another has been molten and that therefore it is unlikely to contain fossils. Secondly there are considerable differences in the age as determined from the different ratio of the isotopes 206/207, 206/238, 207/235, or 208/232. Thus Kulp has published a table giving data for forty-five different samples of material, the lead ratios being determined by mass spectrometer; and of these only seven are believed to be accurate to within 5%. Some are very inaccurate, due, it is believed, to the loss of radon by diffusion from the rocks in the series U^{238}/Pb^{206}. Another difficulty is due to the amount of non-radiogenic lead present in the material. Where this is high there is a corresponding high error in the estimation. This can lead to an error of 700 million years in the exceptional case of the Caribou Mine, Colorado, where the deposit contained as much as 97% lead. The correct age of the deposit was 25 million years old." (R53)

Old minerals in younger rocks. "Isotopic analysis of the lead from the galena and pyrite associated with the uranium ores from the Colorado Plateau and the Blind River districts shows that: (1) lead is substantially enriched in radiogenic Pb^{206} and Pb^{207} compared to common leads, and (2) the Pb^{207}/Pb^{206} ages of this radiogenic component are appreciably older than the Pb^{207}/Pb^{206} ages of the uranium ores or the enclosing rocks." The excess radiogenic leads were thought to have been transported from a pre-existing site in solution form. (R4) Once again, mechanisms can be proposed that will explain (?) a wide range of dates. (WRC)

Zircons of great age. Abstract. "We report here the existence of detrital zircons from Western Australia which are far older than any known terrestrial rocks. They are from quartzites at Mt Narryer, a locality which has created interest because of the nearby occurrence of $3,630 \pm 40$ Myr orthogneisses. The older zircons were discovered during reconnaissance U-Pb determinations of zircon concentrates from Archaean metasediments, using the ion microprobe SHRIMP at the Australian National University. These determinations are being made specifically to search for zircons having ages in the interval 3,800-4,500 Myr, a period unrepresented so far by reliable terrestrial age determinations. Grain-by-grain measurements of one particular concentrate revealed four zircons having near-concordant U-Pb ages between 4,100 and 4,200 Myr, in striking contrast to most grains whose ages are ~3,650 and ~3,500 Myr. These results show that pre-3,800 Myr silica-saturated rocks were indeed present on the Earth's crust. (R45) In instances like this, where the age results are not at variance with any strongly held geological theory, no effort is made to 'explain' away the discordance. See X2 for the Soviet discovery of rocks which may be 6 billion years old! (WRC)

Radiometric dates conflict with archeological expectations. Abstract. "In an attempt to date stone artifacts of Early Man excavated from several sites at the Valsequillo Reservoir, a few kilometers south of Puebla, Mexico, Szabo applied the uranium-series method on bone samples known to be either from the same geologic formation as the sites or in direct association with the artifacts. The geologic context of the bones was studied by Malde, and the archaeological sites were excavated by Irwin-Williams. A date determined for bones associated with an artifact (Caulapan sample M-B-6) agrees with a radiocarbon date for fossil mollusks in the same bed and indicates man's presence more than 20 000 years ago. However, some of these bone dates exceed 200 000 years. Because such dates for man in North America conflict with all prior archaeological evidence here and abroad, we are confronted by a dilemma---either to defend the dates against an onslaught of archaeological thought, or to abandon the uranium method in the application as being so much wasted effort. Faced with these equally undesirable alternatives, and unable to decide where the onus fairly lies (if a choice must be made), we give the uranium-series dates as a possible stimulus for further mutual work in isotopic dating of archaeological material." (R15) In actuality, most archeologists contend that man did not arrive in North America earlier than 12, 000 years ago. Further, other evidence for 200, 000-year dates exists. See the Handbook ANCIENT MAN; also, the still-to-be-published Catalog volumes in the M series. (WRC)

X5. Thorium-lead dating. Thorium-232 is radioactive, decaying to lead-208. This method is sometimes used in conjunction with uranium-lead dating.

J. Woodmorappe tabulates several discordant ages obtained by the thorium-lead method, which in addition do not agree with uranium-lead dates for the same samples. (R39)

Granites from Utah, thought to be less than 70 million years old, were radiometrically dated as: 794 million years (Th^{232}/Pb^{208}); 494 million years (U^{238}/Pb^{206}); and 756 million years (U^{235}/Pb^{207})

Granites from eastern Siberia, supposed to be more than 600 million years old, had radiometric ages of: 420 million years (Th^{232}/Pb^{208}); 370 million years (U^{238}/Pb^{208}); and 410 million years (U^{235}/Pb^{207}).

X6. Samarium/neodymium dating. Sm/Nd dating is relatively new. Its problems are generally the same as with the other radiometric methods, as evidenced by the following: "A sequence of basalts and komatiites in the Abitibi Belt, Canada, gives a whole-rock Sm-Nd isochron of 2, 826 ± 64 Ma, but the age of the rocks is well constrained to less than 2, 697 ± 1. 1 Ma by a U-Pb zircon age on stratigraphically-underlying felsic volcanics, suggesting that this systematic error in the Sm-Nd age results from heterogeneity of initial Nd isotopic ratios of the source. Dupre et al. record variable Sm/Nd ratios within an individual flow elsewhere in the Abitibi Belt and conclude that the variation results from contamination due to melting and assimilation of the underlying flow. Thus, both source heterogeneity and contamination could lead to systematic errors in Sm/Nd whole-rock ages." (R47)

X7. General observations. These are keyed to the questions posed in X0.

1. Number and magnitude of radiometric discordances. Interestingly enough, the only comprehensive survey of discordant radiometric dates found so far is by creationist J. Woodmorappe. (R39) He compiles over 350 radiometric dates that "are very anomalous with respect to accepted values for their biostratigraphic positions." By "very anomaalous" Woodmorappe means either more than 20% too high or 20% too low. To support his immense table, he lists 445 references from the scientific literature. But are the results of Woodmorappe's survey significant?

To support the mainstream contention that radiometric dating is dependable A. N. Strahler quotes G. B. Dalrymple:

> Woodmorappe's "argument is specious and akin to concluding that all wrist-watches do not work because you happen to find one that does not keep accurate time. In fact, the number of 'wrong' ages amounts to only a few percent of the total, and nearly all of these are due to unrecognized geologic factors, to unintentional misapplication of the techniques, or to technical difficulties. Like any complex procedure, radiometric dating does not work all the time under all circumstances. Each technique works only under a particular set of geologic conditions and occasionally a method is inadvertently misapplied. In

addition, scientists are continually learning, and some of the 'errors' and not errors at all but simply results obtained in the continuing effort to explore and improve the methods and their application. There are, to be sure, inconsistencies, errors, and results that are poorly understood, but these are very few in comparison with the vast body of consistent and sensible results that clearly indicate that the methods do work and that the results, properly applied and carefully evaluated, can be trusted." (R50)

As if in response to Dalrymple's claim, Woodmorappe observes: "The uniformitarians may contend that there are many more dates in agreement with accepted values than there are anomalies such as all of Table 1. Even if this were true, it would not appear to be an overwhelming majority, and a significant minority of discrepant dates would probably be sufficient to discredit all of radiometric dating. Since most igneous bodies have wide biostratigraphic limits, it is difficult to tell that a date is not anomalous because it could take on many different values and not be anomalous.

"As a matter of fact, the number of determinations used to define 'correct' values for the geologic column are fewer than the anomalies comprising Table 1, except for the Cenozoic and Cretaceous." (R39)

Perhaps readers have already noticed that the methodology employed in compiling our Catalog of Anomalies is basically the same as that used by Woodmorappe in collecting discordant radiometric dates; that is, the searching of the scientific literature and selection of "facts that do not fit." With radiometric anomalies and scientific anomalies in general, just one, well-verified, discordant result can demolish a theory. This has happened over and over again in the history of science. Nevertheless, Woodmorappe, for all of his great labors, does not have that single, undeniable anomaly. This is simply because radiometric dating is too "plastic", given the ubiquity of open systems in geological dating. But neither is radiometric dating finely tuned and always accurate. (WRC)

2. Reasonableness of explanations of discordant dates. As to be expected, geochronologists and creationists have diametrically opposite views here.

Quoting again from A. N. Strahler's synthesis of scientific "mainstream" opinion: "It turns out that in each case discussed in detail by Dalrymple, a satisfactory explanation is available." As before, Strahler refers to G. B. Dalrymple. (R50) It all boils down to what one considers "satisfactory".

Obviously, J. Woodmorappe finds much that is unsatisfactory about radiometric dating. Summarizing his conclusions after an extensive survey of discordant dates, he comments as follows: "The implications of all these findings are enormous. Any discrepant date can be explained away, and a heating or weathering event can be invented whenever necessary for this purpose. No evidence need be found because its absence can be attributed to it being strong enough to make the unwanted date discrepant, but too weak to show up in thin section. An illogical situation arises because at one time it is claimed that radiometric dates have withstood obvious alteration of the rock, while at other times they supposedly were so sensitive that they were made discrepant by an event too weak to alter the rock itself. A skeptical view of radiometric dating looks at all these lacks of correlation of alteration and discrepancy of dates as evidence that they are just rationalizations, and that discrepant dates are not primarily caused by alteration but by the fundamental invalidity of radiometric dating." (R39)

3. Possible variations of half-lives. If the half life (or decay constant) of any of the radioisotopes employed in radiometric dating could be shown to be sensitive to pressure, temperature, the magnetic field, or some other physical parameter, we would have a serious challenge to geochronology. However, many experiments have found only slight changes in very specialized or unusual situations. (R26-R28). A. N. Strahler's conclusion seems justified: "Except for slight observed deviations in three radioisotopes (C-14, Co-60, Ce-137), the decay constants for the three principal forms of decay used in age determination adhere strictly to the ideal random distribution predicted by theory." (R50) It must be noted, though, that some theorists have ventured that some of the fundamental constants of physics, such as the gravitational constant and speed of light, may have changed substantially over the age of the universe. In this view, radioactive decay constants might have changed too, even though they seem stable in today's laboratories. Geochronologists assume that nothing like this happened; indeed, they must assume this if radiometric dating is to have any validity. (WRC)

4. Possible discarding and "fudging" of data. Creationists have long claimed that many discordant radiometric dates are suppressed and never published. (R39) In addition, it

is said that some analyses are fudged to make the answers come out "right". As a matter of fact, Woodmorappe has collected several allusions from the scientific literature to the effect that "editing" and "fudging" does occur. Any experimentalist knows that "wild points" do occur due to errors, malfunctions, and other factors that have little to do with the phenomenon being investigated. Such points can legitimately be exorcised. Beyond this statement of fact, we have found nothing in the literature examined to date to suggest that geochronologists are blatantly unscientific. (WRC)

References

R1. "Ancient Shells Test Older than Charcoal," Science News Letter, 62:280, 1952. (X1)

R2. Kulp, J. L., and Eckelmann, W. R.; "Anomalous Uranium-Lead Ages," Geological Society of America, Bulletin, 66: 767, 1955. (X4)

R3. Eckelmann, Walter R., and Cobb, James C.; "Discordant Uranium-Lead Ages and Mineral Type," Geological Society of America, Bulletin, 67:1690, 1956. (X4)

R4. Stieff, L. R.; "Original Radiogenic Lead in Pb-U Dating," Geological Society of America, Bulletin, 67:1825, 1956. (X4)

R5. Antevs, Ernst; "Geological Tests of the Varve and Radiocarbon Chronologies," Journal of Geology, 65:129, 1957. (X1)

R6. Miller, Donald S.; "Colorado Plateau Uranium Lead Age Problem," Geological Society of America, Bulletin, 70:1645, 1959. (X4)

R7. Zimmerman, Paul A., ed.; "The Age of the Earth," Darwin, Evolution, and Creation, Saint Louis, 1959, p. 142. (X4)

R8. Reed, Charles A.; "Animal Domestication in the Prehistoric Near East," Science, 130:1630, 1959. (X1)

R9. "Earth's Age Much Underestimated?" New Scientist, 14:720, 1962. (X2)

R10. "Soviet Glaciers Only 500 Years Old?" New Scientist, 22:38, 1964. (X1)

R11. McCulloch, D. S.; "Quaternary Geology of the Alaskan Shore of the Chukchi Sea," in The Bering Land Bridge, David M. Hopkins, ed., Stanford, 1967, p. 110. (X1)

R12. Noble, C. S., and Naughton, J. J.; "Deep-Ocean Basalts: Inert Gas Content and Uncertainties in Age Dating," Science, 162:265, 1968. (X2)

R13. Cook, Melvin A.; "Do Radiological Clocks Need Repair?" Creation Research Society Quarterly, 5:69, 1968. (X7)

R14. Fisher, David E., et al; "Ages of Pacific Deep-Sea Basalts, and Spreading of the Sea Floor," Science, 160:1106, 1968. (X2)

R15. Szabo, Barney J., et al; "Dilemma Posed by Uranium-Series Dates on Archaeologically Significant Bones from Valsequillo, Puebla, Mexico," Earth and Planetary Science Letters, 6:237, 1969. (X4)

R16. Brewer, M. S.; "Excess Radiogenic Argon in Metamorphic Micas from the Eastern Alps, Austria," Earth and Planetary Science Letters, 6:321, 1969. (X2)

R17. Wanless, R. K., et al; "Excess Radiogenic Argon in Biotites," Earth and Planetary Science Letters, 7:167, 1969. (X2)

R18. Laughlin, A. William; "Excess Radiogenic Argon in Pegmatite Minerals," Journal of Geophysical Research, 74: 6684, 1969. (X2)

R19. Whitelaw, Robert L.; "Radiocarbon and Potassium-Argon Dating in the Light of New Discoveries in Cosmic Rays," Creation Research Society Quarterly, 6:71, 1969. (X7)

R20. Brown, R. H.; "Radioactivity Dating Indicates a Young Earth," in Why Not Creation?, Walter E. Lammerts, ed., Grand Rapids, 1970, p. 80. (X7)

R21. Ozima, Minoru, et al; "K-Ar Ages of Submarine Basalts Dredged from Seamounts in the Western Pacific Area and Discussion of Oceanic Crust," Earth and Planetary Science Letters, 8:237, 1970. (X2)

R22. Fisher, David E.; "Comments on 'K-Ar Ages of Submarine Basalts Dredged from Seamounts in the Western Pacific Area and Discussion of Oceanic Crust' by M. Ozima, I. Kaneoka, S. Aramaki," Earth and Planetary Science Letters, 9: 310, 1970. (X2)

R23. Giletti, Bruno J.; "Discordant Isotopic Ages and Excess Argon in Biotites," Earth and Planetary Science Letters, 10: 157, 1971. (X2, X3)

R24. Bender, Michael L.; "The Reliability of He/U Dates on Corals," Eos, 52:366, 1971. (X6)

R25. Hofmann, A.; "Discordant Radiometric Ages from Metamorphosed Belt-Series Sediments, Northern Idaho," Eos, 53: 543, 1972. (X2, X3)

R26. Emery, G. T.; "Perturbation of Nuclear Decay Rates," Annual Review of Nuclear Science, 22:165, 1972. (X7)

R27. Anderson, John Lynde; "Non-Poisson Distributions Observed during Counting of Certain Carbon-14-Labeled Organic (Sub) Monolayers," Journal of Physical

Chemistry, 76:3603, 1972. (X7)
R28. Anderson, John Lynde, and Spangler, George Wesley; "Serial Statistics: Is Radioactive Decay Random?" Journal of Physical Chemistry, 77:3114, 1973. (X7)
R29. Slusher, Harold S.; Critique of Radiometric Dating, Institute for Creation Research, Technical Monograph No. 2, 1973. (X0)
R30. Stearns, Harold T.; "Potassium-Argon Ages of Lavas from the Hawi and Pololu Volcanic Series, Kohala Volcano, Hawaii: Discussion," Geological Society of America, Bulletin, 84:3483, 1973. (X2)
R31. Nevins, Stuart E.; "Post-Flood Strata of the John Day Country, Northeastern Oregon," Creation Research Society Quarterly, 10:191, 1974. (X2)
R32. Morris, Henry M.; "Old or Young?" Scientific Creationism, San Diego, 1974, p. 137. (X0-X7)
R33. Mangerud, Jan, and Gulliksen, Steinar; "Apparent Radiocarbon Ages of Recent Marine Shells from Norway, Spitzbergen, and Arctic Canada," Quaternary Research, 5:263, 1975. (X1)
R34. Daly, Reginald; "Origin of Oil: from Animals Buried by Flood," Earth's Most Challenging Mysteries, Nutley, 1975, pp. 227 and 264. (X1)
R35. Gill, Edmund D.; "Age of Australite Fall," Journal of Geophysical Research, 75:996, 1975. (X1)
R36. Wysong, R. L.; "Youth or Antiquity?" The Creation-Evolution Controversy, East Lansing, 1976, p. 145. (X0, X1)
R37. Brooks, C., et al; "Ancient Lithosphere: Its Role in Young Continental Volcanism," Science, 193:1086, 1976. (X3)
R38. Moorbath, Stephen, and Schramm, N.; "Anomalous Cosmochronology... and Geochronological Anomalies," Nature, 275:478, 1978. (X3, X4)
R39. Woodmorappe, John; "Radiometric Geochronology Reappraised," Creation Research Society Quarterly, 16:102, 1979. (X0-X7)
R40. Campbell, J. A., and Baxter, M. S.; "Radiocarbon Measurements on Submerged Forest Floating Chronologies," Nature, 278:409, 1979. (X1)
R41. Baxter, M. S., et al; "Fossil Carbon in Coastal Sediments," Nature, 287:35, 1980. (X1)
R42. Nambudiri, E. M. V., et al; "Pre-Quaternary Microfossils---A Guide to Errors in Radiocarbon Dating," Geology, 8:123, 1980. (X1)
R43. Weber, Christopher Gregory; "Answers to Creationist Attacks on Carbon-14 Dating," Creation/Evolution, 3:23, Spring 1982. (X1)
R44. Odin, G. S., et al; "Numerical Dating of Precambrian-Cambrian Boundary," Nature, 301:21, 1983. (X2, X3)
R45. Froude, D. O., et al; "Ion Microprobe Identification of 4,100-4,200 Myr-Old Terrestrial Zircons," Nature, 304:616, 1983. (X4)
R46. Riggs, Alan C.; "Major Carbon-14 Deficiency in Modern Snail Shells from Southern Nevada Springs," Science, 224:58, 1984. (X1)
R47. Bickle, M. J.; "Suspect Sm-Nd Whole-Rock Ages," Nature, 312:702, 1985. (X6)
R48. "1470 Skull and Radiometric Dating," Ex Nihilo, 8:9, September 1986. (X2)
R49. Chaffin, Eugene F.; "A Young Earth?---A Survey of Dating Methods," Creation Research Society Quarterly, 24:109, 1987. (X1, X5, X7)
R50. Strahler, Arthur N.; "Age of the Solar System and Earth," Science and Earth History, The Evolution/Creation Controversy, Buffalo, 1987, p. 129. (X0-X7)
R51. Wasserburg, G. J., et al; "A^{40}/K^{40} Ages of Micas and Feldspars from the Glenarm Series near Baltimore, Maryland," Science, 126:355, 1957. (X3)
R52. Broecker, W. S., and Kulp, J. L.; "Lamont Natural Radiocarbon Measurements IV," Science, 126:1324, 1957. (X1)
R53. Kerkut, G. A.; "Radioactive Dating of Rocks," Implications of Evolution, New York, 1960, p. 137. (Cr. R. Calais) (X4)
R54. Keith, M. L., and Anderson, G. M.; "Radiocarbon Dating: Fictitious Results with Mollusk Shells," Science, 141:634, 1963. (X1)
R55. Keith, M. L., and Anderson, G. M.; "Radiocarbon Dating of Mollusk Shells: A Reply," Science, 144:890, 1964. (X1)
R56. Berger, Rainer, et al; "Radiocarbon Content of Marine Shells from the California and Mexican West Coast," Science, 153:864, 1966. (X1)
R57. Funkhouser, John G., and Naughton, John J.; "Radiogenic Helium and Argon in Ultramafic Inclusions from Hawaii," Journal of Geophysical Research, 73:4601, 1968. (X2)
R58. Engles, Joan C.; "Effects of Sample Purity on Discordant Mineral Ages Found in K-Ar Dating," Journal of Geology, 79:609, 1971. (X2)
R59. De Young, Don B.; "The Precision of Nuclear Decay Rates," Creation Research Society Quarterly, 13:38, 1976. (X7)
R60. Tyler, David J.; "The Crisis in Radiocarbon Calibration," Creation Research Society Quarterly, 14:92, 1977. (X1)

R61. Ogden, J. Gordon, III; "The Use and Abuse of Radiocarbon Dates," New York Academy of Sciences, Annals, 288:167, 1977. (Cr. R. Calais) (X1)
R62. Stuiver, Minze; "Radiocarbon Timescale Tested against Magnetic and Other Dating Methods," Nature, 273:271, 1978. (X1)
R63. Lee, Robert E.; "Radiocarbon: Ages in Error," Anthropological Journal of Canada, 19:9, 1981. (Cr. R. Calais) (X1)
R64. Lee, Robert E.; "Radiocarbon: Ages in Error," Creation Research Society Quarterly, 19:117, 1982. (X1)
R65. Smith, Paul V., Jr.; "The Occurrence of Hydrocarbons in Recent Sediments from the Gulf of Mexico," Science, 116:437, 1952. (X1)

ESP13 Zones Where Natural Fission Reactors May Have Existed

Description. Geological localities where the fissionable isotope uranium-235 is depleted and where high concentrations of fission products are found.

Data Evaluation. Data for one suspect zone (Oklo, Gabon) are excellent. Signs are suspicious in a few other areas, but so far no definite evidence for natural chain reactions has been profferred. Rating: 1.

Anomaly Evaluation. Given the higher concentrations of uranium-235 in the distant past (half-life only 710 million years), the occasional coming together of sufficient uranium-235, water moderator, and absence of such reactor poisons as boron is not too surprising. In fact, one wonders why only one relatively certain site has been found. The characteristics of the Oklo site are completely in accordance with current theory, so no anomaly can be claimed. The phenomenon is interesting, however, and may have a bearing on biological evolution. Rating: 4.

Possible Explanations. Natural fission reactions.

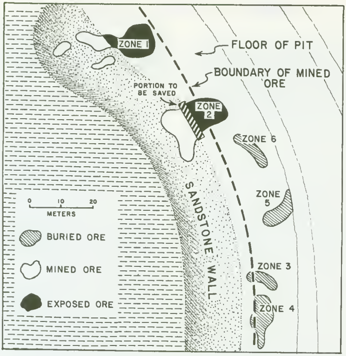
Similar and Related Phenomena. Uranium-lead age discordances (ESP12); radio halos (ESP1); biological evolution (B).

Examples

X0. Introduction. The primary evidence for the past presence of natural fission reactors comes in the form of uranium ores that are depleted in the fissionable isotope uranium-235. Ordinarily, such an isotope anomaly would be classified under ESC2. Here, however, we make an exception because of the concomitant physical considerations in creating a self-sustaining chain reaction, such as the presence of a neutron moderator, reactor poisons, etc.

X1. Oklo, Republic of Gabon. From a report in Nature about an international symposium held in Gabon in 1975:

"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. V. 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,



Six of the natural nuclear reactor zones at Oklo were located in lenses of exceptionally rich ore. (X1) (Adapted from R7)

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, by several scientists, notably by P.K. Kuroda as early as 1956." (R6)

Results of later investigations. "Investigations have shown that there was not just one reactor at Oklo; at least six 'reaction zones' over a relatively small area (a few thousand square metres) have been identified. A question exercising not a few minds was whether one of these was a 'primary' reactor and the others either secondaries or its lineal descendants. The reactors, like reproducing organisms, seem to have been 'propagating' themselves. Naudet, in true detective story style, termed this the 'Oklo mystery'! The age of the phenomenon has now been put back from ~1,800 Myr to nearer 2,000 Myr; the duration of the entire drama at Oklo, from the first spark to the last smoulderings of the atomic fuel has also been extended from ~500,000 years to ~2 (or perhaps several) Myr." (R8) The Naudet mentioned is R. Naudet, a French scientist.

It is believed that the Oklo reaction zones reached 400°C. The Oklo zones are anomalous in two other ways: (1) there is a near-absence of quartz in the high-grade ores; and (2) no one can say how relatively low-grade ore (0.2 to 0.9% U_3O_8) was concentrated to 5 to 70%. (R9)

X2. Okelobondo, 1 kilometer south of Oklo. Ore at this site also seems to have sustained natural fission reactions. (R9)

X3. The Colorado Plateau. Sedimentary deposits of the Colorado Plateau are depleted in uranium-235 by about 0.03%. Since the total uranium reserves of the Plateau are estimated to be 400,000 tons, there has been a net loss of some 5 tons of uranium-235. This represents considerable fission energy and suggests the possibility of natural fission reactors. (R7)

X4. Rabbit Lake, Canada. The uranium ore deposits here are younger and not as richly concentrated as those at Oklo. Nevertheless, the uranium distribution is very inhomogeneous, and there are indications of isotopic redistribution. There are, however, no direct signs of the past presence of natural fission reactors. (R3)

X5. Implications of the Oklo phenomenon.

Biological evolution. "Most ideas concerning the early evolution of life on Earth require sources of energy to produce chemical and biological changes. In a recent paper in Precambrian Research (vol 20, p 283), three scientists argue that the radiation from natural nuclear reactors could have played an important role on Precambrian Earth, roughly 1-4 thousand million years ago. The effects of natural radiation are generally regarded as too small to have influenced early evolution, but then the possible existence natural reactors has also been largely neglected." Since uranium-235 has a half-life of only 710 million years, there would have been much higher concentrations of this fissionable isotope in the earth's early history. Some scientists argue that even small deposits of uranium might have supported chain reactions 3 billion years ago. The radiation emitted by them could have been important mutagenic agents. (R10; R12)

Certainly, if natural fission reactors were common during the early days of earth, the natural abundances of uranium and lead isotopes would have been skewed by fission and transmutation. Radiometric dating might have been compromised in some areas. (WRC)

References

R1. Sullivan, Walter; "A Natural Nuclear Reaction," New York Times, September 26, 1972. (X1)

R2. Smith, Peter J.; "The Oklo Phenomenon," Nature, 252:349, 1974. (X1)

R3. Drozd, R.J., et al; "Heavy Rare Gases from Rabbit Lake (Canada) and the Oklo Mine (Gabon): Natural Spontaneous Chain Reactions in Old Uranium Deposits," Earth and Planetary Science Letters, 23:28, 1974. (X1, X4)

R4. Lancelot, Joel R., et al; "The Oklo Natural Reactor: Age and Evolution Studies by U-Pb and Rb-Sr Systematics," Earth and Planetary Science Letters, 25:189, 1975. (X1)

R5. Naudet, Roget; "Oklo: des Reacteurs Fossiles," La Recherche, 6:508, 1975. (X1) (Cr. C. Maugé) (X1)

R6. Durrani, S.A.; "Nuclear Reactor in the Jungle," Nature, 256:264, 1975. (X1, X5)

R7. Cowan, George A.; "A Natural Fission Reactor," Scientific American, 235:36, July 1976. (X1, X3)

R8. Durrani, S.A.; "Natural Fission Reactors---Oklo Style," Nature, 271:306, 1978. (X1)

R9. Brookins, Douglas C.; "Oklo Reactor Re-Analyzed," Geotimes, 23:27, March 1978. (X1, X2)

R10. "Natural Reactors Helped Evolution," New Scientist, 100:737, 1983. (X5)

R11. Sheng, Z.Z., and Kuroda, P.K.; "The Alpha-Recoil Effects of Uranium in the Oklo Reactor," Nature, 312:535, 1984. (X1)

R12. Draganic, I.G., et al; "Natural Nuclear Reactors and Ionizing Radiation in the Precambrian," Precambrian Research, 20:283, 1983. (X5)

ESP14 Musical Sands

Description. Sand that produces surprisingly loud sounds when disturbed. Three distinct categories are recognized here: (1) Booming sand, occurring rarely and usually in desert regions, and which is sonorous when flowing sheet-like down the sides of sand dunes; (2) Squeaking beach sand, occurring rather frequently on sea, lake, and river beaches; and (3) Squeaking sand that is sonorous only when wet (types 1 and 2 must be very dry) and rubbed between the fingers. Except for some Hawaiian musical sands, booming sand does not squeak and vice versa.

Background. Travellers have commented on musical sand for centuries. Scientific attention arrived in the 1880s, when H. C. Bolton, C. Carus-Wilson, and others collected samples of musical sand worldwide and experimented with them in attempts to discover why they were sonorous. Their results were inconclusive and even contradictory. Interest in musical sands has revived in recent years, but even with modern methods scientists are still unsure which theories of sound generation are correct for each type of musical sand.

Data Evaluation. Data are abundant for booming sands and squeaky beach sands; they include both field observations and laboratory analyses. Recently, geophones and microphones have been carried into the field. On the other hand, squeaky wet sand (type 3 above) seems to be very rare and has received little attention. Rating: 1.

Anomaly Evaluation. Even though we do not know which, if any, of the various proposed theories of musical sands are correct, it is clear that no important tenets of geology are at risk here. Musical sands are curious and fun to investigate. Rating: 3.

Possible Explanations. Perhaps simplistically, some investigators have stated that squeaky sands (types 2 and 3 above) are sonorous due to friction between the grains created by shear forces. This kind of theory does not really tell us how the sound waves are set up and why some sands are musical and others not! Booming sands may be the consequence of rapidly flowing sheets of sand which vibrate something like the diaphragm in a loudspeaker.

Similar and Related Phenomena. Ringing rocks (ESP6); desert hums (GSM6).

Examples

X0. Introduction. Musical sand is not especially rare. Worldwide, it may be found in several score locations, both along beaches and in deserts. Since it is impractical to describe every occurrence, we mention only those for which we have substantive information and supplement these with some survey results (X20). The final entry (X21) summarizes various attempts at explanation.

X1. Sinai Peninsula (Jebel Nagous or "The Mountain of the Bell"). Known for centuries, this is the classical example of booming dunes.

"About four and one-half hours northwest of Tor is the long detached mountain known as Jebel Nagous (or Abu Suweirah). On the steep slopes of this mountain rest several large banks of sand; one of these, which I distinguish by the name Seetzen's Bell Slope, after its discoverer, emits distinct musical sounds whenever the sand slides down the incline either spontaneously or through the agency of man. The mountain consists of massive white sandstone carrying quartz pebbles and veins; it is about three miles long and 1,200 feet high. The huge Bell slope measures 260 feet across the base, five or six feet across the top and is 390 feet high; it is bounded by nearly vertical walls of sandstone. The yellowish white sand rests on the rocks at the high angle of 31^{o}, is very fine grained, and composed chiefly of quartz and calcareous sandstone. The grains are well rounded to subangular, and silt is notably absent. As the sand reposes at a high angle it possesses a curious mobility which causes it to flow down the incline like soft pitch or molasses; the sand above the point of disturbance falls into the depression and this depression advanced up the slope at the same time. This downward flow takes place spontaneously whenever the sand, forced up the incline by the violent winds, accumulates in such quantity as to exceed the angle of rest. The movement is accompanied by a strong vibration and by a musical tone resembling the lowest bass note of an organ with a tremulo stop. The larger the bulk of sand moved the louder the sound; it is by no means so sensitive as the sand of so-called singing beaches (which I have described elsewhere), and fails to emit sounds when struck with the hand or clapped together in a bag. The vertical cliffs on either side yield an echo that may magnify and prolong the sounds, which were loud enough to be heard several hundred feet. The peak of Jebel Nagous rises above the Slope to the height of 955 feet above the sea level.

"The sand of the Slope is derived partly from disintegration of the rock itself and partly from the more distant plain below, from which violent winds blow it up on to the mountain side.

"The Bedouins of the region account for the acoustic phenomenon by attributing it to the Nagous or wooden gong of a subterranean monastery in the heart of the mountain, and claim the sounds can only be heard at the hours of prayers.

"Several other sandbanks presenting a similar appearance to the eye were tested but gave out no musical sounds whatever. Microscopical examination of these sands shows that they contain much silt, which prevents the vibrations necessary to yield the sounds. After careful study, however, of Seetzen's Bell Slope I became convinced that the phenomena could not be unique in the desert as supposed, and I made systematic search for another locality. After testing many sandbanks on the journey northward to Suez I discovered, April 6th, banks of sonorous sand resting on low cliffs a quarter of a mile long. This new locality is in Wadi Werdan about a day and a half from Suez, and is on hillocks called Ojrat Ramadan." (R21)

H. S. Palmer describes the Jebel Nagous sounds more thoroughly: "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 like 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 closely 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." (R4)

The Jebel Nagous sounds are also mentioned in R1-R3, R5, R6, R12, R15, R22, R35.

X2. Kauai, Hawaii (The "barking sands of Hawaii").

"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 the 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 this vine gave sounds at intervals 160 paces westward. At 94 paces further the sand was non-sonorous." (R23)

Profferred explanations. Two interesting theories for the "barking sands" were proposed over a century ago. Of course, they also apply to the many other occurrences of musical sand. The first is by H. C. Bolton; the second, J. Blake.

"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." (R23)

"Dr. James Blake, of the California Academy of Sciences, has investigated with the microscope the structure of the Kauai sand, and states that the grains are chiefly composed of small portions of coral, and apparently calcareous sponges. They are all more or less perforated with small holes, mostly terminating in blind cavities, which are frequently enlarged in the interior, communicating with the surface by a small opening. The structure of the grains, Dr. Blake thinks, fully explains the reason why sounds are emitted when they are set in motion. The mutual friction causes vibrations in their substance, and consequently in the sides of the cavities; and, these vibrations being communicated to the air in the cavities, the result is sound. There are, in fact, millions upon millions of resonant cavities, each giving out a sound which may well acquire a great volume and even resemble a peal of thunder. The sand must be dry, however, in order to produce sound; for, when the cavities are filled with water, the grains are incapable of originating vibrations." (R7) See X21 for more recent theoretical attempts.

Other references to the "barking sands": R9, R24, R27, R31, R37, R65.

X3. The island of Eigg, the Hebrides. "In a small bay---about a mile and a half along the shore to the north of Laig Bay---known as Camas Sgiotaig, musical sands occur. This bay is divided into two portions by a reef of calcareous sandstone jutting out from the cliffs seawards. In both portions, but especially close to the cliffs, a white quartzose sand has accumulated, and this is the only place where musical sands are found in Eigg.

"The sands are derived from the waste of the calcareous sandstone referred to. In places the grains have accumulated in small rifts and cavities in the rocks and in all it was found to be equally musical, showing that long, flat stretches of sand are not essential conditions for the selective action of the winds and sea-waves.

"The usual experiments with various vessels and plungers, &c., were carried out in situ, and the musical effects in all cases were much more pronounced than those produced by the Studland Bay sand.

"An extraordinary volume of sound was obtained by dragging the convex part of a wooden bowl along the surface of the sand patches, one of which was only about 6 feet square. When the same bowl was partially filled, and the sand struck with a wooden plunger, it emitted a noise like the deep bark of a dog, and this could be heard for a considerable distance along the shore.

"These musical sands are found only in

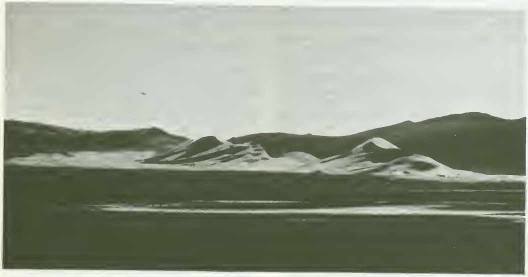
calm weather; in the winter the huge waves carry away all the fine matter, and only the rocks remain---for which reason we must regard it as a fine-weather phenomenon in this island." (R42; R8)

X4. The Inguidi, Africa. "M. Lenz, in a communication made recently to the French Geographical Society, on his journey to Timbuctoo, says that in the Inguidi, a region of sand dunes, he observed the equally rare and interesting phenomenon of resounding or musical sand. 'All at once,' he said, 'there was heard in the desert, issuing from a dune of sand, a prolonged, muffled sound, quite like the sound of a trumpet. It continued for some seconds, then ceased, to be resumed in another direction. The phenomenon made the traveler anxious. I suppose it was occasioned by the friction upon each other of the burning grains of quartz, which are simply placed one by the other, and are continually in motion." (R10; R11)

X5. Sand Mountain, Nevada. Also called the "Singing Mountain", this booming sand dune is 5 kilometers north of U.S. Highway 50, about 25 kilometers southeast of Fallon, Nevada. We present an older, more subjective description and a recent instrumented study.

"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 pinhead. It is so fine that if an ordinary barley sack be filled and placed in a moving waggon (sic), 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 telephone 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." (R13; R18, R20, R57)

"In June 1973, simultaneous seismic and acoustic recordings were conducted at Sand Mountain utilizing a vertical-axis geophone (4.4 Hz resonance frequency) and a wide band (1 to 20,000 Hz) air microphone..... At the time of the visit, the dune sand was extremely dry. Sand at most places on the dune, but especially on the ridge line, could be made to produce a sound by setting in



Sand Mountain, Nevada, noted for its booming sand. (X5) (J.F. Lindsay) motion a mass of sand more than 10 to 15 cm in thickness. On the gentler slopes at the base of the dune, slumping had to be induced artificially; however, higher on the dune where the slope exceeded 52 percent (27°), sound-producing avalanches were readily initiated. Aural observations during the traverse were comparable with earlier descriptions of other booming dunes. Only a single frequency was heard during the first second of an avalanche. After two or three seconds, however, a much lower beat frequency was established. It was possible to stand on the firm subbase of the sand while the upper layers of sand flowed ankle deep around one's feet and feel the vibration produced by the avalanche." During the experiments, the geophone recorded a clean, extremely sinusoidal tone comparable to what one would obtain from a fine string instrument. The air microphone record was more complex and appeared above the noise level 0.05 to 0.1 second before any appreciable signal on the geophone. The tone recorded by the geophone was at 66 Hertz, while the microphone showed two pronounced peaks at 61 and 66 Hertz, with lesser peaks above 100 Hertz. (R65; R64)

X6. Lake Champlain. A beach about 4 1/2 miles south of Plattsburg, New York.

"The acoustic phenomena previously described in connection with Manchester and Eigg are reproduced at Lake Champlain quite perfectly. On the occasion of our visit, however, the sand retained traces of moisture, and the noise, indicated by the syllable groosh, was less strong than it would otherwise have been. Two tests, however, showed that the sound made by rubbing the sand with the hand, and pressing it on the strata below, could be heard distinctly at a distance of more than a hundred feet. The tingling sensation in the toes, produced by striking the sand with the feet, was also perceived. We failed, however, to obtain sounds by rubbing the sand between the palms of the hands,---a method which yielded remarkable results at Manchester and at Eigg; but this failure is doubtless due to the imperfect dryness of the sand. Having learned, by experience with samples from the aforesaid localities, that they lose their acoustic properties after repeated friction, we tested this question directly on the beach. We found, that, by rubbing a definite quantity of sand continuously, it power of emitting sounds gradually diminished, and finally ceased." (R14) It is not clear what this rubbing test shows. Is the sonorousness of sand due to something on the surface of the sand grains? (WRC)

X7. Manchester, Massachusetts (The "singing beach"). "The beach at Manchester forms a small crescent about three-quarters of a mile long, and is terminated at each end by bold promontories of granite, rich in feldspar, and intersected by numerous dykes of igneous rocks among which porphyritic diorite is noticeable. The beach sand resembles at first sight ordinary sea-shore sand, but when struck by the foot, or stroked by the hand, yields a peculiar sound which may be likened to a subdued crushing; the sound is of low intensity and pitch, and is not metallic nor crackling. This phenomenon is confined to that part of the beach lying between water-line and loose sand above the reach of ordinary high tide. Some parts of the beach emit a louder sound than others. The sounding sand is near the surface only; at the depth of one or two feet the acoustic properties disappear, probably owing to the moisture. Only the dry sand has this property. The sounds occur when walking over the beach, increase when the sand is struck obliquely by the foot, and can be intensified by dragging over it a wooden pole or board. A slight noise is perceptible upon mere stirring by the hand, or upon plunging one finger into the sand and suddenly withdrawing it." (R16; R17)

X8. South Africa. On the west side of Langberg mountain, Griqualand West, there is a peculiar sand formation with musical properties. (R25; R32)

X9. Afghanistan (Rig-i-Rawan). "From Kala'h-i-Kih to the Harut-Rud there is a distance of 16 miles in a due westerly direction, and at the fifth mile the famous Ziarat of Iman Zaid is passed on the right of the road. This Ziarat, which is called the Rig-i-rawan, or moving sand, is most remarkable and singular. At the extreme west of the range of hills which has been described as lying in a straight line due north of the Kala'h-i-Kih district, is a hill some 600 feet high and half a mile long. The southern face of this hill, to the very summit, is covered with a drift of fine and very deep sand, which has evidently been there for ages, as testified by the number of large plants growing on its surface. None of the adjacent hills have any traces whatever of sand-drift, and the surface of the surrounding desert is hard and pebbly. The westernmost portion of this elevated ground contains the Ziarat, and the natives say, and with reason and truth, that at times the hill gives out a strange startling noise, which they compare to the rolling of drums. Captain Lovett, who was fortunate enough to hear it, describes its effect upon him as like the wailing of an aeolian harp, or the sound occasioned by the vibration of several telegraph wires---very fine at first, but increasing every moment in volume and intensity, and the secret strain is said sometimes to last as long as an hour at a time. The face of the hill is concave, its cavity is filled with the sand, and underneath there appears to be a hard limestone surface. It would be useless, after a summary inspection, to hazard an opinion as to the cause of the remarkable sounds that proceed from the hill; but it is noticeable that they may be produced by any large number of men, at the top, putting the sand in motion. It should be remarked at the same time that the noise is often heard in perfectly still weather, and when nobody is near the hill; and it is singular, also, that the limit of the sand at the bottom seems never to be encroached upon by falling sand from the summit, though the face of the hill and sand-drift is very steep. On watching the sand this morning, at the time he heard the sound, Captain Lovett observed that its vibrations and the movements of the pilgrims who had gone to the summit of the drift, occurred at the same moment. The natives, of course, ascribe miraculous properties to the hill. It is believed to be the grave of the Imam Zaid, the grandson of Husain, the son of Ali. Tradition says that, being pursued by his enemies, he came to this hill for refuge, was covered one night by the miraculous sand-drift, and has never been seen again." (R36)

X10. Poole Harbour, England. "The beach now, between each groyne, consists of wide and flat deposits of sand, shells, and flint pebbles, but about midway between the dunes and the sea, where the sand is comparatively free from these, musical zones are of frequent occurrence.

"In walking along the shore in a westerly direction, starting from the first groyne, the sounding qualities of the sand notably increase. Thus between the first and second groynes there are no musical patches, between the second and third the sounds are very faint, and between each of the other groynes, until one reaches the last at the Haven Point, the intensity of the sound increases. In a small cove at the Point, formed by the last groyne (constructed of barrels of concrete and an old ship), the sand is remarkably musical.

"The increase of sound observed when walking in a westerly direction is due, I think, to the fact that the prevailing westerly winds, and the littoral drift, separate the finer particles from the sand and carry them eastwards, and a microscopic examination of samples obtained from distances about a mile apart on this shore confirms this." (R38)

X11. Copiapo, Chile. A few miles west of Copiapo, at a place called El Punto del Diablo, is located a ravine filled with windblown beach sand. "On our arrival we found that the sands were quite silent, but on making a glissade down the slope a gradually increasing 'rumble' was heard, which increased in volume as the sand slid away before us. As the sound increased we were subjected to an undulatory movement, so decided that it was difficult to keep one's balance, and as we both had heard that this sand had swept over an old silver mine, there was a clear impression on the minds of both that the vibration might break in the roof of the old workings. I write of this experience for what it is worth. I do not know whether the ground under the sand was hollow or solid. . . ." (R39)

X12. Khotan, China. "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 was and west and 40 li north and south. It reaches a height of 500 ft. The whole mass is entirely consitiuted 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.'" (R43)

X13. The Singing Sands of Lake Michigan. "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 the 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 the loudest, other conditions being the same, but it can clearly be 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." (R44)

E.O. Fippin has recounted how a sack of Lake Michigan's singing sand was shipped to the Bureau of Soils, in Washington. Some months after arrival, presumably now much drier, the sand had lost its singing property. (R46)

X14. Naifa, in the "empty quarter" of Arabia. Quoting H. St. J. B. Philby: "Quite suddenly the great amphitheatre began to boom and drone with a sound not unlike that of a siren or perhaps an aeroplane engine---quite a musical, pleasing, rhythmic sound of astonishing depth. Only once before had I heard the phenomenon of the famous 'Singing Sands' ---near the tumbled dunes of Badr between Yanbu' and Madina in July, 1928,---but on that occasion I had heard them only from afar. Here at Naifa the conditions were ideal for the study of the sand concert, and the first item was sufficiently prolonged---it lasted perhaps about four minutes---for me to recover from my surprise and take in every detail... The key to the situation was Sa'dan, seated on top of the slope. It was evident that the music was being engendered by the sand sliding down the steep slope from under him... When he came down, having had enough of that form of amusement, I went up in his place armed with a bottle (to collect a sample of the sand), notebook and watch." (R52; R51, R55)

X15. South Africa (the roaring sands of the Kalahari Desert). An account by A.D. Lewis: "They lie at the south end of an elongated patch of whitish sand dunes near the southeast 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." (R53)

X16. Nan-hu, the Gobi Desert, longitude 95°E, latitude 40°N. The account of M. Cable after ascending one of the sand dunes: "The downward stretch of the soft slope was an irresistible inducement to slide, and we all came down with a rush, bringing the sand with us like a cataract. Then, for the first time, we experienced the strange sensation of vibrant sands, for as we slid a loud noise came from the very depths of the hill on which we were, and simultaneously a strong vibration shook the dune as though the strings of some gigantic musical instrument were twanged beneath us. We had, unknowingly, chosen for our slide one of the resonant surfaces of the hill, for, curiously enough, only a few of the dunes are musical and most of them are as silent as they are dead." (R54)

Two comments here: (1) Unlike the musical sand on beaches, sound does not seem to be noticed while simply walking through the sand; and (2) once again, only a very few dunes have musical properties, even though they seem identical. (WRC)

X17. Southwestern Egypt. R. A. Bagnold recounts an experience with booming dunes. "'I have heard it,' he says, 'in southwestern Egypt 300 miles from the nearest habitation. On two occasions it happened on a still night, suddenly---a vibrant booming so loud that I had to shout to be heard by my companion. Soon other sources, set going by the disturbance, joined their music to the first, with so close a note that a slow beat was clearly recognized. This weird chorus went on for more than five minutes continuously.'" (R55)

X18. Kremenchug, USSR. "As a result of deepening the channel of the River Dnieper below the town of Kremenchug a small artificial island of sand was formed. This sand ... when trodden on emits a singing sound. Neither very dry nor very wet sand will sing. As a rule the sand emits a high pitch in the morning and a lower pitch towards the evening." (R58) One would not expect dredged sand to be well-sorted or free of fine silt, as deemed necessary in some theories. (WRC)

X19. The Sahara Desert (the booming sands of Korizo). The booming sand from this dune, in southern Libya, cannot be made to emit sound when removed from the desert. The author notes that some desert booming sand remains musical when removed from its dune, but that all squeaking sand from beaches, or almost all, can be made to emit sound in the laboratory. (R59)

X20. Geographical surveys of musical sands. Few scientists have paid much attention to the mysteries of musical sand. Perhaps they do not seem important enough! We have found only two significant geographical surveys, which we now summarize:

The Bolton-Julien research. Beginning in the 1880s, H. C. Bolton and A. A. Julien collected data and samples of the world's musical sands. Because of its ready accessibility, they concentrated on musical beach sands, publishing their first report in 1884. (R19) At this point in time, they had located 92 examples of musical sand worldwide. This paper also contains an interesting chronology, recording the first notice in print of the phenomenon in the 16th. Century, by Emperor Baber!

Bolton later visited Hawaii and trudged the beaches of California. He found many more examples of musical beach sand and demonstrated how common the phenomenon is. In his 1890 papers, Bolton also reports the discovery of musical sand along river beaches, such as those of the Wisconsin River, in the neighborhood of the Wisconsin Dells. (R29, R30)

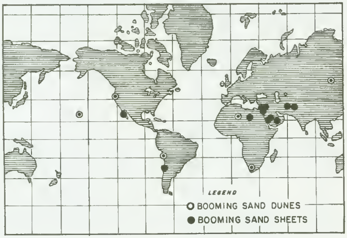
The study of J. F. Lindsay et al. 1976. Almost a century passed before additional scientific work was undertaken. In 1976, J. F. Lindsay et al saw their results published in the Bulletin of the Geological Society of America. These researchers considered desert musical sand (as exemplified by booming dunes) to be distinctly different from the much more common beach musical sand (squeaking sand). We quote here their geographical survey results; in X21, we will present their general scientific observations.

"Booming Sand. Booming dunes have been mentioned in mideast literature for at least 1,500 years 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." For details see the accompanying table. (R65)

"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." (R65) In fact, musical beach sand is so common that Lindsay et al do not even attampt to tabulate examples.

X21. General observations and some theoretical thoughts.

H. C. Bolton. "The evanescent character of the acoustic quality of the sand is very marked. Sand which has been recently wet



Locations of prominent musical and booming sands. (X20) (Adapted from R65)

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 Pagbman Range; sand supply not obvious; booms spontaneously about 12 times a year; loud bollow drum sound

Name and location (lat, long)	Type and size (heigbt x widtb x lengtb)	Comments and references
Rowsa Deffafiat Subbia Itzum	No details	Several nameless dunes identified by nearest oasis, Nefuz desert near El-Hyza, Arabia.
Wadi Hamade	No details	Nortbern Arabia, north of Medina
Nameless Sand of Yadila	Probably barchan 30 m x ? x ?	In Uruq Adh Dhahiy a region of the "empty quarter" of Arabia; like foghorn, 2-min duration
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 billside 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 bumming of telegrapb 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 over-fligbt 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

Name and location (lat, long)	Type and size (height x width x length)	Comments and references
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
Sand Mountain 25 km east of Fallon, Nevada (39°15'N, 118°36'W)	Seif	Short note on bass violin and roaring (recorded)
Kelso Dunes East of Barstow, Calif. (33°55'N, 115°45'W)	Barcban dunes 180 m x 16 km x 16 km	Roaring sounds from Ice 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, Cbile (20°S, 69°W)	Isolated dune	10.4 km west of Pozo (well) de Ramirez
El Punto de Diabolo Copiapo, Cbile (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°42'N, 110°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.
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 Calakob Range; on southern face; no sand on adjacent bills, 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 bumming sound; from a distance, like distant cannon or deep bass of pipe organ; ground vibration and sand detacbment 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

requires thorough drying and insolation (?) before it again resumes its acoustic power. Consequently sandy beaches do not always possess the sonorous power in equal measure, and the seeker sometimes fails to discover musical sand in the locality reported. Meteorological conditions, the dryness or moisture of the atmosphere decidedly affect the sonorousness.

"Musical sand is easily deprived of its acoustic properties in several ways. Wetting it is effectual of course, but long continued friction between the dry sand also accomplishes the result. The quickest way of 'killing' the sand (except by water) is to shake a small quantity in a glass bottle; or better in a tin box. When first agitated in a tin box a peculiar sound is heard which entirely ceases after 20 to 25 up and down movements of the box.

'Under what circumstances and for how long a period of time sonorous sand will preserve its quality is a question which at this writing we cannot defintely answer. The results obtained are very conflicting, but we believe that the sand preserves its power best when hermetically sealed in bottles. When collected in bags it sometimes loses its power in a few hours.

"Attempts to restore 'killed' sand (that is sand rendered mute by any of the above named methods) its sonorous properties have met with indifferent success; experiments are in progress to accomplish this object.

"Experiments made on the beach at Far Rockaway with a gold leaf electroscope gave no evidence that electricity is concerned in the acoustic phenomenon. The instrument was proved to be sensitive but behaved alike with both sonorous and mute sand...

"Sonorous and mute sand occur on the beach closely adjoining but they cannot be distinguished by the eye; friction alone determines the difference. In sand of strongly marked acoustic properties a tingling sensation is perceived in the fingers and also in the toes even through boots." (R19) Presumably, the tingling sensation is acoustical or vibratory in origin. (WRC)

Following a discussion of Hawaiian musical sands, Bolton observed: "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 hillsides 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, Manchester, Mass., and other sea-beaches---a property that the sand of Jebel Nagous fails to 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 feldspar."

.....

"Musical sand yields notes by friction only when <u>dry</u>; squeaking sand yields a harsh, shrill sound (reminding one of the cry of a guinea fowl), best when <u>moist</u>. This latter variety is very rare; we have collected, by correspondence and in person, more than 600 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 display which I have witnessed in the Desert of Sinai, and the somewhat less striking phenomenon at Kauai, are, however, manifestly due to a greater freedom of oscillatory motion than is possible if the particles merely scrape against each other." (R29) Beach musical sand is often called squeaking sand, but above Bolton introduces a third type of sonorous sand, which is squeaky when wet. (WRC)

<u>C. Carus-Wilson</u>. Carus-Wilson was one of the early researchers of sonorous sand. We reproduce here his theory plus some interesting experiments he carried out.

"About three years ago I propounded a theory to account for the emission of these musical sounds from sands; briefly it is that they are the result of the rubbing together of millions of clean sand-grains very uniform in size; two such grains rubbing together would not produce vibrations audible to us, but the <u>accumulation</u> of such vibrations issuing from millions of surfaces, and, approximately, of equal length, would produce a note sufficiently powerful to be sensible to us." (R28) H. C. Bolton maintains that the Carus-Wilson applies only to musical beach sand. (R26)

Carus-Wilson attempted to revive "killed" musical sand and also to make non-musical sand musical. "One sand (an iron-sand composed of more or less polished grains, quartz, and much dust formed of denser minerals) gave a very hopeful 'swish'... in a certain porcelain vessel, and from this---by (1) sifting in sieves, to eliminate the fine material, and to insure uniformity of grain size; (2) rolling down an inclined plane of frosted glass, to separate the rounded grains from the angular quartz; and (3) boiling in dilute hydrochloric acid, to cleanse the surfaces---I succeeded in producing a sand that, in certain glazed vessels, emits musical notes as clear as those emitted from any of my musical sands but that of Eigg. This sand gives F in altissimo, but it very soon becomes 'killed because of the fine dust that is the inevitable result of the attrition of the grains. There remains but one thing to be done, and that is to produce a sand which, like that of Eigg, will be musical in almost any receptacle, and I have reason now to think that this will not be very difficult.

"It has not be possible here to record more than the merest outline of what has been done, or to give instances of the interesting capriciousness of these sands; it should be understood, however, that no ordinary beach or cliff sand has the slightest inclination to 'sing' under any of the 'coaxing' methods known to me." (R33)

R. A. Bagnold's theory. "A sand-dune advances by a series of avalanches down its lee face. The velocity of descent depends on the dilatation of the moving mass, and soon achieves an equilibrium velocity for which the dilatation is stabilized at the 'weak-solid' value giving continual contact between grains. Any momentary increase of velocity above the equilibrium value implies an increase in the dilatation, and this expansion can only occur by an upward motion of the whole overburden. This however brings the dilatation into the true-liquid no-contact region, so the grains rise and fall again freely under gravity; on their descent they compact the mass again to a dilatation too small for its velocity, and the cycle repeats. The mass of sand therefore descends in a series of rapid bounces whose motion is transmitted to the air as a musical tone. Its frequency can be easily calculated if the size of the grains and the dilatation-to-flow relationship is known; and for a typical singing sand (the dunes of the Kalahari desert) it turns out to be 275 c/s. The observed value is 264 c/s.

"The much higher squeak or whistle emitted by some beach sands on being indented by a heel or stick can also be explained by the theory, for the acceleration of the displaced sand is in this case much higher than that of gravity, and the frequency rises accordingly." (R61) It is apparent that Bagnold holds that the sound-producing mechanism is the same in all musical sands. (WRC)

D. W. Humphries. "Summary. The occurrence of the rare phenomena of a booming sand is recorded and an account given of its behavior in the field. Its sedimentological properties are compared with those of a squeaking sand from the seashore. Both sands are moderately to well-sorted, and show similar roundness and sphericity. The desert sand is silent, whereas the seashore sand can be made to emit a noise in the laboratory. The marked distinction between the sands lies in the mechanical analyses based on the number frequency of grains rather than on the weight frequency. A 'body-centred cubic' packing has been proposed for the desert sand and a 'rhombic' packing for the seashore. Shearing tests on the disturbed sands appear to support the hypothesis of two different modes of packing." (R59) Recall that Bolton, above, found that the Jebel Nagous sand both squeaked and boomed. (WRC)

The Newcastle Upon Tyne experiments. A. E. Brown et al placed samples of musical sand in evaporating dishes and struck them with a blunt wooden rod to make them 'sing.'

"They discovered that roundness of grain is not an essential characteristic of singing sands. It is the uniformity in the size of the grains that counts. Nothing else seems to matter except cleanliness. The presence of fine particles impairs the singing properties of the sand and sometimes stops it altogether. When the grains are unpolluted by other material and are nearly all of the same size, the sand sings well.

"The grains of sands that sing, they found, are polished, free from fragments and nearly all within a certain narrow range of size. The ability of the sand to 'sing' is destroyed by constant pounding, but is restored after the fine fragments produced by such pounding are removed by sieving, washing or boiling.

"A 'qualitative explanation' of the singing sands phenomenon is advanced by the Newcastle Upon Tyne scientists. It is clear, they say, that a shearing motion of one layer of sand over the next is essential. When the sand layer is thin and not constrained from the sides (as in a thin dry surface layer on a damp beach) only an oblique blow will produce the sound.

"Striking from above in the laboratory experiments is a convenient way of producing shearing motions, but is only effective when the sand is supported from the sides of the container.

"'We may suppose,' say Messrs. Campbell, Jones and Thomas, 'the sand to consist of equal spheres arranged, when disturbed, so as to occupy minimum volume. When disturbed, the mass may pass through many successive minima of volume before coming to rest, and if we can suppose that the time occupied in passing from one minimum to the next is constant, a musical note should issue.'

"But the mystery of exactly why it issues ---like the reverberating moon---still remains." (R62) It is curious that the effect of moisture, deemed so important by other investigators, is not mentioned. (WRC)

J. F. Lindsay et al. The conclusions of this ambitious study are divided into two parts, in line with their determination that booming and squeaking sands are different phenomena.

"Booming Sand. 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.

"Quartz sand grains from booming dunes have polished surfaces on the micron scale. The grains are only moderately rounded but have high sphericities.

"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.

"Booming sand dunes are most likely to occur at the downwind end of a desert dune field. Alternatively, booming sand may occur on backbeach dunes in dry climates where the sand has long residence time on the beach and where longshore currents are weak.

"The terrestrial booming process is greatly facilitated by the surface properties of the sand grains that control the mechanical coupling 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.

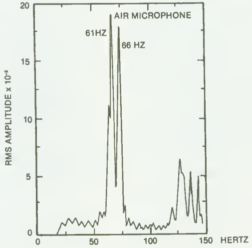
"Booming is a relatively rare phenomenon in the terrestrial environment but may be a common occurrence in the waterless or near waterless environments of the Moon and Mars..."

"Squeaking Sand. Squeaking sand produces sounds in the range from 500 to 2,500 Hz.

"Squeaking beach sand consists largely of quartz grains that are very well-rounded and highly spherical.

"The particle observations support previous suggestions that the ideal squeaking sand should consist of smooth uniform spheres in a close-packed configuration.

"An average squeaking beach sand has a mean grain size of $1.571 \pm 0.222\ \phi$ (336 μm).



Power spectrum of booming from Sand Mountain, Nevada, as recorded by an air microphone. (X21)

It is very well-sorted, symmetrical, and very leptokurtic.

"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 grain size of the sand would determine the frequency of the sound, whereas amplitude could be controlled by the surface texture of the grains." (R65)

P. K. Haff. The final paragraph from Haff's review paper provides a fitting end for this Catalog exercise.

"Our original query into how booming sands work remains unsolved and a challenge. It is to be hoped that the experiments reported here do not muddy the water and discourage further inquiry, but rather that they suggest some lines of thought for others who might be similarly intrigued with the phenomenon. And so, falling back on the words of Lord Curzon, 'in this rather nebulous phase of speculative uncertainty, I leave the Sounding Sands to continue their mysterious song, confining their favors to the lucky few, and exciting the curiosity, but, I hope, no longer the incredulity, of the remainder." (R66)

References

R1. "On the Subterranean Sounds Heard at Nakous, on the Red Sea," Franklin Institute, Journal, 3:257, 1827. (X1)

R2. "On a Peculiar Noise Heard at Nakuh, on Mount Sinai," Edinburgh New Philosophical Journal, 8:74, 1830. (X1)

R3. "Curious Phenomenon," Scientific American, 4:355, 1849. (X1)

R4. Palmer, H. S.; "On an Acoustic Phenomenon at Jebel Nagus, in the Peninsula of Sinai," Report of the British Association, 1871, p. 188. (X1)

R5. "Music of Rolling Sand," Scientific American, 25:257, 1871. (X1)

R6. Lowdon, Ralph; "Underground Sounds," English Mechanic, 15:42, 1872. (X1)

R7. "Sonorous Sand," Popular Science Monthly, 6:764, 1875. (X1, X2)

R8. Fergusson, A., et al; "Mysterious Mountain Sounds," Notes and Queries, 5:7:95, 1877. (X3)

R9. "Musical Sand," Scientific American Supplement, 5:1972, 1878. (X2)

R10. "Resonant Sand," Scientific American, 45:182, 1881. (X4)

R11. Popular Science Monthly, 20:431, 1881. (X4)

R12. "Wind-Sounds in the Desert," Popular Science Monthly, 22:285, 1882. (X1)

R13. Knowledge, 3:63, 1883. (X5)

R14. Bolton, H. C., and Julien, A. A.; "Musical Sand," Science 2:713, 1883. (X6)

R15. "Sounds Produced by Wind," English Mechanic, 37:48, 1883. (X1)

R16. Bolton, H. C., and Julien, A. A.; "The Singing Beach of Manchester, Mass." American Association for the Advancement of Science, Proceedings, 32:251, 1883. (X7)

R17. Julien, A. A., and Bolton, H. C.; "The Singing Beach of Manchester, Mass.," Science, 2:325, 1883. (X7)

R18. "A Remarkable Sand Dune," Scientific American, 48:20, 1883. (X5)

R19. Bolton, H. Carrington, and Julien, Alexis A.; "Musical Sand, Its Wide Distribution and Properties," American Association for the Advancement of Science, Proceedings, 33:408, 1884. (X20, X21)

R20. "Musical Sands," Americal Meteorological Journal, 1:509, 1885. (X5)

R21. Bolton, H. Carrington; "Researches on Sonorous Sand in the Peninsula of Sinai," American Association for the Advancement of Science, Proceedings, 38:137, 1889. (X1, X21)

R22. Bolton, H. Carrington; "A New Mountain of the Bell," Nature, 39:607, 1889. (X1)

R23. Bolton, H. Carrington; "The 'Barking Sands' of the Hawaiian Islands," Science, 16:163, 1890. (X2)

R24. Bolton, H. Carrington; "The 'Barking Sands' of the Hawaiian Islands," Nature, 42:389, 1890. (X2)

R25. Nature, 42:554, 1890. (X8)

R26. Bolton, H. Carrington; "Squeaking Sand versus Musical Sand," Nature, 43:30, 1890. (X21)

R27. Bolton, H. Carrington; "The 'Barking Sands' of the Hawaiian Islands," Scientific American Supplement, 30:12278, 1890. (X2)

R28. Carus-Wilson, Cecil; "Musical Sands," Nature, 42:568, 1890. (X21)

R29. Bolton, H. Carrington; "Researches on Musical Sand in the Hawaiian Islands and California," New York Academy of Sciences, Transactions, 1:10:28, 1890. (X20, X21)

R30. Bolton, H. Carrington; "Note on the Occurrence of Musical Sand on the Pacific Coast of the United States," American Association for the Advancement of Science, Proceedings, 39:255, 1890. (X20)

R31. Bolton, H. Carrington; "The 'Barking Sands' of the Hawaiian Islands," American Association for the Advancement of Science, Proceedings, 39:257, 1890. (X2)

R32. Science, 16:216, 1890. (X8)

R33. Carus-Wilson, Cecil; "The Production of Musical Notes from Non-Musical Sands," Nature, 44:322, 1891. (X21)

R34. "Musical Sands," English Mechanic, 53:222, 1891. (X21)
R35. Scientific American, 74:402, 1896. (X1)
R36. Goldsmid, F. J.; "On the Formation of Sand-Dunes," Geographical Journal, 9:454, 1897. (X9)
R37. Rosenfeld, Georg; "Singing and Speaking Stones," Scientific American Supplement, 66:395, 1908. (X2)
R38. Carus-Wilson, Cecil; "Musical Sands," Nature, 81:69, 1909. (X10)
R39. Gray, M. H.; "Musical Sands in Chile," Nature, 81:126, 1909. (X11)
R40. Carus-Wilson, Cecil; "Musical Sands," Nature, 81:159, 1909. (X21)
R41. Thomas, E.R.; "Musical Sand," Nature, 86:483, 1911. (X21)
R42. Carus-Wilson, Cecil; "Musical Sands of Eigg," Nature, 86:518, 1911. (X3)
R43. Offord, Joseph; "Musical Sand in China," Nature, 95:65, 1915. (X12)
R44. Richardson, W. D.; "The Singing Sands of Lake Michigan," Science, 50:493, 1919. (X13)
R45. Fairchild, H. L.; "Musical Sands," Science, 51:62, 1920. (X20)
R46. Fippin, Elmer O.; "More on Singing Sands," Science, 51:64, 1920. (X13)
R47. Ledoux, Albert R.; "Singing Sands," Science, 51:462, 1920. (X21)
R48. Carus-Wilson, Cecil; "Musical Sands," American Journal of Science, 201:366, 1921. (X21)
R49. "Rocks That Sing," English Mechanics, 1:34, 1926. (X21)
R50. Stenhouse, Andrew G.; "Whistling Sands," English Mechanics, 1:71, 1926. (X21)
R51. Nature, 129:633, 1932. (X14)
R52. "Singing Sands," Science News Letter, 24:265, 1933. (X14)
R53. "Roaring Sands of the Kalahari Desert," Nature, 140:285, 1937. (X15)
R54. "Singing Sands of the Gobi Desert," Royal Astronomical Society of Canada, Journal, 37:295, 1943. (X16)
R55. Yarham, E.R.; "Mystery of Singing Sands," Natural History, 56:324, 1947. (X14, X17)
R56. Goodenough, Glenn H.; "Musical Sand: A Review of the Literature," Rocks and Minerals, 24:451, 1949. (X21)
R57. Murbarger, Nell; "Singing Mountain," Nature Magazine, 45:487, 1952. (X5)
R58. "Singing Sand," Nature, 190:678, 1961. (X18)
R59. Humphries, D. W.; "The Booming Sand of Korizo, and the Squeaking Sand of Gower, S. Wales: A Comparison of the Fundamental Characteristics of Two Musical Sands," Sedimentology, 6:135, 1966. (X19, X21)
R60. Bagnold, R. A.; "The Shearing and Dilatation of Dry Sand and the 'Singing' Mechanism," Royal Society, Proceedings, 295A: 219, 1966. (X21)
R61. "Exact Theory of Singing Sands," New Scientist, 32:737, 1966. (X21)
R62. Brock, Paul; "Mystery of the Singing Sands," Science Digest, 68:63, August 1970. (X21)
R63. Ridgway, K., and Scotton, J. B.; "Whistling Beaches and Seabed Transport," Nature, 238:212, 1972. (X21)
R64. Criswell, David R., et al; "Audio Emissions of a Booming Dune Avalanche," Eos, 55:1151, 1974. (X5)
R65. Lindsay, John F., et al; "Sound-Producing Dune and Beach Sands," Geological Society of America, Bulletin, 87:463, 1976. (X2, X5, X20, X21)
R66. Haff, P. K.; "Booming Dunes," American Scientist, 74:376, 1986. (X21)
R67. Bolton, H. Carrington; "The 'Singing Beaches' of the Baltic," New York Academy of Sciences, Transactions, 1:3:97. 1884. (X9, X14)
R68. Carus-Wilson, Cecil; "Theories and Problems Relating to Musical Sands," Scientific American Supplement, 85:101, 1918. (X21)
R69. Ridgway, K., and Rupp, R.; "Whistling Sand of Porth Oer, Caernarvonshire," Nature, 226:158, 1970.
R70. Ridgway, K., and Scotton, J. B.; "Whistling Sand Beaches in the British Isles," Sedimentology, 20:263, 1973.
R71. Takahara, Hikaru; "Sounding Mechanism of Singing Sand," Acoustical Society of America, Journal, 53:634, 1973. (X21)
R72. Criswell, David R., et al; "Seismic and Acoustic Emissions of a Booming Dune," Journal of Geophysical Research, 80:4963, 1975. (X21)

ESP15 Luminous Rocks

Description. Rocks in nature that become temporarily luminous after being mechanically stressed (earthquakes, blows), heated, insolated, or chemically treated (water immersion).

Data Evaluation. Although about a full dozen reports have been uncovered, these are mostly old, rather casual observations. Except possibly for studies of luminous phenomena in glacier ice, modern science has taken little interest in this subject. Rating: 3.

Anomaly Evaluation. In the laboratory, the phenomena of phosphorescence, fluorescence, triboluminescence, etc. have long been under study, although they are not yet completely understood. So, in no way can the same phenomena be rated highly anomalous when encountered in natural situations. Rating: 3.

Possible Explanations. Matter may become luminous when mechanically stressed, radiated, heated, chemically treated, and so on. Such a statement is, of course, not an explanation in itself; rather, it is a reference to some phenomena of physics for which at least partial answers exist in the physics books.

Similar and Related Phenomena. Earthquake lights (GLD8); luminous phenomena in water and ice (GLD14).

Examples

X1. Detached, naturally luminous stones. The observational data here are very weak, being mostly anecdotal.

California. A farmer neglected to turn off his irrigation water. Remembering his omission during the night, he went out into his flooded fields to stop the flow. There, he noticed some luminous pebbles which he collected. These were sent to a laboratory in Philadelphia for analysis. (R4) The results of the lab tests were never published as far as known.

Australia. Stimulated by the California account (above), J. E. Henderson sent in the following observation to the English Mechanic: "The writer says the paragraph forcibly recalled to his memory a discovery of a similar nature made by himself many years ago in one of our Australian colonies. During his sojurn there, and while engaged in gold-mining with others, he and his companions were much startled one night to see a rock illuminated by, as they thought, a cluster of diamonds. Not being able to get near enough to examine it minutely, they marked the spot, intending to investigate it more closely on the following day. But when the daylight came, they could see nothing extraordinary in the appearance of the rock, which was merely a dull sandstone block, having nothing apparently on its surface to account for its luminous appearance on the preceding night. So brilliant was it when seen at night that Mr. Henderson declares it would have been possible to read a book by its light..." (R5)

The Bologna luminous stones. Although we have found only a single reference to the Bologna luminous stones, this article implies that the stones are well known and have been the subject of laboratory investigations into the cause of their luminosity. For example, Vanino and Zumbusch, in 1911, reported that good specimens of the stones contained 12 to 32% sulfur. Also: "The length of exposure to daylight required to induce the maximum phosphorescence varied with the composition of the stone." (R10) Beyond this, we have little to go on.

Phosphorus and weather. According to a very old report, phosphorus becomes luminous on the approach of storms! (R1)

X2. Luminous rock formations. As in the case of luminous rocks (X1), most observations are anecdotal. The exception is the series of experiments carried out on the Isle of Wight.

Surface luminosity and ore deposits. As far back as 1747, it was recorded that the surface of the earth overlying some ore deposits was luminous. Such phenomena were said to be more striking during thunderstorms. (R6, R7)

Isle of Wight experiments. "The object was to determine whether there was or not at the time of a large earthquake a practically instantaneous transmission of energy to distant regions other than that recorded by seismographs. It was observed and still is observed by many persons that the face of a very large chalk pit at Shide exhibits, after damp days, a flaring luminosity. In a chamber at the end of a tunnel in this pit, a cylinder carrying photographic paper was installed. This cylinder was enclosed in a box, one end of which was a metal plate containing three holes. The plate touched a flat chalk surface. The cylinder took one week to turn; therefore parts of the paper before the holes were very slowly exposed to a chalk surface about 3/16th of an inch distant. On certain weeks the results were nil. Other weeks, after the development of the paper, there were three dark bands corresponding to the position of the holes, suggesting that the chalk had acted like an extremely feeble light." (R8, R9)

Phosphorescent bricks. "At a recent meeting of the Academy of the Natural Sciences, Philadelphia, the first communication which engaged attention was one of a curious phosphorescent variety of limestone from Utah. The miners had found that when struck with a pick this rock gave out a lurid red light, lasting from half a second, when merely touched, to a much longer time, as the result of a blow. They had, therefore, named it the hellfire stone. On examination it proved to be an almost perfectly pure carbonate of lime, with but a slight percentage of impurities. It is a loose grained, white, crystalline limestone, the grains of which are but slightly coherent, giving the rock the appearance of a soft sandstone. It crumbles easily between the fingers, forming a coarse sand. Phosphorescence is developed when the rock is either struck, scratched or heated. When heated in a glass tube over a flame it glows with a deep red light, which lasts for a minute or more after withdrawing the flame. After two or three heatings the phosphorescent property disappears." A similar limestone from India exhibited the same characteristics. (R3)See ESP3-X4.

X3. Luminous phenomena in glaciers and sea ice. Phosphorescence, sparks, and light flashes are occasionally observed in sea ice when it is broken up by ships. (R2) Cracking and deforming glacier ice will sometimes seem to give off sparks. (R11)

References

R1. "Phosphorescence in Connection with Storms and Disease," English Mechanic, 2:21, 1865. (X1)
R2. Allen, J. Allen; "Luminous Phenomena on Rupture of Sea-Ice," Nature, 24:459, 1881. (X3)
R3. "Phosphorescent Bricks," Scientific American Supplement, 17:6872, 1884. (X2)
R4. "Luminous Stones," English Mechanic, 65:428, 1897. (X1)
R5. "Luminous Stones," English Mechanic, 65:546, 1897. (X1)
R6. Scientific American, 96:90, 1907.(X2)
R7. English Mechanic, 85:10, 1907. (X2)
R8. Turner, H. H., et al; "On Seismological Investigations," Report of the British Association, 1907, p. 87. (X2)
R9. Milne, John; "Earthquakes and Luminous Phenomena," Nature, 87:16, 1911. (X2)
R10. "Bologna Luminous Stones," English Mechanic, 94:339, 1911. (X1)
R11. "Sparks in Glacier Ice?" New Scientist, 18:738, 1963. (X3)

ESP16 Explosive Rocks

Description. Detached rocks and exposed rock faces that explode violently either spontaneously or after a slight disturbance.

Data Evaluation. Our literature surveys have located only a small handful of descriptions of this phenomenon. Furthermore, these reports are rather old and provide few scientific details. Rating: 2.

Anomaly Evaluation. All of the examples described below are adequately explained as the natural consequences of tectonic stresses or the internal pressures exerted by gas inclusions. The phenomenon is of curiosity value only. Rating: 4.

Possible Explanations. As just mentioned.

Similar and Related Phenomena. Moving, gravity-created ripples in rock (ETR4); rock bursts (GSD2).

Examples

X1. Exploding gems and crystals.

Diamond. "Prof. Leidy exhibited a black agate sleeve-button, having mounted upon it, centrally in a raised gold band, a rose diamond about 7 millims. broad. It had been submitted to him by Mr. Ernst Kretzmar, jeweler, who informed him that the person who wore it was recently leaning with his head upon his hand, on a window-ledge in the sun, when the diamond exploded audibly, and with sufficient force to drive a fragment into his hand and another into his forehead. On examining the diamond, the fractured surface, following a cleavage plane, exhibits apparently the remains of a thin cavity, such as is sometimes seen in quartz crystals. The fracture also exposes a conspicuous particle of coal. Prof. Leidy thought that the explosion had been due to the sudden expansion of a volatile liquid contained in the cavity, as frequently occurs in cavities in many minerals." (R1) The occurrence of a piece of coal in a diamond, if coal it really was, is more anomalous than the explosion of the diamond. More likely the particle was a bit of carbon. (WRC)

X2. Bursting rock surfaces. All examples of this phenomenon seem adequately explained in terms of stresses within the rocks.

Explosive slickensides. "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 into fragments with explosive violence on being struck, or even scratched by a miner's pick.

.....

"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." (R2)

Two additional examples or bursting rock surfaces from England. "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 in the quarry, where the overlying rock had been removed, what would be called in a coal-mine a 'creep'". (R3)

Vermont marble quarries. "Men who operated the South Wallingford quarries reported that the stone frequently closed in on the drill steel while work was in progress. Attempts to use diamond borers were unsuccessful because the stone closed in on the tools and prevented rotation.

"The Valley quarry was opened on the eastern or lower Columbian deposit. The rock surface is relatively flat or gently rolling; deep rock gorges, so common through much of the marble belt, are entirely lacking. The stone began to burst violently at a depth of about 25 feet, and the ruptures in the floor occurred with such force that channeling machines weighing over one ton were thrown from their tracks.

"The Florentine Blue quarry was opened on a dark-blue marble zone lying almost immediately below the Hudson River slate. Bed rock rises about 60 feet on its western side, and the overburden is about 30 feet deep on the eastern. Solution caverns occur in the southeastern part, but otherwise the rock surface is essentially horizontal. Good stock was produced for a period, especially from the upper part of the middle opening just north of the solution caverns. Then, like the Valley quarry, bursting became a daily event. This trouble has been avoided to a certain extent by first cutting the channel farthest removed from an existing quarry face; the bottom holes for raising the floor are drilled next, and the side walls of a strip of marble are cut simultaneously. Work cannot stop until an entire strip is free, otherwise a diagonal fracture rises from the bottom western part of the strip to the top eastern part." (R5) It is interesting to compare the movement of the stressed marble with the moving ripples of rock in the Culebra Cut, Panama (ETR4). (WRC)

Kolar gold fields, India. "Mr. E. S. Moore presented a paper on the so-called 'air blasts,' a peculiar geological phenomenon of the well-known Kolar gold field of India. These blasts are explosions occurring in the walls of the workings on account of the potential energy in the quartz, schist and dike rocks of the region. The energy becomes active when mining operations relieve the pressure in certain directions. The source of energy is said to be found in the squeezing of the syncline of schist by the granite during compressional movements of the earth's crust." (R4) So-called "rock bursts" have been reported in other mining operations. Some of the underground detonations reported in GSD2 are doubtless consequences of such stresses as described above. (WRC)

References

R1. "Explosion of a diamond," Philosphical Magazine, 5:6:320, 1878. (X1)

R2. Strahan, Aubrey; "On Explosive Slickensides," Geological Magazine, 3:4:400, 1887. (X2)

R3. Hughes, T. McKenny; "Bursting Rock Surfaces," Geological Magazine, 3:4:511, 1887. (X2)

R4. "'Air Blasts' in the Kolar Gold Field," Scientific American, 119:45, 1918. (X2)

R5. Bain, George W.; "Spontaneous Rock Expansion," Journal of Geology, 39:715, 1931. (X2)

ESP17 Dry Quicksand

Description. Sand in which objects sink rapidly with little resistance.

Data Evaluation. A single, old, second-hand account has been located; and even this tale provides little scientific information. Such "quicksands" have also been mentioned in popular works. Rating: 3.

Anomaly Evaluation. Very loosely packed sand is certainly not anomalous, but here the sand seems to defy common sense. One would expect the weight of the upper layers of sand to compact those below---surely at a much lesser depth than that presented in X1. Without more information, one cannot arrive at an evaluation beyond saying that the phenomenon is manifestly curious. Rating: 3.

Possible Explanations. None offered.

Similar and Related Phenomena. Ordinary water-associated quicksand; the "bottomless" pits mentioned (tongue in cheek) in another volume. (ETB8)

Examples

X1. Arabian desert. "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 dust lengthwise the resistance was almost imperceptible. A stone of two pounds weight or more was fastened to a cord sixth 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 the 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." (R1)

References

R1. "A Dry Quicksand," American Meteorological Journal, 3:4, 1886. (X1)

ESP18 Glacières or Natural Refrigerators

Description. Wells, caves, mines, and other subterranean locations where ice forms or survives for long periods of time under anomalous circumstances. "Glacière" is a French word occasionally employed in the literature instead of "ice cave," "ice well," or "natural refrigerator."

Background. The baseline scientific explanation of most ice caves, ice wells, ice gorges, and ice talus slopes is that these sheltered locations remain cold during summers due to cold, dense winter air that is stored nearby in cracks, voids, and other such reservoirs. Given warm-weather water supplies, ice will form even in the summer in such spots. When water supplies freeze up in winter, glacières often lose their ice. Some subterranean ice deposits, however, are relict; that is, they survive under insulating soil, rock, and debris from past cold periods, even the Ice Ages themselves. The intent of this Catalog entry is the description of phenomena that depart from these baseline explanations.

Data Evaluation. The literature contains many descriptions of glacières and relict ice sheets. Generally, though, these accounts are rather old and tend to be found in popular scientific publications. Rarely is anything found in the recent, mainstream scientific journals. Consequently, general descriptions are good, but the phenomena have not been studied scientifically. Rating: 2.

Anomaly Evaluation. The anomalies are diverse and many: (1) some ice wells melt in the summer rather than form new ice; (2) ice caves exist close to geothermal sources of heat; (3) ice in glacières occasionally forms at the bottoms of water bodies rather than the tops; (4) glacière ice exists, rarely, is the form of curious hexagonal plates; (5) some glacière ice is banded horizontally; (6) ice/lava sandwiches may extend thousands of feet into lava formations; etc. Some of these phenomena are probably due to special local conditions; others may be explained by minor changes in glacière theory. More anomalous are apparently relict ice sheets that survive in rather warm climates, implying possibly that the Ice Ages persisted longer than supposed. Also important is the lack of any good theory for the formation of ice/lava deposits of great extent. Rating: 2.

Possible Explanations. See Background above.

Similar and Related Phenomena. Fresh-appearing mammoth remains (ESB4); "apparently" youthful rivers (ETV6).

Examples

X0. Introduction and baseline theory. Over 300 subterranean ice deposits have been found worldwide, almost all in climates with relatively cold winters. To introduce this subject we follow the classification proposed by E. S. Balch. We also present his theory of subterranean ice formation, which is still generally accepted, as he employed it to explain the provenance of the famous Coudersport (Pennsylvania) Ice Mine.

Glacières or "natural refrigerators." "Natural refrigerators fall under something like five main heads:

(1) Gullies and troughs where ice remains (X4 below)

(2) Boulder taluses containing ice (X5)

(3) Ice sheets overlaid by soil or rocks (X3)

(4) Wells, mines and tunnels which freeze at times (X1)

(5) Caves with abnormally low temperatures and mostly containing ice. (X2)

"For four of these five different rock formations, as far as they are connected with ice, we have only two terms in English and those the entirely incorrect ones of 'ice cave' and 'ice gorge,' and the more I have followed up the subject, the more do those names seem misnomers to me. We say 'limestone cave' or 'lava cave' and in the same way we should say 'ice cave' when the sides and roof of a cave are formed of ice; that is, we should reserve the term for the hollows at the ends of glaciers whence the glacier waters make their exit. Curiously enough, the Germans use the same inaccurate phraseology as ourselves, and there is only one term which is really generic, namely, the French glacière naturelle. This is comprehensive and accurate, embracing the geological structure and suggesting the mode of formation of the ice. In my opinion we should either adopt the French glacière or use its English equivalent 'natural refrigerator.'

"The next point I wish to touch on relates to the mode of formation of the ice of these glacières. In every case glacières seem to me to be purely refrigerators, which preserve the supplies of ice and snow stored in them during the winter. They all follow the same general laws as to their origin, modified only in slight degree according to the varying natural conditions of the place, such as the water supply, or the protection from sun or wind, or the thickness of the overhead rocks, or the altitude or latitude. I cannot see that there is anything very remarkable about the fact that the cold of winter is able to penetrate and make itself felt sometimes for a very slight depth in the earth's crust, a depth so far as yet known never exceeding 150 meters. And it seems to me that glacières only emphasize a law of nature which has doubtless been formulated many times in connection with springs and phreatic waters, and that is, that where we find cold waters underground, we may be sure that they have penetrated from the outside." (R15) Despite Balch's confidence, there are several anomalies, which we shall shortly enumerate, that may require reassessment of his theory. (WRC)

The Coudersport Ice Mine. "About four miles east of Coudersport, Pennsylvania, and some three hundred yards southwest of the little village of Sweden Valley on the state road to Wellsboro, is a 'glacière naturelle,' or natural refrigerator, known as the 'Coudersport Ice Mine.' It is situated on a hillside and a rough mountain road enables you to drive a motor to within six feet of the entrance.

.....

"The Ice Mine is located on the side of a hill, now sometimes spoken of as the Ice Mountain, and its surroundings are true glacière country, damp, shady, and free from draughts or sunlight. The exposure of the Ice Mine is north and the sides of the hill are covered with thick second-growth forest which completely shelters the Mine from sun and wind. If this forest were ever cut down, it is almost certain that the ice would stop forming.

"The Ice Mine is surrounded by a tall wooden fence with a locked door, which the female guardian of a little restaurant immediately adjacent to the Mine opens for 50 cents a person. After you have put on your overcoat, paid your fee, and passed through the guarded portal, you find yourself on a level space, with rocks rising some fifteen feet in front of you surmounted by the wooden fence, and with the shaft, a big, nearly square hole, some ten feet in length by eight in breadth and thirty in depth, going straight down into the rock. The top of the shaft is covered with a wooden floor with a large trap door, which is usually kept shut, as people frequently climb over the fence. The floor of the shaft is reached by a long ladder, and when I visited the Mine, on the 12th of August, 1921, was covered by a layer, perhaps two or three feet thick, of dirty ice. On three of the sides rather thin ice curtains were streaming down. These were melting, as was also the ice floor, the glacière in fact being in a state of thaw, with the thermometer several degrees above freezing point.

"The ice, it is said, begins to form about April and to be its best perhaps in June.

After this it slowly diminishes and vanishes by about October. The ice goes quickest in rainy weather and more slowly in warm weather. Both these times of the appearance and disappearance of the ice and these effects of wet or dry weather are normal glacière phenomena.

"The only theory about the formation and the disappearance of the Coudersport ice which meets all the facts is the theory which applies universally to all glacières. Two things are necessary for the formation of ice: cold and water. In glacières the cold of winter furnishes the cold and the thaws of spring furnish the water. That the winter's cold furnishes the cold is proved by the fact that every known glacière is in a place where there is snow and ice in the open in winter. The winter air sinks from its weight into the glacière and the rock cracks leading into it. And the reason ice does not form then is that at that time the water is all frozen up on the outside. But when the thaws of spring melt the outside ice and snow into water this flows into the glacière and its communicating rock cracks and, meeting the cold air within, congeals. The only effect of the heat of summer is slowly to melt the ice." (R20) Balch also notes that the Coudersport Ice Mine is a very small glacière compared to those in Europe.

We shall now proceed to the various types of glacières and some phenomena which do not seem satisfactorily described by Balch's theory (the "standard" one for subterranean ice deposits). Finally, it should be emphasized that when Balch uses the term "refrigerator" above, he is not implying that a heat engine exists, as in modern household refrigerators, merely that the glacières are reservoirs of cold air. (WRC)

X1. Frozen wells.

Owego, New York. "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 we 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.

.....

"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.'" In concluding, the author observed that the well-known ice caves of Europe ice up during the summers, while the Owego wells do so during the winter, and that in the summer their waters are as warm as those of normal wells in the area. (R1) Points of interest are: (1) ice wells freeze in the winter rather than the summer like the ice caves; (2) a cover on the well halts the phenomenon; and (3) the freezing begins at the bottom, not at the water surface, implying that cold air is not the freezing medium. (WRC)

Brandon, Vermont. "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°; at two feet from the surface of the ice in the well, the mercury sank to 32°. (R5) Of particular interest above is the frozen stratum encountered in the digging of the well, a subject we shall return to in X3. (WRC)

Further data on the Brandon ice well: "A lighted candle was lowered down into the well, and it continued to burn; the flame was not in any manner deflected; so there was no current of air in the well. Numerous springs and wells in every direction around the frozen well were examined, and none of them were frozen, or were remarkable for coldness of their waters.

"It was thus ascertained that the frozen stratum in which Trombley's well was sunk is quite limited, and that it is confined to the gravel-bed, or to the mass of frozen drift pebbles, which shows itself on the roadside at the Hogback, four hundred and fifty feet northwest from the well." (R4) The very limited geographical extent of the phenomenon is of interest here. (WRC)

X2. Ice caves and mines. The Coudersport Ice Mine was described in X0. Now, we move on to peculiarities noted for other ice caves.

Sezelitze, Hungary. "An instance of these summer-produced ice-caverns occurs near the village of Sezelitze, in Upper Hungary. The neighbouring country is hilly, occupied by the limestone of the Carpathian mountains. It abounds with woods, and the air is sharp and cold. The entrance of the cavern, which faces the north, is 36 yards high and 16 broad, consequently ample enough to receive a large supply of the external air, which here generally blows with great violence. Subterraneous passages stretch away from it southward to a greater distance than has yet been penetrated. In the midst of winter the air in this cavern is warm, but in summer, when the heat of the sun without is scarcely supportable, the cold within is not only very piercing, but so intense that the roof is covered with icicles of great size, which, spreading into ramifications, form very grotesque figures. When the snow melts in spring, the inside of this cave, where its surface roof is exposed to the sun, emits a pellucid water, which immediately congeals as it drops, and this forms the icicles mentioned, and the water that drops from them on the sandy floor, freezes in an instant. It is even observed that the greater the heat is without the more severe the cold within; so that in the dog-days all parts of this cavern are covered with ice, which the inhabitants of Sezelitze use for cooling their liquors. The quantity of ice thus formed is sometimes so great that it has been estimated at as much as six hundred waggons would be able to remove in a week. In autumn, when the heat of the day begins to abate, and the nights grow cold, the ice begins to dissolve, and is quite cleared away by the arrival of Christmas. When the cavern is perfectly dry it has an agreeable temperature, and is the haunt of swarms of flies, gnats, bats, owls, hares, and foxes, resorting to it as a winter retreat." (R6) The baseline glacière is supposed to be coldest in the winters, a consequence of the postulated reservoir of cold air in the surrounding structures and the cold outside temperatures. To illustrate, the ice cave at Decorah, Iowa, where temperatures have been measured at various locations year-round, is always colder in winter. (R16)

Teneriffe, Canary Islands. "The ice cave is situated on the 'Peak of Teneriffe,' over 10,000 feet above the level of the sea, and nearly 2,000 feet from the summit. The point that most calls my attention is, not that it exists there (as it is quite cold there even in summer), but the fact that the mountain is an extinct volcano, and by many supposed to be only slumbering now. Nor is this the only point that merits remark, for there is the added fact that the water in the cave is not congealed on the surface, but on the bottom.

"The cave supplies the ice consumed in these islands, from which it may be inferred that the quantity is not insignificant.

"The mouth of the cave is an opening or well hole, in which seems to be an immense pile of bowlders; the mouth is irregular in shape, and about two yards square. The entrance is made by being lowered perpendicularly some 15 feet to terra firma, where one finds himself on a small plot of earth and stone, say five yards square, and almost surrounded by what seems a small pond of clear water. After the eyes are a little accustomed to the dim light the visitor can see the walls of the cave, which are of earth and stone. The cave is about 100 feet long by 30 feet wide, with a roof 10 to 15 feet in height.

The water is from 1 to 2 feet deep over the ice, which has to be dug out with pick-axes. The ice is not like that in our American waters, being granulated and coming out in irregular shaped lumps, from the size of an egg to that of a man's head. When extracted it is found more or less dirty from the earth and pebbles mixed with it. It serves, however, for medicinal purposes, and for making ice creams, etc. In several places the water drops slowly from the roof, but the chief supply seems to trickle through small crevices in the walls.

"Some distance higher up the mountain, and some 400 yards away from the cave, there are seen a number of jets of what seems smoke or steam issuing from small crevices in the rocks, and on applying the hand the heat is found to be unsupportable for even a moment." (R9) Here we find ice forming underneath the water, as in some ice wells, and evidently not frozen by the air in the cave. The existence of geothermal heat nearby is also a fascinating situation. (WRC)

Western Alberta. "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." (R30) Unfortunately, the above abstract, quoted in full, leaves one desirous of more information about these ice plates, which are apparently unique to this single ice cave. (WRC)

X3. Buried ice layers. It is not unusual in far northern climes to find relict buried ice; that is, ice from the Ice Ages that has not yet melted, because it is well-insulated by a covering of dirt, plant material, and glacial drift. For example, R. F. Flint mentions the prevalence of "ice-cored end moraines" in Scandanavian mountains and elsewhere. Radiocarbon dating reveals that some of these ice cores are thousands of years old. (R32) Buried glaciers are to be found in Greenland, and many strata of ice may be seen along the banks of the Yukon. Some of the Yukon ice strata are over 30 meters thick. Given the frigid conditions of these regions, these surviving ice sheets cannot be considered anomalous. (R15) There are, however, other ice sheets and strata that are more difficult to accept, or which have disturbing implications.

Kowak River, Alaska. "The Kowak river rises in the northwestern part of Alaska, and after a tortuous easterly course of about 550 miles, the greater portion of which is within the Arctic circle, it flows into Hotham inlet, a large body of fresh water opening into Kotzebue sound. During the summers of 1884-'85 it was my good fortune to visit this region and to make a reconnaissance of the stream from its mouth to its headwaters. Among the many novel and interesting features of the region, which had never previously been visited by white men, none were more striking than a remarkable series of ice-cliffs observed along the banks of the river about 80 miles from its mouth. These deposits of ice were first seen in some of the low silt banks of the delta, and it was supposed that they were the result of the spring freshets in the river forcing large masses of ice into the soft, yielding soil of the banks. But when on our emerging from the delta and reaching the higher land of the interior we still found these ice deposits in the form of cliffs, from 80 to 150 feet high, the theory of current formation had to be abandoned. The banks of the stream in the region where the ice-cliffs are found are not all filled with ice, and the water-marks on those which are composed only of soil and rock show beyond question that the water has never reached a sufficiently high stage to have transported the ice to its present position.

"At two points the cliffs attain an altitude of over 150 feet, and one cliff measured by sextant angles showed 185 feet. The tops of all the cliffs were superposed by a layer of black, silt-like soil from 6 to 8 feet thick, and from this springs a luxuriant growth of mosses, grass, and the characteristic Arctic shrubbery, consisting for the most part of willow, alder, and berry bushes, and a dense forest of spruce trees from 50 to 80 feet high and from 4 to 8 inches in diameter.

"Where the face of the cliffs was towards the south the upper portion of the formation would be found undergoing the process of destruction under the melting action of the sun's rays, while in other situations the erosion of the river current was constantly undermining the cliffs. Both of these destructive agents caused great masses of soil and tree-laden ice to become detached and fall into the stream. Where the retreating waters of spring had left these masses of detached ice stranded on the adjacent beaches or bars, piles of soft dust almost entirely free from any gritty substance would be left as a monument to mark the spot where the ice had been melted by the summer sun." (R14) The purpose of this entry is the demonstration of how very cold climates have somehow created extensive ice sheets that still survive. Such may have a bearing on the more remarkable phenomena that follow. This is not to say that science understands exactly how the Kowak River ice sheet was formed or why more of it has not ablated during the thousands of years since the postulated Ice Ages. (WRC)

Mauna Kea, Hawaii. "The tropical island of Hawaii has been found to contain a deposit of ice that may be a remnant of glaciation in Pleistocene times. The mixture of subsurface ice and lava is near the summit of a 13,775-foot dormant volcano, Mauna Kea." Seismic measurements indicate that the ice sheet extends for hundreds of meters and is tens of meters thick. (R31; R38) Even though Hawaii is tropical, the climate at 13,775 feet is relatively cold. But whence the ice sheet, and why is it in association with lava like so many of the other ice sheets mentioned below? (WRC)

Tierra del Fuego, Argentina. "...in Tierra del Fuego, ice and lava are said to be found interstratified for a great depth, each winter's snow being covered by a new lava sheet." (R15) Somehow lava/ice sandwiches do not seem compatible. (WRC)

Eastern Washington. "At the northern edge of this lava plateau, inflowing ice complicated geophysical features. Great coulees were formed by rivers of flowing ice. The Columbia Valley, Moses Coulee, and Grand Coulee are several examples. Throughout this area, particularly in Northern Washington, but also occasionally in Idaho and Oregon, we find the phenomena of ice caves. Much ice remains, sandwiched in between layers of lava (of igneous origin), and that which has melted has left empty areas, the caves themselves.

"When the Milwaukee Railroad was being built, section gangs discovered ice caves in the Frenchman Hills in southern Grant County, Washington, and they used them to refrigerate their beef. When road construction crews made great cuts through the lava hills of the Grand Coulee country, they again ran into great pockets of ice residing within the lava hills. In Okanogan County, Washington, in the hills above Tonasket, an ice cave exists which spelunkers have followed for 7,000 feet without finding its end." (R29; R33) Are the ice caves found in lava true glacières or relict ice? (WRC)

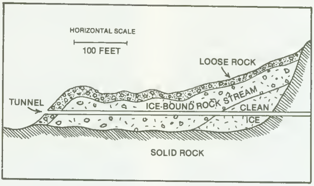
Clear Creek County, Colorado. At McClellan Mountain. "The Stevens Mine is situated in the southwestern bed of the great horseshoe; it opens from the northwestern. A tunnel was driven into the mountain on the lode, where the rock is almost perpendicular. Nothing unusual occurred until a distance of some 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 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." The author doubts that surface frost could ever have penetrated through 200 feet of solid rock. Perhaps, he ventures, the ice is left over from the Glacial Era. (R7)

Silverton Quadrangle, Colorado. What seems to be a buried glacier, possibly of great age, was found while tunnelling into a rock slide during mining operations.

"The tunnel was started in, and for the first few feet penetrated typical rock-stream debris consisting of angular blocks. For the next three hundred feet the material was cemented by ice, but the quantity of rock and ice varied, as did the size of the angular blocks of rocks. After penetrating this material, the tunnel was driven for one hundred feet through very clean ice before reaching solid rock. The relations of the various kinds of material can be seen from Figure 1.

.....

"It is believed that the ice encountered in the tunnel is glacial ice, but one must consider the possibility that this supposed glacier is merely a large snow bank that was



Section along a tunnel cut into a Colorado rock stream, where a clean-ice deposit was discovered. (X3)

covered by rockslides. Snow banks, however, usually lie on talus slopes, and there is no slide rock below the ice. It might be objected also that if this is glacial ice, it should have melted away. In this connection it is noteworthy that veins in the vicinity contain vugs full of ice to a depth of over three hundred feet. Also, the body of clean ice is only melting very slightly along the sides of the tunnel, although the ice in the upper part of the rock slide does melt considerably each summer.

"Hurricane Basin is one of the numerous cirques of the San Juan region. The last remnants of most of the glaciers almost certainly remained in these cirques long after the end of the last glacial epoch. It is believed from the field evidence that the ice in question may be the remnant of one glacier which has survived until the present time. The covering of the glacier can probably be accounted for by the suggestion of Cross and Howe. After being covered, it seems to have resisted thawing, as it does today." (R37)

Brandon, Vermont. This curious ice well, described in more detail in X1, must be reintroduced here because of the icy stratum encountered while it was being dug. Here follows a better assessment of the frozen layer.

"After sinking through loam and sandy subsoil twenty feet, a bed of frozen gravel, with lumps of ice, was met with, and the whole bed was frozen to the thickness of about fifteen feet. The gravel consisted of large and small pebbles, imbedded in mud, which was all frozen. Some lumps of ice, of the size of twelve-pound cannon-balls, were taken out. Below this frozen deposit, sand was struck at the depth of thirty-five feet from the surface, and three springs of water came in from below, and still supply water." (R4)

"In 1860, four shafts were sunk in immediate proximity to the well without striking frozen ground.... 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 20 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." (R5) In Alaska, the discovery of such a lens of ice would occasion no surprise. (WRC)

Grants, New Mexico. What follows is a popular account of one of the more famous ice deposits in lava formations.

"A lava bed whose surface is unpleasantly warm to the touch does not seem a likely setting for a deposit of perpetual ice. Yet in just such a locality, where the brazen New Mexico sun beats down upon a surface which was once molten stone, a deposit of perpetual ice does exist.

"Signboards lead the traveler to a volcanic sink, an abrupt depression of an estimated depth of seventy-five feet. This was produced when a natural tunnel in the lava bed caved in. The tunnel was caused by the flowing away of molten lava from the lower part of the bed after the upper surface had cooled and hardened.

"The floor of the sink is covered by jagged chunks of grayish black basalt which once formed a roof above the cavity. The accumulated warmth of the air in the depression strikes one almost like the blast from a furnace. One wonders how ice could possibly withstand a temperature such as this."

After the visitor descends into the cave: "The sight which greets his eyes is well worth the effort he has spent. Imagine a bank of solid ice, mild aquamarine in color, from 12 to 14 feet in height and some 50 feet in width, calmly resting in a tunnel of what once was molten stone---the hottest manifestation of the earth's internal heat.

.....

"The ice is horizontally banded by strange dark lines of stratification. The nearly vertical face of the mass is gracefully curved from left to right. There is very little water from melted ice at the base of the deposit, and what there is registers 32 degrees Fahrenheit.

.....

"The bluish-green tint of the ice is probably produced by pollen wafted onto the ice surface at times when the mass was slowly forming, from the pines that grow on the lava outside. The darker bands of stratification were formed by layers of dust similarly deposited. From a distance, or from a photograph, it might be supposed that these bands could be used as reference marks for tracing the age of the deposit as are growth rings in a tree. Actually, the dust bands are not distinct when seen at close range." (R22)

No indication is given in this article about whether the ice is a superficial deposit or whether it continues deep into the lava formation. Does the ice face grow and melt seasonally, as in a true glacière? No hint is given. The stratification implies that the ice sheet grew horizontal layer upon horizontal layer---this is difficult to imagine. One cannot tell whether the Grants ice cave is a true glacière or a relict ice sheet left over from the Ice Ages. (WRC)

<u>An overview of ice deposits in lava in the American Southwest.</u> "That some of the hottest, most arid sections of the desert Southwest should contain huge caves packed with solid ice of unknown age and depth, is one of Nature's strangest anomalies.

"While the most noted ice caves are those of Modoc lava beds in northeastern California, and those near Sunset volcanic crater in northern Arizona, another important group is situated near the base of Bandera crater in Valencia county, New Mexico. Only partially explored, and until recent years difficult of access, the latter group of caves is virtually unknown.

"Regardless of location, all these refrigerated caverns are basically similar. Also, the fact that all are restricted to areas deeply blanketed beaneath ancient lava flows, explains in part the actual conditions.

"During some long ago, turbulent age, geologists tell us, a mighty tide of molten lava engulfed the land. Contact with air cooled the surface, while the center remained hot. As the molten part drained away, the hard surface crust remained. The result was a series of chambers ranging from tiny pockets to great vaulted halls.

"Not so easily determined is the reason that a few of these underground pockets came to be filled with seemingly perpetual ice.

"In the largest of several caverns on the Candelaria Ranch, near Bandera crater, the ice deposit has assumed an aquamarine color and shows dark, horizontal stripes. Although openly exposed to the air and less than twenty feet below the surface of the lava-encrusted earth, the cave's contents have never been known to melt, even during the scorching days of mid-summer. In addition to a floor of solid ice, extending downward downward to unknown depths, the cavern has a great backwall of ice, fifty feet wide and from eight to fourteen feet in height. It is also not known how far this icy river may extend beneath the plain.

"Neither does anyone know how long the cold, blue wall may have stood intact. Earliest white settlers in the region have left records of chipping great loads of ice from it, using the ice for refrigeration and as a source of water in this arid land, where surface flows are virtually non-existent. As the ice constantly replaces itself, it is possible to go back still farther and presume that it was likewise employed by prehistoric tribesmen who inhabited the region over a long period of time and in considerable numbers." (R27)

The specific ice cave mentioned at the end of the above survey is that same one as that near Grants, New Mexico. Since this cave's ice face "replaces itself", one infers that typical glacière action occurs, as in the ice caves in the American Northeast; but this region of New Mexico is practically devoid of the water needed for glacière action. It should also be pointed out that, although local glaciation occurred, the Southwest was far from the great ice sheets postulated for the northern parts of the continent. So, the extents of these ice/lava formations and their mode(s) of origin are uncertain. (WRC)

Quenamari, Peruvian Andes. Here there is an ice plateau, 2-3 miles wide, 12 miles long, and several hundred feet thick. The region is normally free of ice and snow most of the year. Despite negligible precipitation and the absence of any glacial or other source, this ice plateau persists. Although the altitude is high---18,000 feet---scientists are not sure why the ice survives here and nowhere else in the area. (R28) It is unclear from the account whether this ice sheet is covered with soil and vegetation like those in the Arctic. (WRC)

X4. Rock gorge refrigerators. These phenomena do not seem anomalous in any way. We present a few brief descriptions only.

A short survey. "Of rock gorges which act as refrigerators I have seen three in the Eastern United States. One is the, so-called, Ice Glen at Stockbridge, Mass. I was told that ice remained there later than elsewhere in the neighborhood, sometimes as late as May. On the 3d of July there was no trace of ice or snow, and the temperatures were normal.

"There is a great gorge near Randolph, N.H., north of the Presidential Range, between Crescent and Black Mountains. This is called the Ice Gulch. The sides are quite sheer in many places, and the bottom is choked with an accumulation of boulders. Among these was a small quantity of ice in one or two places on the 11th of August last. This ice was unusual in formation, neither solid nor prismatic, but full of air bubbles. It crumbled away in small pieces under the teeth.

"In the Presidental Range itself is the great King's Ravine, on Mount Adams. The bottom is covered with huge boulders, and among these, some years ago at the end of September, there was plenty of prismatic ice." (R15) According to glacière theory, winter cold is stored in the crevices and cracks of these sheltered spots.

X5. Rock talus refrigerators. As with the rock gorge glacières, winter cold permeates and is stored for a long period in these reservoirs of broken rock. Two examples will suffice.

Lower Ausable Pond, New York. Here "is a huge talus of great Laurentian (?) boulders, among which are numerous hollows, which might by courtesy be called caves. On the 12th of July, Mr. E.I.H. Howell went with me to this spot, and in three hollows we found ice, in two of these places in considerable quantities. Mr. Howell has been repeatedly at this spot during past summers and always found ice, so it must be considered a perennial glacière." (R15)

Ice Mountain, West Virginia. "The northwest slope of the mountain is mantled with a very large, deep talus slope of mammoth Oriskany sandstone blocks, which have tumbled down, during long periods of time, from the rocky summit. This pile of loose rock is a natural reservoir for cold air stored up during each winter season. 'Tis said that, in some years, summer ice crystals are plentiful among the rocks---but at any rate it is unusual, on a hot summer day, to feel icy air flowing down the slope around one's ankles and into the creek, like water from hillside springs." (R24)

References

R1. Brocklesby, John; "The Frozen Wells of Owego," American Association for the Advancement of Science, Proceedings, 9:175, 1855. (X1)
R2. "Ice Wells," Scientific American, 14: 299, 1859. (X1, X3)
R3. "Phenomenon of the Frozen Wells," Scientific American, 1:37, 1859. (X1, X3) (New series of this journal.)
R4. Jackson, C.T.; Daedalus, 4:269, 1859. (X1, X3)
R5. "The Frozen Well of Brandon, Vermont," Scientific American, 27:248, 1872. (X1, X3)
R6. Lowdon, Ralph; "Ice, Mephitic, and Osseous Caverns," English Mechanic, 17:381, 1873. (X2)
R7. Weiser, R.; "Permanent Ice in a Mine in the Rocky Mountains," American Journal of Science, 3:8:477, 1874. (X3)
R8. Weiser, R.; "Permanent Ice in a Mine in the Rocky Mountains," Philosophical Magazine, 4:49:77, 1875. (X3)
R9. "The Ice Cave of Teneriffe," Scientific American, 41:308, 1879. (X2)
R10. Lowe, N.M.; "Paradoxical Phenomena in Ice-Caves," Journal of Science, 16: 524, 1879. (X1)
R11. Hovey, H.C.; "A Remarkable Ice Well," Scientific American, 49:211, 1883. (X1)
R12. "A Remarkable Ice Well," Scientific American, 49:258, 1883. (X1)

R13. Russell, Israel C.; "Ice Cliffs on Kowak River, Alaska, Observed by Lieut. Cantwell," American Geologist, 6:49, 1890. (X3)
R14. Cantwell, J. C.; "Ice-Cliffs on the Kowak River," National Geographic Magazine, 7:345, 1896. (X3)
R15. Balch, Edwin Swift; "Subterranean Ice Deposits in America," Franklin Institute, Journal, 147:286, 1899. (X0-X5)
R16. Kovarik, Alois F.; "The Decorah Ice Cave and Its Explanation," Scientific American Supplement, 46:19158, 1898. (X2)
R17. "Ice Caves and Frozen Wells in the United States," Geographical Journal, 19:220, 1902. X1-X3, X5)
R18. Andrews, Marlin O.; "The Sweden Valley Ice Mine and Its Explanation," Popular Science Monthly, 82:280, 1913. (X2)
R19. Vandermuelen, Charles Arthur; "An Ice Mine That Freezes in Summer and Melts in Winter," Scientific American, 114:470, 1916. (X2)
R20. Balch, Edwin Swift; "The Coudersport Ice Mine," American Philosophical Society, Proceedings, 60:553, 1921. (X0, X2)
R21. Peck, A.P.; "Perpetual Ice in a Lava Bed," Scientific American, 153:305, 1935. (X3)
R22. MacClary, John Stewart; "Perpetual Ice under Lava," Natural History, 38:56, 1936. (X3)
R23. Baxter, W.T.; "Shoshone Ice Caverns of Idaho," Rocks and Minerals, 16:58, 1941. (X3)
R24. Hawkins, A. C.; "Ice in Cave, Mine and Mountain," Rocks and Minerals, 16:292, 1941. (X5)
R25. Fritz, B. J.; "An Ice Cave in Washington," Rocks and Minerals, 16:325, 1941. (X1, X2)
R26. Rogers, W.T.; "Ice Spring in Central Utah," Rocks and Minerals, 17:10, 1942. (X2)
R27. Murbarger, Nell; "'Ice Boxes' of the Desert," Nature Magazine, 44:408, 1951. (X3)
R28. "Ice that Should Not Exist," New Scientist, 1:30, December 6, 1956. (X3)
R29. Patten, Donald Wesley; "Glaciogenesis: The Cause of the Ice Epoch," in The Biblical Flood and the Ice Epoch, Seattle, 1966, p. 120. (X3)
R30. Wigley, T, M. L., et al; "Micrometeorological Investigations in a Remarkable Ice Cave," American Geophysical Union, Transactions, 49:693, 1968. (X2)
R31. "Fossil Ice in Hawaii," Science News, 97:579, 1970. (X3)
R32. Flint, Richard Foster; "Morphology of Glacial Drift," in Glacial and Quaternary Geology, New York, 1971, p. 206. (X0)
R33. "The Ice Caves of Washington Territory," Overland Monthly, 3:421, 1869. (X3)
R34. Balch, Edwin Swift; "Ice Caves and the Causes of Subterranean Ice," Franklin Institute, Journal, 143:161, 1897. (X0)
R35. Kimball, H. H.; "Ice Caves and Frozen Wells as Meteorological Phenomena," Monthly Weather Review, 29:366, 1901. (X1-X4)
R36. "Ice Caves and Freezing Wells," Monthly Weather Review, 29:509, 1901. (X1)
R37. Brown, W. Horatio; "A Probable Fossil Glacier," Journal of Geology, 33:464, 1925. (X3)
R38. Woodcock, A. H., et al; "Fossil Ice in Hawaii?" Nature, 226:873, 1970. (X3)

ESP19 Unusually Radioactive Fossils

Description. Bones, scales, and other fossilized biological entities that are much more radioactive than the surrounding rock matrix and other fossils in the area in which they were found.

Data Evaluation. Substantiation of this phenomenon is very limited, coming only from two widely separated geographical locations. The handful of reports, however, is based upon modern radiometric methods, and the reality of highly radioactive fossils is difficult to dispute. Rating: 2.

Anomaly Evaluation. Many organic compounds and structures composed of them tend to concentrate various chemicals that circulate in subterranean fluids. Since some of the elements in the circulating fluids may be radioactive (uranium and thorium, expecially), it cannot be considered anomalous for some fossils to be unusually radioactive. Rating: 4.

Possible Explanations. None required beyond the above statement.

Similar and Related Phenomena. Radiohalos in coalified wood (ESP1). The chemicals in some water-conditioning systems act to concentrate chemical impurities, just as some fossils do. Petrified wood is an even more appropriate analogy.

Examples

X1. Fossil fish, Scotland. "During recent investigations on the distribution of radioactive elements in phosphates, it was noted that many of the Old Red Sandstone fish remains from north-east Scotland have an abnormally high radioactivity; in particular an unidentified Homostius plate (GSM 89090) was shown by rough radiometric assay to have an activity equivalent to 0.5 per cent U_3O_8." (R1)

Nine years after the above report, in 1965, another analysis of these Scottish fossil fish appeared in Nature. It confirmed the unusual radioactivity of the fish remains, but differed from the earlier report in attributing the radioactivity to the uranium decay chain rather than that of thorium. (R2)

X2. Fossil bones from various animals, Mongolia. Fossil bones collected from the Gobi Desert, in the years 1963-1965, were found to be highly radioactive. The samples included dinosaur, mammal, turtle, and crocodile bones. (R3)

References

R1. Bowie, S. H. U., and Atkin, D.; "An Unusually Radioactive Fossil Fish from Thurso, Scotland," Nature, 177:487, 1956. (X1)

R2. Diggle, W.R., and Saxon, J.; "An Unusually Radioactive Fossil Fish from Thurso, Scotland," Nature, 208:400, 1965. (X1)

R3. Jaworowski, Zbigniew, and Pensko, Jerzy; "Unusually Radioactive Fossil Bones from Mongolia," Nature, 214:161, 1967. (X2)

ESP20 Clustering of Mineralogical Dates in Time and Space

Description. The tendency of radiometrically determined mineralogenic dates to cluster in periodically spaced intervals, about 175 million years wide and repeating every 350-500 million years. In North America, but not other continents, the bands of like mineralogenic dates are concentric around the continent, with younger ages outward.

Data Evaluation. So far, there is only one scientific survey of mineralogenic dates in our data base. Rating: 2.

Anomaly Evaluation. The periodicity of mineralogenic dates implies that major crustal or orogenic events are also cyclic. Such periodicity has long been suspected, but the cause is not known; it could be an internal mechanism of some sort or astronomically induced catastrophism. The unique concentric bands of like mineralogenic dates around North America is also a puzzle. Why is North America different? In sum, the distribution of mineralogenic dates in time and space seems to indicate the existence of major geological and/or astronomical phenomena about which we know very little. Rating: 1.

Possible Explanations. Periodic terrestrial catastrophism caused by asteroid impacts.

Similar and Related Phenomena. The iridium layer and other chemical anomalies (ESC1, ESC2); periodicity of biological extinctions (ESB1); periodicity of geomagnetic reversals (EZ); the periodicity of terrestrial crater ages (ETC4); continental accretion of terranes (ESG3).

Examples

X1. Survey results. "Abstract. Most igneous and metamorphic mineral dates indicate times of rock cooling, the terminal events of crustal adjustment. Accordingly, the distribution of mineral dates in time indicates the periodicity of such events, and the distribution in space indicates the geometry of their occurrence. By this we may test the validity of such concepts as 'orogenic periodicity', 'cyclic orogeny', and 'continental accretion'.

"A plot of mineral date abundance against age shows that crustal adjustments are periodic and roughly cyclic. Intervals for which abundant mineral dates have been preserved are about 175 million years in length, with cycles of about 350 to 500 million years. Intervals of date abundance fall in the ranges: -2710 to -2490 m.y., -2220 to -2060 m.y., -1860 to -1650 m.y., -1480 to -1300 m.y., -1100 to -930 m.y., -620 to -280 m.y., and -120 to the present.

"Mineralogenic events of very different ages are commonly recorded in the same area, not infrequently in the same rock. Large areas, however, can be characterized by the mineral dates of the last interval of mineralogenic activity by which they were seriously affected. In North America these mineralogenic provinces show a crudely concentric pattern, younger dates outward. Similar arrangements have not been found in other continents." In his Conclusions, the author claims that the distribution of dates in time and space do not support the hypothesis of continental accretion. (R1)

References

R1. Gastil, Gordon; "The Distribution of Mineral Dates in Time and Space," American Journal of Science, 258:1, 1960. (X1)

ESP21 Random Cracking around Radioactive Inclusions

Description. The presence of random cracking of the mineral matrix around radioactive inclusions that undergo large volume changes as radioactive decay progresses. The normal expectation, over the fullness of geological time, would be that the slow decay and slow volume changes would produce cracking along cohesion minima and grain boundaries.

Data Evaluation. An allusion to a research paper that we have not examined. Rating: 3.

Anomaly Evaluation. The implications of the random cracking of the matrix could be very anomalous. Such random cracking might be the consequence of rapid volume changes of the radioactive inclusion. A radical interpretation of this phenomenon (the one favored by some scientific creationists) is that radioactive decay rates were once much higher, resulting in an almost explosive volume change. More conservative explanations have not been found as of this date. Rating: 2.

Possible Explanations. See above.

Similar and Related Phenomena. Radioactive halos (ESP1). Some scientists have proposed that some of the fundamental physical "constants" do change with time. See Category C, to be cataloged later.

Examples

X1. Observations of P. Ramdohr. "Ramdohr in his extensive mineral studies has observed radioactive halos in polished mineral sections which exhibit an unusual appearance. Radioactive inclusions (such as Zircon), which show a considerable volume increase due to isotropization from radioactive decay, have in numerous cases been observed to fracture the surrounding mineral in a random pattern.

Ramdohr points out that the surrounding mineral should expand slowly over geological time due to radioactive isotropization, and individual cracks should appear as soon as the elastic limit is reached. He further points out that, while these expansion cracks should occur first, along cohesion minimums and grain boundaries, nothing like this happens.

"Individual cracks surrounding the radioactive inclusion are randomly distributed and evidently occur quite suddenly in the form of an explosive fracture and not a slow expansion. Figure 1 shows a (sketch based on a Ramdohr photograph) of such a phenomenon wherein the isotropic central inclusion fractures the non-isotropic outer zone. The occurrence of this phenomenon is worldwide in extent." Sketch not reproduced. (R1)

References

R1. Gentry, Robert V.; "On the Variance of the Decay Constant over Geological Time," Creation Research Society Quarterly, 5: 83, 1968. For an English translation of Ramdohr's work, Gentry refers the reader to Oak Ridge National Laboratory Translation ORNL-Tt-755, 1957.

TIME INDEX

Age Index (Years)

Geological Period Index

Time-of-Event Index

PLACE INDEX

FIRST-AUTHOR INDEX

SOURCE INDEX

SUBJECT INDEX