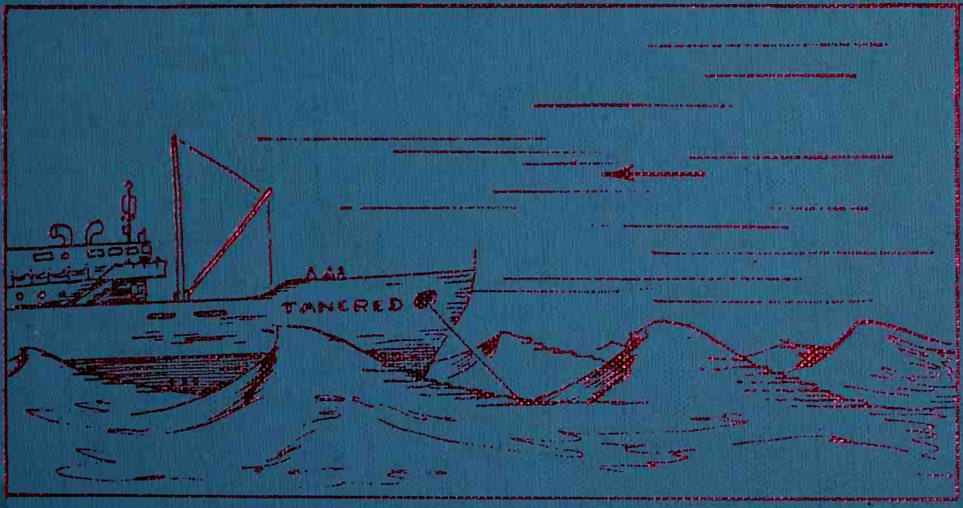
EARTHQUAKES, TIDES, UNIDENTIFIED SOUNDS AND RELATED PHENOMENA

Compiled by:

William R. Corliss



A CATALOG OF GEOPHYSICAL ANOMALIES

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Compiled by:

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P.O. Box 107
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PREFACE

After more than ten 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 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 realize what is well-explained. Nevertheless, here begins the first publication of a Catalog of Anomalies; the product largely of one person's library research, carried forward without a single public or foundation dollar.

Under the aegis of the Sourcebook Project, I have already published 16 volumes, comprising well over 7,000 pages, of source material on scientific anomalies. (See page iv for a list of titles.) As of this moment these 16 volumes represent only about 20% of my collection of scientific anomalies. New material is being added at the rate of about 1,200 new articles and items per year, 300 of which are from the current literature. These rates could be easily multiplied several times over by spending more time in the libraries. After ten 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 publications in other languages, university theses, government reports, bulletins of scientific research facilities, conference papers, and not the least, books and newspapers. The cataloging task is just beginning, for the anomalies in the world's scientific and semiscientific literature seem nearly infinite in number.

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 of about the same size as 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.

Will the Catalog of Anomalies revolutionize science? Probably not---at least not immediately. Quite often the initial reaction to the books of anomalies already published has been disbelief. 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 these complaints. 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
September 1, 1983

"ROUND ABOUT THE ACCREDITED AND ORDERLY FACTS OF EVERY SCIENCE THERE EVER FLOATS A SORT OF DUST-CLOUD OF EXCEPTIONAL OBSERVATIONS, OF OCCURRENCES MINUTE AND IRREGULAR AND SELDOM 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. AND WHEN THE SCIENCE IS RENEWED, 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 in 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 therefore have a ready-made foundation for beginning further investigations into 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. Few persons would have difficulty classifying a phenomenon as biological, astronomical, etc. The second, third, and fourth levels of classification are also based upon generally recognized attributes, such as luminosity, sound, etc. The similarity of this method of categorization to those employed in natural history field guides is purely intentional. Like bird identification, phenomenon classification soon becomes second nature. In fact, almost all of the phenomena described in the Catalog are accessible to everyone with five normal senses and perhaps binoculars and telescope.

Most catalogs boast numbering systems and this one is no exception. Rather than employ a purely numerical system, the first three levels of classification are designated with letters. The triplets of letters chosen have some mnemonic value. Thus, a GSD anomaly is easily recognized as being in the geophysics class (G), involving sound (S), and possessing the quality of a detonation (D). The number added to the triplet of letters marks the fourth level of classification, so that GSD1 signifies the so-called "waterguns" (Barisal Guns, etc.). Every anomaly type has a unique alphanumeric code, like GSD1. All cross references and indexes are based upon this system. Catalog additional and revisions are made much easier with this scheme.

The Catalog codes may seem cumbersome at first but their mnemonic value to the compiler has been significant. Hopefully, they will help other users, too. The codes are simple, yet flexible enough to encompass the several thousand types of anomalies identified so far.

A glance through this volume of the Catalog will reveal that each example of a specific anomaly type bears an X-number, and each reference an R-number. GSD1-X12 therefore specifies the twelfth example of waterguns, and GSD1-R17 the seventeenth reference to waterguns. Indexes and cross references can consequently be made more precise than conventional page references.

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 validity questionable.

4 Unacceptable, poor-quality data. Such phenomena are included only for purposes of comparison or amplification. Only two such items are registered in this volume.

First-order classification	Second-order classification	Third-order classification	Fourth-order classification
A Astronomy	E Atmospheric optics		
B Biology	H Hydrospheric phenomena	D Detonations	1 Waterguns
C Chemistry & physics	L Luminous phenomena	E Echos	2 Seismic sounds
E Earth sciences	M Magnetic phenomena	H Hums and Hisses	
G Geophysics	Q Earthquakes	I Infrasound	
L Logic & math	S Sound	M Natural Music	
M Archeology	V Volcanic phenomena	W Air Waves	
P Psychology	W Weather		
X Unclassified			

Catalog Coding Scheme

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, with no entries at all in this volume of the Catalog, and only one in the first Catalog volume. 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. The following matrix summarizes the ratings assigned in this volume.

Anomaly Ratings

		1	2	3	4
Data Ratings	1-	0	6	10	4
	2-	0	12	16	3
	3-	2	7	16	2
	4-	0	1	1	0

Total: 80 anomaly types

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 if available. Some of the more significant geophysical events, such as the remarkable Haicheng earthquake of 1975, may appear in several references, all of which are proivded in full and keyed to the X-number of the example. Powerful earthquakes are represented by many examples, but only a single example of an electrostatic phenomenon associated with an earthquake has been found. When library research has made many examples of an anomaly type available, several of the most interesting and instructive are reported in some detail. Direct quotations from the eye-witness accounts are frequently employed to convey accurately the characteristics of the phenomenon to the reader. These selected examples are printed full-width in the Catalog columns. Examples of less import are indented to separate them visually.

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 references come from the scientific literature. Heavily represented in this volume of the Catalog are: Nature, Science, Monthly Weather Review, Meteorological Magazine, and the Quarterly Journal of the Royal Meteorological Society. Several less technical publications are also frequently mentioned: Marine Observer, Scientific American, and English Mechanic. The Marine Observer is a publication of the U.K. Meteorological Office. The English Mechanic was for many years an important English technical magazine, much like Scientific American. All of the serials mentioned so far are considered generally reliable, although one must always be wary. In addition to these often-referenced journals, there is a very wide selection of other publications. Some of these are more popular in character. In this context, it should be remembered that unusual phenomena do not seek out scientists, and the laymen who observe many anomalies have no knowledge of or access to scientific journals.

The time span covered by the sources ranges over 150 years. Many excellent reports of anomalies come from the latter half of the Nineteenth Century. Although many scientists frown on such old reports, the quality is often good, and they should not be discarded arbitrarily. Not only were the observers of a century ago competent, they were unbiased by knowledge of modern theories and lived in an environment unpolluted by modern vehicles, effluxes, and other contaminants. It should also be mentioned here that the modern meteorological literature tends heavily toward mathematical modelling and theory as opposed to eye-witness accounts of strange phenomena. Two journals that are exceptions to this rule are the Marine Observer and the U.K. Journal of Meteorology.

The Indexes

Each Catalog volume concludes 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 events and unusual natural phenomena, each idex has its special utility.

The subject index is essential in any work of this type. It is placed last for easy access. The time-of-event and place-of-event indexes are analytical tools for the anomaly researcher. They help identify phenomena that are reported separately (perhaps in widely different journals) but are really different aspects of the same event. This integrating feature will become more apparent as additional Catalog volumes appear. To illustrate, the 1908 Tunguska Event produced luminous and barometric phenomena as well as atmospheric optical effects. It is possible that composite time-of-event and place-of-event indexes covering all scientific fields will reveal cause-and-effect relationships that have not been recognized before. It is the intent of the Catalog effort to generate a composite set of indexes when all four Catalog volumes in geophysics are published as well as a final master index covering all of science.

The source index shows immediately the dependence of this Catalog upon scientific literature rather than newspapers and other popular publications. Its real purpose, though, is the rapid checking to determine if a specific reference has or has not been caught already in the fishing nets of this Catalog project. The source index is doubly valuable because many footnotes and bibliographies in the scientific literature display sources only; that is, titles and authors are omitted entirely. The researcher also comes across many vague references to 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 are actually only distillations of huge quantities of source material. The Anomaly Data Research Center/Sourcebook Project has already published 16 volumes of source material, as detailed on page iv.

Catalog Addenda and Revisions

Over 1,000 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 new material assignable to a Catalog volume already in print is acquired, it appears first in the serial ANOMALY REGISTER, published frequently by the Anomaly Data Research Center. (Ordering information on page iv.) When sufficient new material has been assembled in a Catalog area, that volume of the Catalog will be revised and published with all additions and corrections incorporated.

Request for Additions and Corrections

The Anomaly Data Research Center welcomes reports of new anomalies and examples of unusual phenomena. If you discover a report of an anomaly not listed in the Catalog, send a xerox of the article to the Anomaly Data Research Center for evaluation. If the report is added to our data base, credit will be given to the submitter in the ANOMALY REGISTER and the revised edition of the Catalog. Reports from recognized scientific journals are preferred but everything is grist for the mill! The address of the Anomaly Data Research Center is: P.O. Box 107, Glen Arm, MD 21057.

INTRODUCTION TO PHENOMENA OF THE HYDROSPHERE

"Weather" is a phenomenon of the atmosphere, but seven-tenths of the earth is covered with a thin coating of water possessing "weather" of an entirely different sort. The most accessible of these water phenomena occur on ocean and lake surfaces: the waves. The more ponderous movements of water that we call tides make themselves known at the land-sea boundaries. What transpires below the surface is still largely a mystery. We can conjecture from surface clues and a scattering of subsurface measurements that underwater "winds" and "storms" are not only very complicated but surprisingly powerful.

The difficulty of exploring the subsurface realm necessarily focusses our attention on events transpiring when the sea and atmosphere meet. Centuries of sea lore plus data from a fleet of research vessels and thousands of shore instruments have discerned tidal irregularities and charted enigmatic wave patterns on many seas and lakes. The photographs sent back by earth satellites reveal waves hundreds of miles long, separated by several miles, that surface ships cannot appreciate. It is all, however, an empirical business, with unpredicted phenomena frequently sending scientists back to their computers to modify their theories and models.

Besides the global motions of the tides and the hurrying surface waves, even the casual observer may note harbors and lakes festooned with slicks, curious lines of foam (especially on the Dead Sea), and incongruous calm patches. Whence these unassuming phenomena? Do they have prosaic explanations? And where the hydrosphere actually coexists with the land, there are cold-water geysers to ponder, as well as periodically erupting springs, water wells, and oil wells. These phenomena seem to wax and wane in step with the weather, with tidal forces, with natural siphon action, and sometimes according to no discernable force.

GHC UNUSUAL PHENOMENA OF WATER SURFACES

Key to Phenomena

GHC0 Introduction

If the wind-generated waves could be subtracted, the surfaces of the oceans would still be marked by curious rips, rollings, slicks, calms, and sundry disturbances. Many of these phenomena are probably manifestations of the subsurface movements of water. Internal ocean waves that intersect the surface and submarine upwellings can turn a calm water surface into roiling patches and long, linear patterns of choppy sea that contrast in color and temperature with the surrounding waters. Submarine volcanos and quakes often spew forth mud, bubbles, geysers of hot water, and dead fish. (Although certainly startling, such earthquake and volcano phenomena are easily explained and therefore not included in this Catalog.) Huge shoals of fish and miles-long windrows of floating plants also festoon the ocean surfaces. This chapter presents a unique group of phenomena that are not so much unexplained as they are strange and unexpected (at least to "landlubbers").

Moving inland away from our planet's rolling oceans, which are so big and so little-explored that anomalies are to be expected, we find that even rivers, lakes, and ponds display surface phenomena---though sparingly. In addition to such fresh-water popular puzzles as the sudden disappearance of ice in the spring and the bulging of channel waters in swift rivers, one finds seemingly minor idiosyncracies of nature that lead to serious philosophical questions.

GHC1 Foam Strips on Inland Waters

Description. Long, whitish lines of foam, straight or gently curved, stretching across inland waters. In the case of the Dead Sea, as many as 20 parallel lines have been seen arrayed across its length (about 47 miles). The form and extent of the phenomenon seems to depend upon wind speed. The foam consists mainly of bubbles and plant debris.

Background. Although the foam strips of the Dead Sea are the most spectacular and best known, the same phenomenon apparently occurs on lakes and other inland seas.

Data Evaluation. Many individuals have seen and remarked upon the Dead Sea foam lines. Photographs also exist. But the frequency and distribution of foam strips on other inland waters are unknown. Rating: 1.

Anomaly Evaluation. Several mechanisms have been suggested to account for the foam strips, but there is no general agreement. Nevertheless, the phenomenon, curious though it may be, seems very likely to have one of the prosaic explanations listed below. In other words, foam strips do not seem very anomalous. Rating: 3.

Possible Explanations. Possible foam sources: springs and inflowing rivers may contribute debris and foam-encouraging chemicals; wind-caused turbulence may create bubbles; underwater fissures and faults may also inject impurities and particulate matter. Possible sources of the arrays of strips: cyclic occurrence of the conditions conducive to foaming combined with wind-drifting of the lines; convection cells; internal waves; wave interference patterns.

Similar and Related Phenomena. Dead Sea whitenings (GHC4); slicks and calms (GHC2); marine phosphorescent bands (GLW1).

Examples of Foam Strips on Inland Waters

X1. Frequent occurrence. The Dead Sea. "A peculiar phenomenon often to be seen on the northern waters of the Dead Sea is that of arcs of foam, more or less semicircular, spreading out fan-wise from certain points of the west and east shores. The arcs seem to spread from the shores in early morning and often meet and even cross during the forenoon. These lines of foam often bear reeds and other vegetation debris that have reached the Dead Sea by inflowing rivers, and, at the seasons of migration, the foam may attract flocks of birds searching for food. Dr. D. Ashbel has recorded some of his observations on this phenomenon and offers an explanation (Geog. Rev., Jan. 1938). The arcs originate from springs on the two shores, and they make discontinuities between bodies of water of different salinity and density. When the outflow of the springs is strong, the arc is frequently not smooth but zig-zag. This explanation contradicts the earlier one of Blanckenhorn that the lines of foam originate from warm water arising along lines of fault on the sea floor. That suggestion does not explain lack of replacement of the lines as each moves forward, which Dr. Ashbel thinks is due to the gentle winds that frequently blow from the land on to the sea during the night and early morning. These winds do not ruffle the water and so mixing does not occur. Gusty west winds such as often occur in the afternoon cause mixing and so the lines of discontinuity disappear." (R4) See R3 for Ashbel's complete report. An earlier reference to this phenomenon is R1. A somewhat different view of the strips was reported as follows: "The Dead Sea seen from the air during a gale on February 7th, 1932, presented a striking appearance. The height of the aircraft was about 4,000 feet, and at this height the wind was south-westerly 65-70 m.p.h. The wind in the deep depression near the Dead Sea was therefore probably S.-SSW., force 6-8. The surface of the sea was 'moderate' on the sea disturbance scale, but the striking feature was the parallel bands of white foam which ran the whole length of the sea. These bands were orientated roughly south by west and north by east---i.e., slightly across the sea's major axis. The impression was that the lines of foam were interference bands due to the two sets of waves or to one set of waves and their reflections from one shore. As the sea was obscured at times by cloud and rain, it was not possible to count the number of bands accurately, but it is estimated that there were about 20 between the east and the west shore." (R2) The greatest width of the

Dead Sea is about $9\frac{1}{2}$ miles, so the bands were about a half mile apart in this observation. (WRC)

X2. Frequent occurrence. Malham Tarn, England. "The occurrence of 'foam strips' on inland waters provides a phenomenon for which I can find no serious explanation in meteorological literature. A recent visit to the Malham Tarn Field Centre (Council for the Promotion of Field Studies) revived my interest in the matter, for I have seldom seen it so well formed as there. Long ribbons of foam stretched almost from one side of the lake to the other, and this rich development would appear to be accounted for by the open nature of the surrounding landscape. Although I have not investigated the issue properly, the appearance of the strips seems to correspond roughly with the occurrence of Beaufort wind-forces of 5 or 6. It seems significant that the Beaufort Scale stipulates 'crested wavelets form on inland waters' at force 5, for the bubbles necessary for the strips are formed at this force." (W.E. Richardson) "During the recent course at Malham Tarn the same phenomenon as that observed by Mr. Richardson was seen. Winds greater than about force 6 appeared to destroy the 'foam strip' effect, and a close examination of the crest-bubbles showed that those formed between the strips burst at once while those within them persisted. It seems likely that the strips may be due to a spiral cellular motion in the surface layers similar to the parallel development of cumulus clouds running down wind." (C.D. Ovey) (R5)

References

R1. "The Dead Sea Not Dead," English Mechanic, 107:26, 1918. (X1)
R2. Durward, J.; "Bands of Foam on the Dead Sea," Meteorological Magazine, 67:41, 1932. (X1)
R3. Ashbel, D.; "A Peculiar Phenomenon of the Dead Sea: The Floating Lines of Foam," Geographical Review, 29:128, 1939. (X1)
R4. "Foam on the Dead Sea," Nature, 143: 468, 1939. (X1)
R5. Richardson, W.E., and Ovey, C.D.; "Foam Strips on Inland Waters," Weather, 5:361, 1950. (X2)

GHC2 Streaks, Slicks, and Calm Patches

Description. Long lanes, parallel bands, and extensive patches of water surfaces that stand out visually against the surrounding water surface. The physical extent of the phenomenon may vary from a few feet to many miles. In most instances, the water surface of the bands and patches is smooth in sharp contrast to neighboring rough water. Data range from casual observations on lakes and ponds to satellite photographs revealing large-scale, geometrically regular slick patterns.

Background. Almost everyone who ventures near natural bodies of water notices the slicks and streaks. Intuition immediately assigns their cause to currents, the wind, and floating pollutants. The real situation is more complex and a bit more mysterious.

Data Evaluation. Although slicks and calms are omnipresent, scientific investigation is sadly lacking---possibly because they are so common and their origin supposedly well-explained. A few scientific investigations have been made, and satellite photos confirm the reality of the phenomenon. Rating: 1.

Anomaly Evaluation. A multiplicity of explanations exists; all of them rather prosaic. The scientific challenge here lies primarily in selecting the proper explanation for each facet of this delightfully complex phenomenon. No basic geophysical laws are challenged, but all with a curiosity about the natural world would like answers to such questions as: why are some slicks so stable and so sharply demarcated, and how do the patterns of bands arise? Rating: 3.

Possible Explanations. Wind-drifted pollutants (oil); wind-drifted biological matter (Gulfweed); current patterns; internal wave effects on the surface; wind-shadowing by islands.

Similar and Related Phenomena. Foam strips (GHC1); marine phosphorescent bands (GLW1).

Examples of Streaks, Slicks, and Calms

X1. General observations. "If one walks up onto cliffs overlooking the sea on a moderately windy day one can often see what look like 'lanes' of smooth water running somewhat irregularly over the surface of the sea, joining larger patches together, as if someone had drawn a road map on the sea. These 'lanes' are a few metres wide, and can be of the order of a kilometre in length. On any one day the lanes and patches are remarkably stable, remaining in the same position with no visible change for as long as one cares to watch. But on different days they may be in quite different positions. The smooth areas can take other forms, but that of long winding lanes in quite typical. In fact these lanes or other well defined smooth and rough areas are not confined to coastal regions; they can often also be seen on the Thames, or on much smaller rivers, lakes and even with an effort on small paddling pools. It seems that waves on water can be divided into three types; those which could be called 'long' waves, with lengths of the order of metres or more, travel distances without much change; 'short' ones of a few millimetres can be stirred up by a gust of wind, and die out again almost instantaneously. But the 'medium' waves with lengths of a few centimetres, produce the phenomenon in question. Or, more accurately, they are present all over the rough areas of the surface. But when they approach the edge of one of the apparently smooth lanes or patches, these 'medium' waves fade away within a second or two, with no visible reason, as if a spell had been cast upon them. In this way the boundary of the smooth region is kept well-defined. Presumably the phenomenon is somehow produced by air currents. But exactly how does it take place? Why should the water surface be clearly divided into regions covered with centimetre waves, and those in which these waves are virtually completely lacking? Why are the boundaries between these regions sharply defined, to within a few centimetres, and stable and unchanging, even on days when the wind seems a bit gusty and variable? And why should the smooth patches frequently take the form of long narrow winding lanes? Can anyone explain?" (R9)

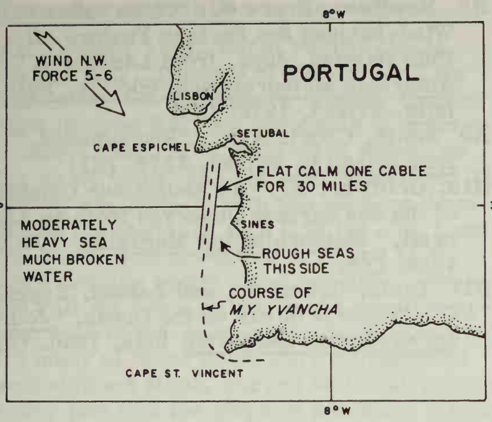
"Band slicks on the sea surface... are commonly seen along the shore when the wind is a light breeze. Dietz and La Fond of the Naval Electronics Laboratory in San Diego, California, have observed such slicks in coastal waters of California, Australia, and Samoa, around the Marquesas Islands, and near the Antarctic ice pack. Woodcock and Wyman have observed and photographed similar 'bands of light and dark appearance' in the Gulf of Panama. They attributed the effect to a systematic variation in the pattern of small waves on the sea surface associated with a corresponding variation in wind speed, which they explained in terms of roll vortices caused by convection in the air or in terms of an internal wave in the air caused by wind shear near the sea surface. They observed the effect at all wind speeds up to 7.5 m per sec and described the bands as oriented with their long axes roughly parallel to the wind. Dietz and La Fond have found that the primary mechanism controlling the formation of slicks in bands is a film of some substance at the sea surface which lowers the surface tension in the bands where ripples are absent, the role of the wind in this connection being merely to generate ripples which reveal the peculiar disposition of the surface film. A secondary mechanism must be sought to explain why the surface film is unevenly distributed." (R1)

"Most natural bodies of water have a streaky appearance which results from a natural process, although artificial streaks (due to the passage of a ship, for example) are also frequently observed. There has been quite a difference of opinion in the literature as to the nature of the process which produces streaks. I am personally inclined to admit that under certain circumstances any one of the processes suggested may account for them; to attribute all streaks to the same mechanism would be a great mistake. I should like, therefore, to review briefly what little material there is in the literature about these streaks on the surface of natural bodies of water. The streaks themselves may consist of accumulations of floating objects, such as Gulf-weed, pine needles or bubbles of foam, all of which are visible because of their colour. Others are local concentrations of an oil film (presumably of planktonic origin) which damp the tiny wind-raised capillary waves. These are visible because of the marked difference in reflectivity of sky light between ruffled and slick areas. Single Streaks. Single long streaks are often observed in harbours. They may stream out from a continuous source of contamination, and run down wind with the surface water, or follow tidal or other currents. For convenience they may be called 'trail-streaks'. Single long streaks may also develop from an initially localized concentration of surface contamination in regions of strong horizontal shear by a simple stretching of elements of water in the shear zone. These 'shear-streaks' occur on the edges of strong tidal currents and in rivers. A third kind of commonly observed single streak is seen to remain parallel to a coast-line a hundred feet or so offshore, most frequently with an onshore wind. The cause of these 'shore-streaks' is not known, but I venture to suggest that they are due to the horizontal convergence and sinking of surface water which is driven toward the shore by the wind, sinking somewhere offshore, where the water is reasonably deep, rather than at the vanishingly small depths at the very water's edge. The kinds of streaks mentioned above are described in order to avoid confusion with other kinds which are really more interesting. I am referring to the large numbers of streaks often arranged in geometric patterns over large areas of a lake or ocean. Although it may be dangerous to draw a sharp distinction, these multiple streaks usually appear either in long parallel lines or with a vein-like pattern. I find it convenient to call them 'parallel' and 'venous' streaks respectively. Parallel and venous streaks are plentiful in nature. Windrows of Gulf-weed in the deep ocean are conspicuous examples of parallel streaks.....Similar streaks are observed on lakes, and have been carefully studied." (Section on various theories omitted.) "Cinematographic Studies. During June and July of last year I made a number of cinematographic studies of streaks on small ponds on Cape Cod, Massachusetts. They were of the venous and parallel types, and consisted of oil-slicks and lines of foam. The steadier the wind direction, the more nearly parallel they seemed. Upon showing the pictures at some 80 times their normal speed interesting features, which otherwise escaped the eye, were visible: the structure of the wind was so gusty and turbulent that it was obvious that no permanent structure in the air maintained the streaks; these were so quickly re-oriented after a shift of wind (only 1 or 2 minutes was necessary) that deep motions such as those reported by Langmuir did not seem likely. Thermal convection seemed also unlikely because the streaks occurred at times of intense heating of the ponds and with a very stable epilimnion ($0.1^{\circ}C.m^{-1}$). Although surface convergence into the lines was confirmed, using Woodstock's ballasted-bottle technique, cellular motions were not observed at depths of one foot or deeper. The indications were that these streaks were due to a process confined to the top few inches at most, and did not play a role in the formation of the deep thermocline, which in this instance was at a depth of about thirty feet. It seems, therefore, that they were due to yet another process, perhaps associated with differences of wind-stress in and out of streaks, but which I must admit I do not understand. It would be misleading to conclude that this classification of various types of surface marking is complete. For example, Woodcock and Wyman have published photographs of mysterious bands on the surface of the ocean which may be to some still undiscovered process." (R2)

X2. Frequent occurrence. North Atlantic Ocean off the coast of North America. Satellite imagery shows lines of wedge-shaped packets of slicks, parallel to the coast, 20-30 kilometers apart. Each packet consists of curved slicks with lengths diminishing in a seaward direction. May be due to internal waves. (R7)

X3. Frequent occurrence. Satellite photos often reveal anomalous dark patches and streaks within sunglint areas, which are likely due to low sea states. (R6) But why are the sea states low in these areas? (WRC)

X4. September 16, 1958. Atlantic Ocean off the coast of Portugal. "An extraordinary experience happened to me during a passage from Gibraltar to the United Kingdom, and I should be grateful for an explanation. I am a master of a small motor yacht of a little over 60 tons, and on 10 September 1958, I was on passage from Gibraltar to England. I rounded Cape St. Vincent at about 0830 and ran into a pretty stiff north-west wind about Force 4; course was set, 310°, for Cape Espichel with the intention of putting into Lisbon, but after steaming for about four hours the wind from the north-west began to increase and a bad sea was now running with much salt water on board, and I was thinking of running all the way back to the shelter of Cape St. Vincent if the bad weather continued to increase. However, by reducing speed from 10 knots to about 6, the going was made more comfortable, and I kept on course until we were abeam Sines, which was 12 miles distant. We were still having a pretty horrible time when there appeared ahead quite a calm patch with no broken water and a little more than half an hour's steaming brought us up to it. I was quite dumfounded at what I was about to experience. This calm patch was at least a cable wide and stretched away in a north-easterly direction for about 30 miles. I was able to steam along it for three hours in almost a complete



30-mile-long avenue of calm water off Spanish coast (X4)

calm at full speed, while on either side of me was a steep sea. The lane was absolutely dead straight and the demarcation line of where the broken water flattened itself out into this marine autobahn had to be seen to be believed. Needless to say, I kept in it and steamed right into Sebutal without even any spray on deck. The points to remember are: (i) the wind was north-west and blowing 5 to 6 on land, (ii) we were in deep water, (iii) we were 12 miles from the nearest point of land when we came upon the entrance (12 miles off Cape Sine). I have spent over 30 years at sea and have made the passage to the Mediterranean on many occasions, but I have never experienced such a phenomenon as this before. It was most definitely not an oil slick; there was no sign of any oil and the lane was dead straight for 30 miles with clearly defined sides on both port and starboard sides. Had it come from an oil leakage I am sure it would have been curved from the source as it was blown away by the wind." (R3)

X5. December 23, 1960. North Atlantic Ocean. "At 1815 GMT a patch of brilliant blue water was observed some 50 by 100 yd. in extent and oval in shape. The surrounding sea was dark grey in colour and had been so, for the past 24 hours." (R4)

X6. October 2, 1963. Mediterranean Sea. "At 0700 GMT the vessel passed through a patch of calm water approx. 2,000 yd wide and several miles long, extending in a line lying 350°-170°. The wind at the time was force 5 and all the surrounding sea was covered with breaking wave crests. There was no sign of oil on the surface of the water." (R5)

X7. November 2, 1972. South Pacific Ocean. When over Pulu Bawean, Landsat-1 photographed an elongated dark pattern on the ocean that was not present on photos from passes before and after. It was hypothesized that this calm area may have been a wind-shadow effect downwind from Pulu Bawean. (R8)

X8. September 9, 1979. Equatorial Atlantic Ocean. "An unusual feature in the sea surface was observed near the equator (0°26'N, 18°44'W) on 9 September 1979 during the detachment of the Meteorological Research Flight Hercules aircraft to Dakar, Senegal. Two different colours of sea surface were separated by a pronounced dark-blue band a few hundred metres wide orientated roughly east-west and extending to the horizon in both directions. No significant cloud formations were observed in association with the differing sea surfaces, the sky being clear apart from a few patches of small cumulus. ....The water just to the north of the band appeared quite turbulent, showing many white crests, although elsewhere the sea was relatively calm. Later in the day the band was seen to branch." It was surmised that the band may have been due to ocean currents. (R10)

X9. General observations based on many sea voyages. "Abstract. Slicks are smooth glassy streaks or patches on the ocean. Prominent slicks are confined largely to near-shore areas where organic production is high. Experiments and observations are described which show that slicks are contaminate films of organic oil, probably derived primarily from diatoms which contain droplets of oil in their cells to assist in flotation and/or as an emergency food supply. Slicks are discernible because of their damping effect on small wavelets. The parallel slicks that develop in light to moderate winds result because the contaminate films pile up at the top of convergences in the homogeneous, wind-stirred layer above the thermocline." The authors also mention that internal waves may play a role in developing slicks. (R11)

References

R1. Ewing, Gifford C.; "Relation between Band Slicks at the Surface and Internal Waves in the Sea," Science, 111:91, 1950. (X1)

R2. Stommel, H.; "Streaks on Natural Water Surfaces," Weather, 6:72, 1951. (X1)
R3. Batt, Edward H.; "Calm Patch," Weather, 16:86, 1961. (X4)
R4. Cooke, A.H.; "Unidentified Phenomenon," Marine Observer, 31:181, 1961. (X5)
R5. Newman, J.B.; "Patch of Calm Water," Marine Observer, 34:174, 1964. (X6)
R6. Strong, Alan E., and McClain, E. Paul; Eos, 50:186, 1969. (X3)
R7. Sawyer, C.; "An Atlas of Oceanic Internal Wave Signatures Seen from a Satellite," Eos, 57:943, 1976. (X2)
R8. Needham, Bruce H.; "Observation of Wind-Induced Sea Surface Feature off Pulu Bawean, Java, from Landsat-1," American Meteorological Society, Bulletin, 57:444, 1976. (X7)
R9. Smith, Cedric A.B.; "Phenomenon," New Scientist, 75:185, 1977. (X1)
R10. Griffiths, H.; "An Anomalous Condition of the Sea Surface Observed from an Aircraft," Meteorological Magazine, 109:211, 1980. (X8)
R11. Dietz, Robert S., and Lafond, Eugene C.; "Natural Slicks on the Ocean," Journal of Marine Research, 9:69, 1950. (X9)

GHC3 Stratified Typhoon Waves

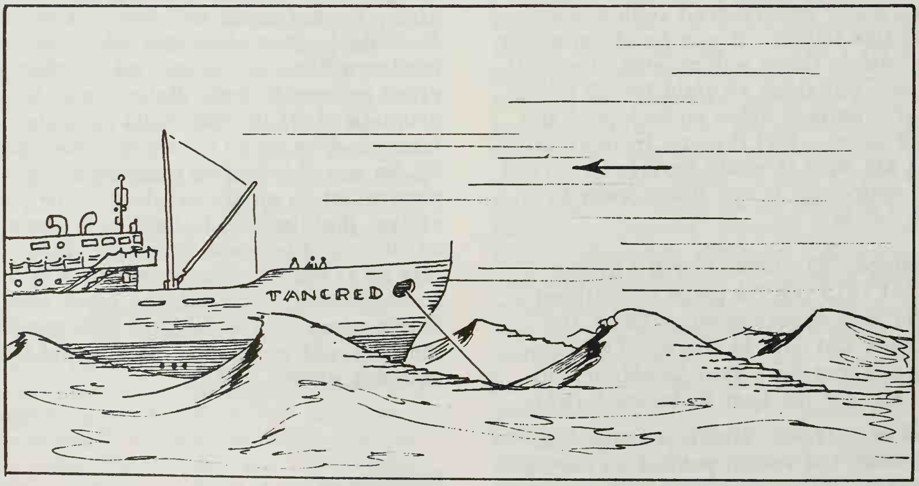
Description. Well-defined steps incised in the slopes of waves facing typhoon-generated winds. As many as twenty steps have been counted; length, 1-2 meters. The steps are nicely parallel and relatively stable.

Data Evaluation. A single but carefully made observation. Rating: 2.

Anomaly Evaluation. The steps on the wave fronts may indicate some unappreciated fine structure in typhoon winds. Another possibility is that strong winds hitting waves at certain angles create a bizarre rippling action. No one really knows. Rating: 2.

Possible Explanations. See above.

Similar and Related Phenomena. None.



Stratified typhoon waves observed in Kobe Bay (X1)

Examples of Stratified Typhoon Waves

X1. October 1954. North Pacific Ocean. "While M. V. Tancred of the Barber Line was riding out the typhoon of early October 1954 in Kobe Bay, we were able to observe a unique shape of typhoon wave which, so far as we know, has not been described. The vessel was hove-to with two anchors down facing the incoming gale (133 km./hr.) and the waves with crests up to 10 and 15 ft. were passing neatly along her side. From the rail we were struck by the peculiar appearance of the wave-slopes facing the wind. On many of these there were a number of well-defined steps, carved so to say into the water just like the steps of a ladder, starting from the trough of the wave up to about half its height. Although the waves were moving quickly the steps remained steady, extending parallel to each other for one or two metres in length. There were at times as many as twenty of these nicely successive steps cut into the body of the wave. We tried to photograph them; but the poor visibility and the fast motion of the waves resulted only in a blurred print. Were these steps carved in the wave slopes by high harmonics of the period of the typhoon squalls? These higher harmonics have been registered by sensitive modern microbarographs, and they might have something to do with the quite peculiar screaming of the wind, often reported by seamen during the squalls of tropical storms. Strangely enough, the peculiar whistling has never been noticed in the squall line of extratropical storms." (R1)

References

R1. Gherzi, E.; "Peculiar Stratified Shape of Typhoon Waves," Nature, 175:310, 1955. (X1)

GHC4 Sudden Whitening of the Dead Sea

Description. The whitening of the Dead Sea over all or most of its area, in the matter of a few hours, through the addition of immense quantities of calcium carbonate.

Data Evaluation. One reliable modern observation, plus vague references from ancient times. Rating: 2.

Anomaly Evaluation. The mechanism by which a large body of water can be suddenly and completely colored by calcium carbonate is a real puzzle, particularly when no nearby geological activity has been detected. Rating: 2.

Possible Explanations. Very likely, some sort of geological action injects huge quantities of calcium carbonate into the Dead Sea waters; say, through earthquake action, faulting, and/or the emission of quantities of subterranean fluids.

Similar and Related Phenomena. Foam strips on the Dead Sea (GHC1); the milky sea (GLW9).

Examples of Whitening of the Dead Sea

X1. August 25, 1943. Dead Sea, Israel. "On the morning of August 25, 1943, it was observed that the whole Dead Sea, which at this season is always perfectly clear, had become milky white. The same observation was made on the same morning at the northern and southern ends, which are seventy kilometres apart, and it was further ascertained that during the night the whole Dead Sea had turned white. During winter storms a seam of some 100 metres occurs frequently along the shores, turbid and yellowish, but it has never been observed that the whole Dead Sea surface had turned white. The turbidity gradually disappeared and in December 1943 the water became almost clear again." The whiteness was due to calcium carbonate; and a rough calculation based on water samples led to the conclusion that a million tons of calcium carbonate had been spread over the entire sea overnight. No significant earthquakes took place immediately before or after the phenomenon. A search of historical references to the Dead Sea uncovered only a few vague allusions to past whitenings. (R1)

X2. September 10, 1943. Dead Sea, Israel. An earthquake caused a portion of the Dead sea to become turbid with chalk.

(R2) This letter to Nature was in response to R1 but does not account for the fact that the whitening had actually occurred more than two weeks earlier. (WRC)

References

R1. Bloch, R., et al; "Occasional Whiteness of the Dead Sea," Nature, 154:402, 1944. (X1)

R2. Shalem, N.; "Whitening of the Waters of the Dead Sea," Nature, 164:72, 1949. (X2)

GHC5 Dead Water and Slippery Seas

Description. The presence of a low density layer of surface water capable of sliding almost without friction over denser water underneath. To ships this phenomenon is made manifest by fickle, wind-driven currents (slippery seas) and difficulty in making headway (dead water). In tropical seas, the sliding surface layer is due to a sharp temperature difference between the surface layer and deeper water; in polar regions, a layer of low density fresh water is contributed by melting ice and snow.

Data Evaluation. Only two rather popular accounts are at hand, but there are doubtless many more in literature associated with the sea. Rating: 2.

Anomaly Evaluation. From what has been uncovered so far, this phenomenon is at the very least poorly investigated. It is difficult to ascertain the significance of this anomaly, but it is likely to be only a minor problem. Rating; 3.

Possible Explanations. The water is stratified by virtue of sharp density differences so that the lighter surface layer slides over the deeper, denser water with little mixing or transfer of momentum.

Similar and Related Phenomena. None.

Examples of Slippery Seas and Dead Water

X1. September 1968. North Pacific Ocean. From a British investigation prior to the 1968 Olympic yachting competition off Acapulco. "The direction and approximate speed of the currents was observed daily from various points on the race area using weighted spars floating freely in the top metre of the sea surface. For the first two weeks (from 24 September 1968) the surface water behaved just like the slippery layer which had been postulated. With a temperature of 30° to 31°C it moved almost directly downwind at speeds of up to two knots, depending on how long the wind had been blowing from a particular direction. When the wind dropped to calm the water continued in the same direction with little change in speed and it took a wind from the opposite direction some 24 to 36 hours to stop the water and get it moving the other way." (R1)

X2. August 1893. Polar North Atlantic Ocean. "It took us more than one watch to steam a distance we could have rowed in half an hour or less. We could hardly get on at all for the dead-water, and we swept the whole sea along with us. It is a peculiar phenomenon, this dead water. We had at present a better opportunity of studying it than we desired. It occurs where a surface layer of fresh water rests upon the salt water of the sea, and this fresh water is carried along with the ship, gliding on the heavier sea beneath as if on a fixed foundation. The difference between the two strata was in this case so great that while we had drinking water on the surface the water we got from the bottom cock of the engine-room was far too salt to be used for the boiler. Dead-water manifests itself in the form of larger or smaller ripples or waves stretching across the wake, the one behind the other, arising sometimes as far forward as almost midships. We made loops in our course, turned sometimes right around, tried all sorts of antics to get clear of it, but to very little purpose. The moment the engine stopped it seemed as if the ship were sucked back. In spite of the Fram's weight, and the momentum she usually has, we could in the present instance go at full speed till within a fathom or two of the edge of the ice, and hardly feel a shock when she touched.' (R2) This encounter with dead water occurred early in Nansen's 1893-1896 polar expedition. (WRC)

X3. General observations. "Ships may also generate unseen internal waves on the interface between two layers of water of different density. In regions of rapidly melting ice or near the mouths of large rivers, a layer of fresh water often rests on the heavier oceanic salt water with little or no mixing. When this layering happens the progress of slow-moving ships is retarded because most of their propulsive energy goes into generating waves on the boundary between the fresh and salt water. These subsurface waves may be much higher and move much slower than the visible surface waves generated at the same time. This phenomenon is known as the 'Hall effect' after two brothers who studied it intensively in an Edinburgh wave tank in 1830. Much later V.W. Eckman, investigating strange tales of Norwegian fishermen who claimed their boats got 'stuck' in the 'dead water' of fjords, gave the following explanation: The deep and still salt water of the fjord is 'flooded' with fresh water. The bow of a fishing boat moving in the lighter-density upper layer causes a rise in pressure that depresses the fresh-salt interface just as though a thin flexible membrane separated the two. This sets a train of waves in motion on the surface of the salt water which move at about one eighth the speed of those on an air-water interface. These waves in effect 'capture' the boat that creates them so that waves and boat move together as a unit. Then the resistance of the slow internal waves adds to that of the ship." (R3)

References

R1. Houghton, David, and Woods, John; "The Slippery Seas of Acapulco," New Scientist, 41:134, 1969. (X1)

R2. Nansen, Fridtjof; "Voyage through the Kara Sea," Farthest North, London, 1897, vol. 1, p. 121. (X2)

R3. Bascom, Willard; "Impulsively Generated Waves," Waves and Beaches, Garden City, 1964, p. 125. (X3)

GHC6 Bulging River Surfaces

Description. Surfaces of swift rivers that bulge upwards at their centers.

Data Evaluation. A single passing reference to this phenomena, which in actuality may be well-covered in the unexamined literature of hydrology. Rating: 3.

Anomaly Evaluation. This phenomenon doubtless has a simple explanation (see below) but it is too curious and engaging to omit from this Catalog. Rating: 4 tentatively.

Possible Explanations. Fast-flowing rivers may bulge in their centers because the rocks and debris along the bottom deflect the water upward, making it bulge most at the surface where the water is swiftest. (R1)

Similar and Related Phenomena. Unequal heights of river banks in flat countryside.

Examples of Bulging River Surfaces

X1. General observations. "It has long been known that swift streams are higher at the centre than near the banks, that driftwood moves to the banks during the rise and crest of a flood and returns to the centre as the waters fall, and that foam is generally abundant on a rising stream and absent from one that is falling, but owing to the imperfect development of the science of hydrology as applied to streams, the causes of these phenomena are not generally known." (R1)

References

R1. "When Rivers Heap Up in the Middle," English Mechanic, 104:206, 1916. (X1)

GHC7 Swiftly Travelling Surface Disturbances

Description. Small, very rapid V-shaped wakes appearing on water surfaces. Careful observation seems to rule out wind, insects, and fish.

Data Evaluation. Only one offhand reference has been discovered so far in the literature. However, the compiler can verify this phenomenon from personal experience, although he always believed it due to unseen fish. Complete elimination of aquatic life under even the best viewing conditions is difficult. Rating: 3.

Anomaly Evaluation. Almost certainly this curious phenomenon derives from swift unseen aquatic life, although confirmation of this hypothesis is maddeningly elusive in the field. Rating: 3.

Possible Explanations. As discussed above.

Similar and Related Phenomena. None.

Examples of Small Rapid Water Disturbances

X1. General observation. "In following my hobby of angling I have been puzzled by the curious disturbance that travels along the water surface in V form. I cannot see how the wind could produce it. It is too rapid for the movement of an insect, and the closest observation shows that it is not caused by a fish. What is it?" (R1)

References

R1. "Water Phenomenon," English Mechanic, 110:9, 1919. (X1)

GHC8 The Sudden Disappearance of Ice from Lakes in the Spring

Description. The complete disappearance, within a few hours, of thick sheets of ice from large lakes in the spring. Prerequisites for the phenomenon are some prior "rotting" of the ice and a stiff wind.

Background. Almost an item of folklore, the sudden disappearance of ice is popularly blamed upon its sinking (physically impossible) or, more often, on some mysterious and unknown agency.

Data Evaluation. A well-attested phenomenon of which much was written a century ago, but which is scarcely mentioned now. Rating: 1.

Anomaly Evaluation. This phenomenon possesses a convincing scientific explanation and is presented here because it is still thought by some to be a natural mystery. Rating: 4.

Possible Explanations. The surface layer of ice is underlain by denser, liquid water a few degrees above the freezing point (Water is densest at about 4^{o}C.). Strong winds break the rotten ice and mix the fragments with the warmer subsurface waters. The ice then melts very quickly.

Similar and Related Phenomena. None.

Examples of the Sudden Disappearance of Ice from Lakes

X1. Frequent occurrence. Lake Champlain, from the New York side. "At the close of a day in April, I think, the whole surface of Lake Champlain, with the exception of a very few 'air holes' or unfrozen portions of at most a few acres each, and a strip of water next the shores, was one great expanse of ice, of a thickness not less than twelve inches, and apparently, looking merely at the surface, as solid as ever. During the following night there arose a strong wind from the southward, blowing, therefore, nearly lengthwise of the lake; and when I looked out the following morning not a particle of ice was to be seen, but instead thereof, a lively play of water sparkling with 'white caps.' There was, as determined by immediate and close examination, absolutely no ice upon the water nor in the water; not a fragment, large or small. Upon the lee shore of a bay close at hand, there was however, a fringe of broken ice that had been washed up by waves; and in the condition of these few remains of the night's work was to be found, it seemed to me, a satisfactory explanation of a change certainly very surprising from its suddenness and completeness, and deemed indeed, even by high authority in philosophy, so much to partake of the marvellous as to require a higher solution than philosophy was able, consistently to supply." (R2) Several explanations of this sudden and curious phenomenon concur in blaming the ice's disappearance upon the breakup of rotten ice by the wind and its subsequent mixing with warmer bottom waters, as delineated above. (R1-R4)

References

R1. Thompson, Zadock; "On the Sudden Disappearance of the Ice on Lake Champlain at the Breaking up of Winter," American Journal of Science, 2:12:22, 1851. (X1)

R2. Totten, J.G.; "On the Sudden Disappearance of the Ice of Our Northern Lakes in the Spring," American Journal of Science, 2:28:359, 1859. (X1)

R3. Barnes, H.T.; "On the Apparent Sinking of Surface Ice in Lakes," Science, 31:856, 1910. (X1)

R4. Humphreys, W.J.; "The 'Sinking' of Lake and River Ice," Science, 79:562, 1934. (X1)

GHC9 Honeycomb Appearance of Flowing Water

Description. The hexagonal or honeycomb appearance of the surfaces of small patches of flowing water. The hexagonal dimpled effect seems to depend upon clusters of air bubbles derived from the ground over which the water flows. The honeycomb patches are only a few inches in extent and occur in thin (a half inch or less) sheets of water.

Data Evaluation. Only one observation found to date. Rating: 3.

Anomaly Evaluation. This is just one of nature's delightful idiosyncracies---an example of its tendency to form hexagonal geometries under certain conditions. Mud cracks, stone polygons in the Arctic, bees' combs, etc. are all examples of this more general phenomenon. Such polygons are usually explained in terms of nature's penchant for minimizing effort or space or something else. Explanations of this kind say nothing about why nature adopts such conservation strategies when she is so profligate in other ways. In short, trivial though the hexagonal appearance of flowing water may seem, it is indicative of some "philosophical" anomalies which will be considered toward the end of this series of Catalogs. Rating: 4.

Possible Explanations. Layers of clustered bubbles often take on polygonal shapes. Physics usually explains this kind of phenomenon in terms of minimum energy configuration, etc.

Similar and Related Phenomena. Bees' honeycombs, periglacial phenomena (ES), steam-devil patterns (GWW3).

Examples of the Honeycomb Appearance of Water

X1. November 7, 1890. Tynron, England. "This afternoon, while ascending a mountain pathway adown which water was trickling, after the torrents of rain that fell in the morning had ceased, I observed an appearance of the surface of running water so exactly like the hexagons of the bees' cells that I looked at it carefully for some time. Little air-bells of water seemed to issue from under the withered leaves lying in the tract, which rushed towards the hexagons, occupying an irregular space about four inches by five. As soon as these air-bells arrived at the hexagons, they arranged themselves into new cells, making up, apparently, for the loss occasioned by the continual bursting here and there of the cell-walls. No sooner had these cell-walls burst, then others closed in and took their places. The worst-formed hexagons were those at the under or lower side of the surface---the part of the surface farthest down the hill; here they were larger and more like circles. By an ingenious mechanical theory, Darwin accounts for the hexagonal structures of the cells of the bee-hive so as to supercede the necessity of supposing that the hive-bee constructed its comb as if it were a mathematician. But here the blind forces of Nature, under peculiar conditions, had presented an appearance, on running water less than half an inch in depth, so entirely like the surface of a honeycomb, that it would be a startling result could it be reproduced in a laboratory." (R1)

References

R1. Shaw, J.; "Honeycomb Appearance of Water," Nature, 43:30, 1890. (X1)

GHG GEYSERS, PERIODIC WELLS, BLOWING CAVES

Key to Phenomena

GHG0 Introduction

A portion of the earth's hydrosphere---both air and water---is always trapped underground within pores, crevices, and caves. Several natural forces are capable of forcing these fluids out of the ground, producing geysers of water, wells that ebb and flow like clockwork, and the so-called "blowing" or "breathing" caves that are harnessed to the barometer. The most important external forces are barometric pressure and the tidal forces exerted by the moon and sun. Internally, the earth generates heat and high-pressure gases which can also cause the eruption of fluids at the surface. In consequence, geysers, wells, caves, and springs---all natural orifices of the earth---exhale and inhale air and water. Sometimes the process is rhythmic, as with Old Faithful at Yellowstone. In other instances, the approach of a low-pressure area allows the escape of higher-pressure air from caves and wells, creating the "weather wells" and blowing caves.

Fascinating as these phenomena are, they are accompanied by only a handful of enigmas. The processes by which tidal forces alter geyser periods are not fully understood; neither are the details of periodic cold-water geysers. Sometimes several natural forces seem to work together to generate phenomena that are perplexing in both frequency of occurrence and phase. Even "normal" geyser activity, described so confidently in the textbooks, does not always suffice. Indeed, there are many geyser "models" with some controversy as to which ones are the most important.

GHG1 Geysers at Sea

Description. The rhythmic eruption of geysers of water from the ocean surface. In one reported case, the geyser column was almost 500 feet high.

Data Evaluation. Only one observation of this phenomenon has been recorded. Rating: 3.

Anomaly Evaluation. An extremely powerful jet of water is inferred from the great height of the single reported instance and the penetration of this jet through a layer of seawater (depth not specified). The underwater geyser, if that is what is at the root of this phenomenon, must be significantly larger than recognized terrestrial geysers. Rating: 2.

Possible Explanations. A temporary and very powerful underwater geyser. A misidentified incipient waterspout is also a possibility, as is a large-scale release of steam and other gases from a seafloor vent.

Similar and Related Phenomena. Land-based geysers, waterspouts, volcanic plumes.

Examples of Geysers at Sea

X1. December 4, 1960. Mediterranean Sea. "At 0830 GMT, as the ship was steaming through a calm to slight sea at 12 kt. on a course of 124° towards Benghazi, a strange-looking column of what seemed to be white Cu. cloud appeared to rise vertically from near the horizon, about 45° on the starboard bow, and vanished a few seconds later. The officer on watch believed his eyes to be deceiving him due to the sun's glare, but within a few minutes all the observers named above saw the column reappear. On examination with binoculars it was seen to be a jet of water rising in the air at regular intervals of about 2 min. 20 sec. Each spurt lasted for about 7 sec. and then disappeared. They were visible until the vessel left them far astern. The radar was switched on but no echo appeared on the screen; however, by sextant altitude and calculation the jets were found to be 494 ft. high; they resembled an underwater explosion but no such noise was heard." (R1)

References

R1. Evans, M.D.; "Unidentified Phenomenon," Marine Observer, 31:183, 1961. (X1)

GHG2 Geysers and Blowing Wells Correlated with Weather Phenomena

Description. Geysers whose performance (frequency and strength of eruption) are correlated with barometric pressure, local temperature, winds and other weather variables.

Background. Included in this category are all weather-dependent emissions of gases and liquids from wells, caves, geysers, and other natural orifices. Blowing wells and breathing caves have always been subjects of great curiosity; the latter were even employed in early aeronautical research.

Data Evaluation. Blowing wells and caves correlated with barometric pressure are well-documented. Correlations with temperature, wind, and other weather factors is on a weaker observational foundation. Rating: 2.

Anomaly Evaluation. Good explanations exist for breathing caves and blowing wells: the reduction of outside air pressure causes the release of higher pressure air within these reservoirs through restricted orifices. Likewise, caves, wells, and geysers can be understandably affected by temperatures and winds (see below). Most aspects of this phenomenon can be explained. Rating: 3.

Possible Explanations. The role of barometric pressure was detailed above. Temperature differences between the air in caves and the outside air can give rise to natural circulation. Strong winds can, via the Bernoulli Effect, can also change air pressures at natural orifices.

Similar and Related Phenomena. The effect of tidal forces on blowing wells and geysers (GHG3); the effects of earthquakes on wells and geysers (GQE); the formation of ice in caves (E).

Examples of Geysers and Blowing Wells Correlated with Weather

X1. Permanent feature. Decatur County, Georgia. A 'blowing cave.' "The cave is at the bottom of a small natural basin (whose diameter at any point will not exceed thirty feet), in a perfectly smooth plain, and surrounded with a dense copse of wood. From the mouth of this cave issue strong currents of air, with a continuous roar that is heard seventy yards off. At certain hours of the day, a hat or vail (sic), or other light objects thrown at it, are blown six or seven feet high into the air, and at other hours of the day, with a suction relatively great, the mouth of the cave draws in any such article placed near it." (R1) From the description, this blowing cave would appear to have a diurnal cycle, perhaps related to local temperature, and thus seems suited to this category. (WRC)

X2. Permanent feature. Northallerton, Langdon Hall, and Ornhams, England. Three blowing wells, all extremely sensitive to barometric pressure, described. None of the other wells in the district, some within a mile of the blowing wells, possess this weather-sensitive property. (R2)

X3. Permanent feature. Shelby, Nebraska. "In the neighborhood of Shelby, Polk County, Nebraska, are many wells which exhibit peculiar phenomena of intermittence. The wells of the district vary from 100 to 140 ft. in depth, and ebb and flow irregularly. The flow is accompanied by a roaring sound like that of the sea, as though a distant wave were coming in, and at the same time a current of air issues out of the mouth of the well. The ebb is accompanied by a draught of air downward into the well. The period of ebb and flow does not appear to depend upon heat or cold, upon the dampness or dryness of the atmosphere, upon the season of the year, or upon the time of day; but, on the other hand, seems to be in some way connected with the direction of the winds. When the winds blow from the south, south-east of south-west, the phenomena of flow occur, while the ebb is synchronous with a north, north-east, or north-west wind. The roaring sound before mentioned is observed to occur some time before the wind commences to blow. One of these intermittent wells, 113 ft. in depth, is situated on the farm of George Bull, at Shelby, Polk County. Similar wells occur in the adjoining county of Butler." (R3) Although ebb and flow are reportedly correlated with wind direction, the wind direction itself is usually related to the approach of low and high pressure systems. (WRC)

X4. Permanent feature. Dunigan, California. A well 160 feet deep, 6 inches in diameter, produced a roaring noise 2-3 days in advance of a storm. (R4) It is unclear how this well can be affected so far in advance of an approaching storm. (WRC)

X5. Permanent feature. Looxahoma, Mississippi. A blowing well showing greatest activity just before a rain. (R5)

X6. Permanent feature. Great Valley, New York. A dry well capped with a flat stone with a hole in it whistles as a storm approaches. (R6)

X7. Permanent features. Nebraska. "One class of wells found throughout a large part of the State, especially south of the Platte, deserves particular notice. These wells are known as 'blowing,' 'roaring,' 'breathing,' 'singing,' or 'weather' wells. These wells are held in doubt elsewhere, but the fact of their existence is established. In some communities such wells are distinguished at a distance because of the mound of earth heaped up to check the wind. The attention of the writer was first called to this matter by inquiries for explanation of and remedy for the freezing of pipes in wells at a depth of 30, 50, 60, 80, and even 120 feet below the surface. Reports have come in from about twenty counties. The information is derived from land owners, farmers, well diggers, ministers, principals of schools, civil engineers, and students whose fathers own such wells. These accounts agree with personal observations.

There are periods when these wells blow out for consecutive days, and an equal period when they are reversed. This is tested with the flames of candles and by dropping paper, chaff, feathers, etc., into the casing to see it blown out by some force or drawn in. It is further stated that blowing often indicates high or low conditions of barometer, and that some wells blow most audibly when the wind is from the northwest, where upon water rises to a higher level in the well than before; but when conditions are reversed, air is drawn in. Many observers notice a reversal of the current according as it is morning or evening, and according as the temperature is high or low. During the progress of a low barometer area over one of these regions, the wind is expelled with a noise audible for several rods. Upon the following of a high-barometer area, the current is reversed. Steam rises from the curbing, melting the snow. After the current is reversed, the thawed circle freezes again. The pipes are most often thawed out when the well blows. The periods of most pronounced exhalation or inhalation are coincident with exceptionally low and exceptionally high barometer areas.....The wind may be the cause in some places. At times the friction of the wind is sufficient to drive the water of the Platte across its bed, leaving the north side dry while the south is flooded. Equilibrium is disturbed. There must be readjustment. In the vicinity water rises in wells, at a distance there is a wave of transmitted energy which can but affect every portion of the underflow of the Platte. This may show itself in a rise of water and displacement of air, and a rise over a wide area might expel a large volume of air." (R7) This freezing within wells is closely related to the phenomenon of ice caves (E).

X8. Permanent feature. Norwich, England. Three blowing wells with actions associated with weather changes. (R8)

X9. Permanent feature. Oundle, England. A blowing well which emits a drumming sound that is possibly the result of perculator action. (R9)

X10. Permanent feature. Tennessee. "Many of the caves developed in tilted strata in eastern Tennessee are called 'blowing' caves because currents of air issue from their openings. Actually, the same openings that 'blow' in one season 'suck' in another. The 'blowing' and 'sucking' phenomenon exhibited by a cave are caused by the free circulation of air through underground passages in response to differences in air temperatures within and without. In the cold seasons, when the cave air is warmer than that outside, the former is expelled through the higher openings to the surface by cold outside air which crowds into the cave at lower openings. In the warm seasons, when the cave air is cooler than that outside, the former moved out through lower openings and is replaced by warmer air which enters through higher openings. Thus, in the cold season, the cave 'blows' at the higher openings and 'sucks' at the lower openings, and in the warm season, it 'blows' at the lower openings and 'sucks' at the higher openings. In order for a cave to exhibit 'blowing' and 'sucking' phenomena, it must have spacious and extensive underground passages with openings to the surface at both high and low levels. There must be a difference in the temperature of the air inside and outside the cave." (R10) Apparently, these Tennessee caves are truly temperature-sensitive as opposed to most of the others described here which are barometer-sensitive. (WRC)

X11. General observation. The old coal-miner belief stating that mine explosions are often associated with bad weather has much truth to it. During storms, when the barometer is low, methane in the rocks and abandoned sections of the mines migrates into the areas being worked due to reduced atmospheric pressure. The increased concentration of methane increases the possibility of an explosion during these periods. (R11)

X12. Permanent feature. Calistoga, California. Discussion of factors that influence geyser frequency. "The third important mechanical force is a regular annual cyclic variation in barometric pressure that ranges from 6 to 10 mm of Hg. The influence of barometric pressure on geyser performance manifests itself prominently and obviously at Old Faithful, Calistoga, California. High barometric pressure, which occurs in the winter, shortens the interval, and low barometric pressure, which occurs during summer, lengthens it, the usual range being from approximately 40 to 49 min. The 70-day delayed response, which was obtained by cross correlation methods, would seem to be due to the mechanical sluggishness of the basin in which the geyser is located." (R12, R13) White and Marler, in a critique of Rinehart's paper in the Journal of Geophysical Research, do not concur that the Calistoga Old Faithful geyser responds to annual barometric trends. This would require the geyser to "remember" previous barometric changes for 40-105 days. Actually, one would expect a geyser to react immediately to the rather large short-term barometric changes, if it responds at all. Many hot spring systems behave like this; that is, they are influenced by short-term barometric changes. In addition studies of Yellowstone geysers have revealed no influences of long-term barometric changes. White and Marler propose that Calistoga Old Faithful's variation in eruption frequency can be explained just as well by appealing to the annual variation in rainfall, which is similar to the annual changes in barometric pressure. In Rinehart's reply, he maintains that geysers and hot spring systems are quite different and that, although a rainfall effect exists, the annual variation in barometric pressure is more important in geysers. (R14)

References

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R2. Fairley, Thomas; "On the Blowing Wells near Northallerton," Report of the British Association, 1881, p. 544. (X2)
R3. "Intermittent Wells in Nebraska," English Mechanic, 37:170, 1883. (X3)
R4. "A Storm-Predicting Well," American Meteorological Journal, 2:246, 1855. (X4)
R5. Wadley, C.P.; "A Blowing Well," Scientific American, 58:133, 1888. (X5)
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R8. Long, Sydney H.; "'Blowing' Wells," Nature, 80:339, 1909. (X8)
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R11. "Storms Cause Explosions," Science News Letter, 71:310, 1957. (X11)
R12. Rinehart, J.S.; "Geysers," Eos, 55: 1052, 1974. (X12)
R13. Rinehart, John S.; "Fluctuations in Geyser Activity Caused by Variations in Earth Tidal Forces, Barometric Pressure, and Tectonic Stresses," Journal of Geophysical Research, 77: 342, 1972. (X12)
R14. White, Donald E., and Marler, George D.; "Comments on a Paper by John S. Rinehart, ..." Journal of Geophysical Research, 77:5825, 1972. (X12)

GHG3 Geysers and Intermittent Wells Correlated with Tidal Forces

Description. The variation of well flow and geyser period with the tidal forces created by the sun and moon. The signs and phases of these phenomena seem to vary from example to example, suggesting a rather complicated situation. In addition, some geysers respond only to long-period forces (i.e., 18.6 years), while others follow only the shorter cycles.

Data Evaluation. Very little has been uncovered on this intriguing phenomenon. American geysers, probably because of their popular appeal, have received a modicum of scientific attention, but intermittent wells have not even been cataloged. Rating: 3.

Anomaly Evaluation. Like many other phenomena in this Catalog, this one is almost certainly explainable in terms of current physical theories---if only we knew the details of each water reservoir, rock porosity, the mechanical response of the strata to tidal forces, etc. Rating: 3.

Possible Explanations. Each intermittent well and geyser is a complex mechanical system with reservoirs, pores, crevices, and channels that vary as tidal forces slightly bend the strata. In view of this structural complexity, it is not surprising that each example has a different frequency response.

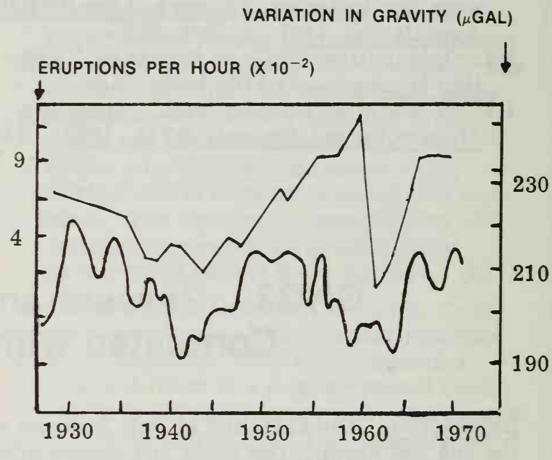
Similar and Related Phenomena. Geysers and blowing wells correlated with weather phenomena (GHG2); tides in general (GHS), which are far more complex than suggested by the standard textbook portrayals.

Examples of Geysers and Wells Affected by Tidal Forces

X1. Permanent feature. Beardstown, Illinois. "This well was drilled in 1891, the strata pierced being 100 feet of drift as sand and gravel, 200 feet of corniferous (sic) limestone, 200 feet of slate and shale, passing into 20 feet of crystallized sandstone, a depth altogether of 520 feet. At this depth water began to rise into the well, and when reaching the surface spouted up to a height of 50 feet. The water is a saline mineral water, strongly impregnated with natural gas. The pressure gauge indicated 60 lb. Sufficient gas was obtained to supply two 60 horse power boilers with fuel. This well flows or spouts for eight days, when it ceases for twenty days, not varying a day from these periodic intermissions since it first began flowing. It invariably begins with the new moon. The quantity of water discharged is 4,000 gallons per hour. The gas is still utilized, 'when well flows,' in an electric lighting station near by. There has been no perceptible diminution in the quantity of gas or water. The well ceased spouting January 28; it is due and will certainly begin again February 15, after twenty days' rest." (R1) It is not clear how tidal forces at new moon could stimulate a well to flow. (WRC)

X2. Permanent feature. Yellowstone Park, Wyoming. "The Riverside geyser, on the other hand, responds best to earth tides. The computed total variation in gravity caused by the Sun and the Moon again shows a close negative correlation with the five-day average intervals between Riverside's eruptions, the fortnightly component linked with new and full moon being especially dominant during the summer months. The effect suffers a two-to-three-day time lag. Old Faithful (Yellowstone) behaves in much the same manner. But Old Faithful the Imposter lacks this short term response, earth tides probably being masked by ocean tides near the Pacific Coast. However, longer-term tidal effects, over a time-span of seven years, show up well in this geyser." (R2-R4) White and Marler cast doubt on Rinehart's conclusions about the effect of tidal forces on geyser period. In particular, they question the 2-3 day lag of geyser response behind the tidal force. Furthermore, Marler's studies of the Riverside Geyser show little if any effects of earth tides. They admit, however, that Old Faithful does respond to earth tides. (R5)

X3. Permanent feature. Yellowstone Park, Wyoming. "The 18.6-yr tidal component that causes the average tidal force to vary by about 10% can influence dramatically the action of a geyser. Over some 4 decades of observations, at least 15 per season and in some seasons many more---enough to be of statistical significance---the interval between eruptions of Grand Geyser has varied from 8 to 40 hr, with two periods of dormancy. During times of high tidal force, around 1930, 1955, and 1970, the geyser erupted 2 to 3 times daily, only to become almost dormant during the years 1943 and 1960, when the tidal force was lowest." (R3) In both X2 and X3, high tidal forces increase the frequency of eruption, which is apparently the opposite of what happens to the periodic well of X1. (WRC)



Observed temporal variation in frequency of eruption of Grand Geyser, Yellowstone, and computed variation in gravity due to earth tidal forces (X3)

X4. General observations. In the time period 1948-1970, 80% of the eruptions of a group of mud volcanos occurred when the earth, moon, and sun were aligned. (R6)

References

R1. Ehrhardt, H.; "A Phenomenal Well," Scientific American, 68:87, 1893. (X1)

R2. "The Stresses that Upset Three Old Geysers," New Scientist, 53:529, 1972. (X2)

R3. Rinehart, J.S.; "Geysers," Eos, 55: 1052, 1974. (X2, X3)

R4. Rinehart, John S.; "Fluctuations in Geyser Activity Caused by Variations in Earth Tidal Forces, Barometric Pressure, and Tectonic Stresses," Journal of Geophysical Research, 77:342, 1972. (X2-X3)

R5. White, Donald E., and Marler, George D.; "Comments on Paper by John S. Rinehart," Journal of Geophysical Research, 77:5825, 1972. (X2)

R6. "Mud and the Moon," Science News, 103:26, 1973. (X4)

GHG4 Cold-Water Geysers and Periodic Springs and Wells

Description. The rhythmic augmentation of flow in wells, springs, and geysers that occurs without the driving power of the heat engines that cause ordinary natural geysers.

Data Evaluation. Periodic springs commonly depend upon natural siphons. Except for a typical example, such springs are excluded here. The remaining examples are few in number and, save for cold-water geysers, little-studied. Rating: 3.

Anomaly Evaluation. Since cold-water geysers and some periodic springs and wells are not driven by heat engines or natural siphons, scientific explanations focus on supplies of subterranean gases for motive power. These periodic phenomena would thus be analogous to compressed-air engines and their kin. Although no one seems to have really closely studied the situation in nature, this explanation is quite reasonable. It would seem that this phenomenon is merely a curiosity. Rating: 3.

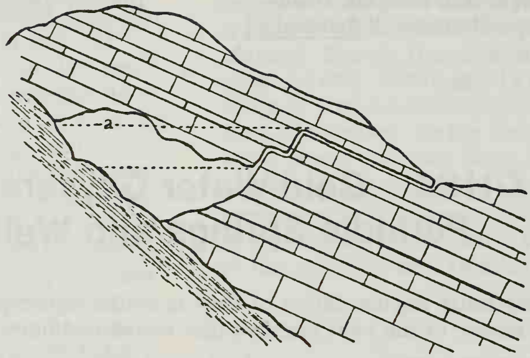
Possible Explanations. See above and the explanation in X5.

Similar and Related Phenomena. None.

Examples of Periodic Springs

X1. Permanent feature. Pontarlier, Switzerland. "The Fontaine Ronde is situated about a league and a half from Pontarlier, in the road from thence to Lusanne. This very powerful spring has no proper basin, for the water rushes immediately from a declivitous bottom, covered with coarse gravel, which is fifteen paces in length, and six or eight in breadth. The water issues forth uninterruptedly from the deepest lying part of the bottom, but from the highest part it ebbs once and flows once every six minutes. This spring, therefore, is not intermittent, but periodical. Springs of this description are, in general, but rare occurrences, and the phenomena they exhibit have always attracted the attention of the curious. Long ago Heron of Alexandria proposed a plausible explanation of the intermittence of springs, in supposing that there were, in the interior of the earth, reservoirs of water provided with natural syphons. This explanation asnwers well for most cases; hence it has been adopted by natural philosophers. If the intermittence if of unequal continuance, or the swelling of variable height, and if these inequalities are repeated regularly and periodically, we explain them by supposing that there are many dissimilar reservoirs, and that each has its peculiar syphon. All this is possible, and art can, by arrangements of this description, produce appearances resembling those in nature. But, however appropriate this explanation may be, we must not forget that it is a mere hypothesis, and that nature may have other means, besides those already mentioned, for producing the intermittence of springs. The careful study of the Fontaine Ronde has afforded me a proof of this." Dutrochet's investigations suggested that the evolution of carbon dioxide from the interior of the earth was the primary cause of this spring's periodicity. (R1)

X2. Permanent feature. Butler, Pennsylvania. "Phillips Bros.' well near Butler, Pa., is one of the most phenomenal wells ever seen in the whole oil regions, and all interest is



Schematic of a natural siphon creating a periodic spring (X3)

now centered there, to the exclusion of the lately discovered Glade district, which is rapidly waning. Phillips' well was drilled on Aug. 30, and has been producing since over 1,300 barrels daily, reaching on the 7th 100 barrels an hour. It flows with the regularity of clockwork, the oil gushing out at intervals of nine minutes and a half, the flows lasting about four minutes." (R2)

X3. Permanent feature. Atkins, Virginia. A typical periodic spring dependent upon siphon action. The steady flow of the spring is periodically augmented, producing high volumes of water for about 7 minutes each cycle. The length of the cycle seems to vary with weather conditions. (R3)

X4. Permanent feature. Yellowstone Park, Wyoming. Crater Hills geyser is a cold-water geyser, probably obtaining its energy from subterranean gases. (R4)

X5. Permanent features. Green River, Utah. "Both of the geysering wells in Utah lie in regions where subterranean carbon dioxide and helium are known to exist in high concentration. The smaller of the two lies in a flat alluvial basin about 48 km northwest of the town. It was activated about the turn of the century when a 13-cm-diameter well was drilled to a depth of 1000 m. The well, though flowing water at a temperature of 15°C, began erupting and now throws water to a height of about 50 m, playing for about 5 min at intervals of 40 min. Crystal, the larger geyser, is found on the east bank of the Green River, 8 km south of the town. The jet issues from a 45-cm-diameter steel casing emplaced to a depth of a few meters. Presumably this geyser became active when a geophysical exploration group put down a fairly shallow hole. It erupts on a 5-hr schedule, playing a massive and impressive stream of water for 5 to 10 min to a height of 60 m. Each major eruption is followed 25 min later by a minor one, which plays for a minute to a height of about 6 m. The water in the tube before an eruption is also cool, 15°C. No scientific explanation of this geyser action has appeared in the literature. Possibly carbon dioxide from surrounding geological formations is fed at a more or less continuous rate to the well water, which eventually becomes saturated. The concentration of dissolved carbon dioxide varies along the column, being higher at the greater depths, since its solubility in water increases rapidly with increasing pressure. Finally, when the water can take up no more carbon dioxide, gas bubbles rise toward the surface, perhaps coalescing, raising the column of water, and reducing the hydrostatic head. This release of pressure acts as a trigger, and the column begins to cascade as additional carbon dioxide is released, more bubbles are formed, and the pressure is lowered still further. It is somewhat analogous to shaking a can of beer." (R4) Note that the "beer can" theory is only a theory. (WRC)

X6. Permanent feature. Cephalonia, Greece. "A recent writer in the daily press has called attention to the 'unsolved mystery' presented by the phenomenon of streams of salt water running inland from the sea in the island of Cephalonia, and he suggests that it is time that scientific men should turn their attention to this strange phenomenon. This seems to imply that he is unaware of the amount of discussion already devoted to these underground rivers of salt water, which, as is well known, have for a number of years been harnessed by man as a motive power for water-mills." The flow at one 'mill' was measured at 17.5 cubic feet per second. Dye dropped into the water at one mill was discovered to have colored the water the next day in the sea around the mill, suggesting a redischarge of the salt water. (R5) It is not clear from the description whether we have a natural siphon operating here or some different phenomenon. For the moment, it will be classified GHG4. (WRC)

References

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R2. "An Intermittent Oil Well," Scientific American, 51:194, 1884. (X2)

R3. Shuler, Ellis W.; "The Intermittent Siphon in Nature," Scientific American, 119:131, 1918. (X3)

R4. Rinehart, J.S.; "Geysers," Eos, 55: 1052, 1974. (X4, X5)

R5. "The 'Sea-mills' of Argostoli, Cephalonia," Geographical Magazine, 57:62, 1921. (X6)

GHS THE BEWILDERING VARIETY OF TIDES

Key to Phenomena

GHS0 Introduction

For most people living on the sea coast, tides come and go with clockwork regularity twice a day. Some places, though, experience only one tide per day; in others, the tides follow the sun rather than the moon. Elsewhere, the situation becomes even more complicated, with "secondary undulations" superimposed on the otherwise well-behaved ebb and flow.

Basically, tides are the oscillations of the oceans in their relatively shallow basins (2 miles deep on the average, but thousands of miles across) under the combined influences of the sun and moon. Obviously, the shape of the coastline and bottom contour have strong effects, too. Geophysicists are generally satisfied that the tides, regardless of their idiosyncracies, can be explained by appealing to the fluctuating attractions of the sun and moon and the natural frequencies of oscillation of the various ocean basins. Despite this assurance, the reader will probably agree that some tidal phenomena are very peculiar, though perhaps not serious scientific anomalies. Theoretical explanations cannot detract from the foaming walls of water advancing up the estuary of the Amazon and other rivers properly configured for tidal bores.

Although the theory of the tides may have trouble explaining some of the overtones and inuendoes, tides are not nearly as anomalous as some critics of science suggest. Four commonly raised objections are: (1) Theory does not predict the radically different heights of tides separated by the narrow Isthmus of Panama; (2) Some tides seem to flow "uphill" from regions of low tide to regions of high tide; (3) The moon should produce only one bulge in the earth's hydrosphere, and this should excite only one high tide per day everywhere; and (4) Newton's Law of Gravitation predicts that the sun, by virtue of its much greater mass, should affect tides more than the moon. Perhaps the real problem here is that explanations of the tides have been oversimplified, particularly those diagrams with two bulges. In truth, we have basins of water of various complex shapes oscillating in many modes. Anyone who will go through the mathematical analysis will see that each of the four objections, while possessing a certain "common-sense" appeal, is simply not valid. This is not the place to refute all objections---indeed, some objections are probably valid---but let us dispose of (4), which is mentioned frequently. It is true that the sun exerts a stronger gravitational force on each particle of seawater than the moon, if one applies Newton's inverse square law. The actual tide-raising force, however, is the vector sum of several forces, which when expressed mathematically turns out to have an inverse cube term. The sun's great mass, therefore, is overpowered by the moon's nearness to earth. This is not scientific sleight of hand, only straightforward analysis. The other three objections can be removed through like reasoning.

GHS1 Sun-Dominated Tides

Description. Tides that follow the sun rather than the moon in the sense that high and low tides do not occur roughly 50 minutes later each day but rather tend to take place near noon and midnight (highs) and 6 AM and 6PM (lows). Because the moon's effect is never zero and is added to that of the sun, the high and low tides sometimes lead and lag the appointed sun-controlled times. Tahiti and Tuesday Island, in the Pacific, are the only places known where the moon is dominated by the sun.

Background. Since conventional wisdom insists that the tides follow the moon, the reports of early explorers coming in from the Pacific describing high tides fixed at noon and midnight naturally met with disbelief. The stories were true, as it turned out, but the high tides only averaged noon and midnight; and they were confined to only two places.

Data Evaluation. None of the data found in the literature so far is recent, although one would expect that modern tidal gauges would now be installed at such fascinating spots as Tahiti and Tuesday Island. Furthermore, the data from Tahiti shows considerable variability, although this may be due to the unreliability of the phenomenon. Rating: 2.

Anomaly Evaluation. As explained below, the dominance of the sun over the moon in certain locales is not anomalous; however, two features of the Tahitian data seem unusual. (1) The sudden switch from midafternoon (lagging) to midmorning (leading) tides; and (2) The fact that some tide readings reveal highs occurring at any time of the day. It is not known if these anomalies can be explained by mathematical superposition of the varying solar and lunar cycles. Rating: 2.

Possible Explanations. According to modern tidal theory, those few spots when the solar tide dominates the lunar tide occur at nodal points of the ocean's standing waves; that is, the moon-induced standing waves. Tahiti happens to be located near one of these nodes. But the snapping back of Tahitian high tides from midafternoon to midmorning, which apparently occurs over the period of a single day, requires some contribution from the moon, for the effect recurs every lunar cycle. Presumably the superposition of lunar and solar effects would show this abrupt switch from PM to AM high tides, but such analysis has not been discovered so far. Since the lunar and solar influences vary in strength from day to day, year to year, and in even longer cycles, it is possible that "normal" moon-dominated tides may occasionally appear, as in X1/R4.

Similar and Related Phenomena. Solitary waves and anomalous groups of waves (GHW).

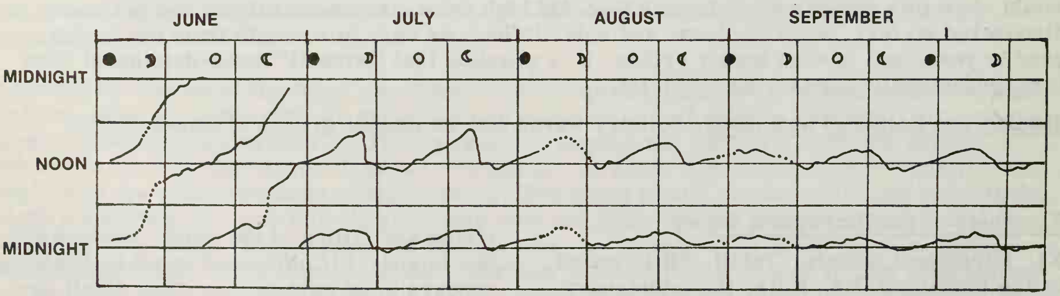
Examples of Sun-Dominated Tides

X1. Permanent feature. Tahiti. "It is stated by the intelligent Mr. Ellis, the missionary who resided several years in Tahiti (Otaheite) and the Sandwich Islands, that the rising and falling of the tides, (in the South Sea islands,) if influenced at all by the Moon, appears to be only so in a very small degree. The height, says he, to which the tide rises, varies but a few inches during the whole year; and at no time is it elevated more than a foot or a foot and a half..... During the year, whatever be the age or situation of the moon, the water is lowest at six in the morning and the same hour in the evening, and highest at noon and midnight. This is so well established, that the time of night is marked by the ebbing and flowing of the tide; and in all the islands the time of high water and for midnight is the same. The same thing is stated by Messrs. Tyerman and Bennet, in their journal of voyages and travels: it is generally known, they observe, but may be repeated here, in connection with the aforementioned periodical but irregular inundations of the sea, that the tides throughout the Pacific ocean do not appear to obey the influence of the moon in the slightest degree. It is always high water about twelve, and low about six o'clock, day and night." (R1, R3) The preceding facts turned out to be not so well-established after all, as subsequent investigations proved. (WRC)

A report by Captain Edward Belcher. "By a reference to the Tide Registry annexed, it will be found that there are two distinct periods of high water, during each interval of twenty-four hours; and that during the seven days preceding, and seven days following the full and change, they are confined between the limits of 10 A. M. and $2^h\ 30^m$ P. M., the whole range of interval, by day as well as by night, being about $4^h\ 27^m$. Commencing with the seventh day preceding the full moon, viz. the 9th of April, it will be perceived that high water occurs at 10 A. M., this being the greatest A. M. interval from noon; and that on the 16th, at the full moon, it occurs nearly at noon. Passing on to the 23rd, it reaches the greatest P. M. limit at $2^h\ 30^m$, and on the 2nd of May again reaches the noon period. Between the 23rd and 24th, however, a sudden anomaly presents itself. Throughout the day of the 23rd, the variation of the level does not exceed 2 1/2 inches, and the general motion is observed to be 'irregular.' The time of high water is also the extreme P. M. limit. On the 24th we discover that it has suddenly resumed the most distant A. M. period, viz. 10 A. M., but proceeds regularly to the noon period at the change. Although the differences of level do not at full and change exceed 1 foot 4 1/2 inches, still I presume that we have sufficient data to establish the fact, ---that it is not invariably high water at noon (as asserted by Kotzebue, Beechey and others); and, further, that we have corresponding nightly periods of high water." Thus, the tides at Tahiti do vary, contrary to early assertions. The sudden switch from a 2:30 PM high tide to one at 10:00 AM is, as Belcher admits, an anomaly. (WRC) (R2)

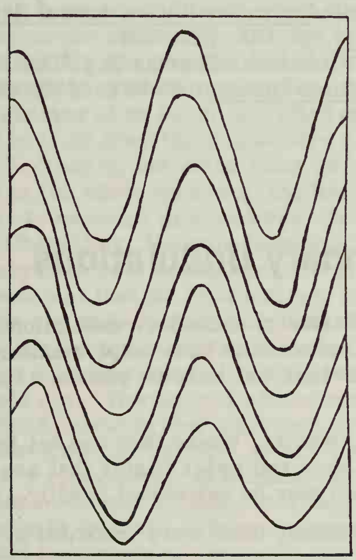
"The town of Papeete, on the island of Tahiti, was selected by Captain Rodgers, and the tide-gauge left there under the charge of an intelligent French soldier. The observations began on the 27th of April, 1856, but up to June 2d were so frequently interrupted as to be of little use, After that date, they are nearly complete to October 12th, subsequent to which time no observations have been received. On the accompanying diagram the mean local time of each high-water has been plotted in such a manner that the abscissae represent the days of the month, the ordinates the hours of the day. An inspection of the diagram will show that during part of the month of June the tide appears to have followed the general rule, occurring later every day, so that there was a high-water successively at all the hours of the twenty-four. In July, however, the case

TIMES OF HIGH WATER



Curious tidal records from Tahiti recorded in 1856 (X1) was quite different. The high-waters occurred at a later hour on successive days, but only until they had reached three or four hours, and, in one case, five, after noon or midnight, when they came back abruptly to the neighborhood of 12, to follow again a similar cycle. This type they preserved to October 12th, when the observations ceased, only the range and the abruptness of the return to an earlier hour becoming lessened." (R4) The June data are definitely anomalous. The other observations conform generally with those of R2, except that the cycle does not begin as early in the morning or evening. (WRC)

The following is by H. A. Marmer, an authority on tides in his day. "At first glance the behavior of the tide at Tahiti seems to be altogether unexceptional, the rise and fall appearing to exhibit no unusual features. Examining a typical tide curve for this island

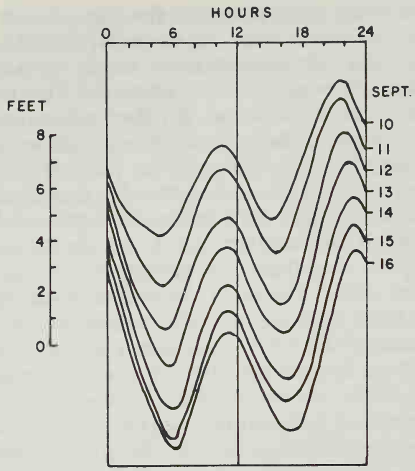


Sun-controlled tides at Tahiti (X1)

.....we find it much like the tide curve at numerous other places. The range of the tide, to be sure, is small, being on the average less than a foot; but the general appearance of the curve is that of a regular tide curve. If, however, we examine the succession in time of tide at Tahiti from day to day, the fact will soon come to light that here the tide does not come later each day by the interval of fifty minutes which characterizes the tide at other places. Instead, there will be periods of a week or more when each phase of the tide comes about the same time on successive days. Here, the tide curves for a week, arranged in serried ranks, do not show the distinct shift to the right found at other places; on the contrary, there is a pronounced tendency for the various phases of the tide, from day to day, to fall almost vertically under each other as exemplified by the tide curves for a week in September, 1924, as shown in the diagram.... Within the period of a week the tide at other places in the world would have kept time with the moon's motion so that at the end of the week each phase of the tide would be five hours later than at the beginning of the week. At Tahiti, however, as the week of tide curves shows, there is a barely perceptible shift to the right from top to bottom---instead of five hours it is somewhat less than two hours---and every day high water comes about twelve o'clock, morning and night, while the low water comes about six o'clock in the morning and six in the evening. It is in this feature that the tide at Tahiti is exceptional. Instead of becoming later each day by very nearly an hour, the tide here tends to come about the same time every day. Indeed, as a general rule it is not incorrect to say that at Tahiti the tide is high about twelve o'clock morning and night, and low about six o'clock morning and evening. Colloquially, therefore, the tide at Tahiti may be summarized as 'high-water, noon and midnight; low water, breakfast and supper.' The local term, <u>tooerarpo</u>, is used alike to express high water and midnight. And it is altogether likely that the tides served the easy-going Tahitians as a sufficiently satisfactory timepiece. When life is pleasant and unhurried what difference, really, does an hour or two make?" (R7) Marmer ignores the fact that the Tahitian tides stop progressing during the lunar cycle and suddenly revert to pre-noon high tides. (WRC)

The general features of the Tahitian tides are reviewed in several other articles. (R5, R6, R9, R10)

X2. Permanent feature. Tuesday Island, South Pacific Ocean. "More recently a larger solar tide has come to light on Tuesday Island, a small island in Torres Strait about 15 miles from the northern point of the Australian mainland. Here the tide has a mean range of a little over three feet, but comes about the same time day after day." (R8, R9)



Sun-controlled tides at Tuesday Island in the Pacific (X2)

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R9. Marmer, H. A.; "The Variety in Tides," Smithsonian Institution Annual Report, 1934, p. 181. (X1, X2)
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GHS2 Sea Seiches or Secondary Undulations

Description. The superposition upon the normal diurnal tides of secondary undulations of one or more additional periods. Generally, secondary undulations have much smaller amplitudes that the normal tides, but they may amount to several feet in some places. Periods range from 10 minutes to as long as 10 hours.

Background. Seiches are well-known in lakes and inland waters, where they are set into motion by barometric disturbances and earthquakes. Lakes and water basins that are nearly landlocked possess natural periods of oscillation which may be calculated readily.

Data Evaluation. Although the data accumulated are not recent, most were recorded by adequate tide gauges and are not suspect. Rating: 1.

Anomaly Evaluation. Most sea seiches follow the natural periods of the basins they occupy and present no anomaly in this respect. There is, though, the question of seiche excitation, particularly when the secondary undulations are permanent features. In some instances, no continuous exciting sources are known. Beyond this are several minor points: (1) Some seiche periods are not the same as the basin's fundamental period nor any harmonic of it; (2) Occasionally, seiches are harmonics of the fundamental period rather than the fundamental period itself; (3) In some places the seiche period varies from one location to another around the basin; and (4) In some Japanese bays, the phase of the undulation is identical everywhere around the shores of the bay, contrary to what one would expect if the water were sloshing back and forth. Generally speaking, these anomalies are minor in nature. Rating: 3.

Possible Explanations. Sea seiches may be excited by: barometric disturbances, earthquakes and the seawaves they generate, solitary and internal waves, winds, and sea surges. There are no obvious explanations of the four "minor" points.

Similar and Related Phenomena. Non-diurnal tides (GHS10), all anomalous waves (GHW).

Examples of Sea Seiches

X1. Permanent feature. Nova Scotia and New Brunswick, Canada. "The observations to which reference is made were taken by a tide gauge fixed upon a wharf at the north end of the naval yard at Halifax. The tides there are small in amount, the spring tides rising from 6 1/2 to 9 feet at Halifax, and 8 feet at Sambro Isle, twelve miles south of that place. The tides themselves appear to be quite regular; but in addition to the ordinary tide-wave there occurs a series of undulations succeeding each other at intervals of twenty minutes or half an hour, the difference of elevation and depression rarely exceeding 6 inches, and being usually much less. They are more perceptible near low water; but occur at all times of tide, and are very distinctly marked upon the curve traced by the self-acting tide-gauge. The question to be considered is what is the cause of these small waves? 1. They do not arise from any influence which the casual swell of the sea might exercise upon the tide-gauge; for the rise and fall of one of these waves very seldom takes less time than a quarter of an hour, and often requires half an hour or even three-quarters of an hour. 2. They do not arise from undulatory motion in the whole waters of the harbour. In order to examine this question, Mr. Edgcumbe Chevallier, the storekeeper in Halifax Dockyard, went to Sambro, ten or twelve miles south of Halifax, and entirely clear of the harbour, and erected upon Power Island a temporary gauge, with which he took the height of the water every five minutes for the whole day. Having laid off the results in a form similar to that employed with the fixed tide-gauge at Halifax, it was found that every irregularity at Halifax was preceded ten or fifteen minutes by a larger irregularity at Sambro. These observations show that the irregular waves do not arise from the peculiar form of the harbour at Halifax." Similar irregularities are also found elsewhere around Nova Scotia and may originate in the Bay of Fundy. (R1)

"(1) The Phenomena are very common. At St. John, New Brunswick, on the coast of the Bay of Fundy, the oscillations have a fairly constant period of 43 minutes. At Quaco, a few miles further up the bay, the period is only 12 1/2 minutes. At Halifax, Nova Scotia, on the Atlantic coast, the period is 23 1/2 minutes. In the Gulf of St. Lawrence, at South-West Point (Anticosti), the oscillations are rapid but irregular; at St. Paul's Island, very rapid and irregular; at Forteau Bay, small and irregular; at Carleton (Quebec) there is some indication of a 22-minute period; at Souris (Price Edward Island) the oscillations are rapid and irregular; at Pictou (Nova Scotia), small and irregular; at St. Peter's Island, very rapid and irregular. (2) Any explanation must account for two distinct things: the origin of the fluctuations, and their periodicity. Let us take these in reverse order. (3) The period of the oscillations (where they have a definite period) is, I believe, simply the period of the free natural vibrations of a semi-confined body of water 'wish-washing' to and fro like water in a wash-bowl, the oscillations being sometimes fundamental--that is, consisting in the vibration of the body of water as a whole; and in other cases (perhaps the majority of cases) partial---that is, due to the body of water dividing up into two vibrating halves or three-thirds, &c. In a very irregular basin, like the Gulf of St. Lawrence, regular vibrations are impossible. In some other cases the basin is of sufficiently regular form to admit of fairly regular oscillations, but not regular enough for the period to be deduced mathematically." Possible stimuli of these oscillations might be barometric disturbances and heavy ground swell. (R4)

An exchange of letters regarding the adequacy of the tidal records used by Duff (R4). Duff maintained that they were. (R5)

Duff subsequently made a more thorough study of "secondary undulations," arriving at the following positions. "A. Facts. (1) Secondary undulations occur at most of the places where observations have been made (Eastern Canada), the undulations at any place being sometimes irregular but at other times of a regular periodic nature. (2) When the undulations are regular, the period of the undulation has a distinct and characteristic value for each place, varying, from place to place, from less than a minute to over an hour. (3) At some places at least two systems of regular periodic undulations of different periods are found; they usually occur at different times, sometimes they occur together; at one station the period at high tide is entirely distinct from that at low tide. (4) Undulations usually occur simultaneously at stations on the Atlantic Ocean (including the Bay of Fundy), but there is apparently no connection between this occurrence at stations on the Atlantic and stations on the Gulf of St. Lawrence. (5) Barometric records show no similar periodic oscillations, but they do show disturbances at or about the times of marked secondary undulations. (6) As the head of a bay is approached secondary undulations do not become more marked and frequent, but apparently less. (7) According to the best available evidence the period at St. John is less the greater the depth to which the tide fills the Bay of Fundy. B. Deductions. (1) The theory of atmospheric billows does not and cannot explain the characteristic local period of secondary undulations. (2) As an explanation of the origin of secondary undulations the theory of atmospheric billows seems at variance with certain facts of fundamental importance to the theory. (3) The seiche theory, which is fully established in the case of lakes, has a high inherent probability and is not at variance with any ascertained facts and in certain respects receives strong confirmation. (4) Even if the 'seiche' theory be correct, it still remains to be explained why the oscillations at certain places are usually binodal, at others trinodal, etc., and why in one striking case (Yarmouth) the oscillations are always uninodal at high tide and binodal at low tide. (5) The whole subject is apparently much more complex than has hitherto been supposed and it may yet be found that no single explanation will apply to all cases." (R6)

X2. Permanent feature. The Euripus, Greece. "The tides in this narrow strait between Euboea and the mainland of Greece, have from classic times been a scientific puzzle, for which a solution has been recently suggested by M. Forel, in a paper before the Paris Academy of Sciences. The currents through the strait are sometimes 'regular' and sometimes 'irregular.' When 'regular,' the direction changes four times in the lunar day. When 'irregular,' the changes number from eleven to fourteen or even more in a lunar day. The current is 'irregular' from the 7th to 13th and from the 21st to 26th day of the lunar month, or at the times of quadrature, and 'regular' the rest of the time or about the syzygies. M. Forel attributes the 'regular' tides to the ordinary tides of the Aegean Sea, which would be stronger at the syzygies. The 'irregular' tides he thinks are due to seiches in the channel of Talauda (which forms a nearly closed lake to the northwest of Euripus), these prevailing over the weaker Aegean tides of the quadratures." (R2)

X3. Permanent feature. Malta. "It is a matter of common knowledge to naval officers and others concerned, that the irregular variations of sea level in the Maltese inlets are at times sufficiently great to completely mask the slight lunar tide; and that the Port Officials are in the habit of insisting on a considerable margin of depth before permitting vessels to pass over the sills of the dry docks. These extra tidal variations of sea level have been ascribed to various causes, such as the direction and strength of prevailing winds, currents setting towards the mouth of the inlet, or to what is vaguely called the natural period of the harbour. My observations showed conclusively that there is at certain times in Malta Grand Harbour a perfectly regular ebb and flow with a period of twenty-three minutes; about the same period obtaining in Sydney Harbour, which Mr. Russell gives as twenty-six minutes." (R3)

X4. Frequent occurrence. Sydney Harbor, Nova Scotia, Canada. Secondary oscillations with a period of 26 minutes are reported. This period is very close to that prevailing in Grand Malta Harbor, despite the widely different areas of the two harbors. (R3) The 26-minute figure may be in error, for A.K. Easton reports seiches with a period of about 120 minutes are induced by weather systems along the coast of Nova Scotia. The computed natural period of Syndey Harbor is 120-132 minutes. (R12)

X5. Permanent features. Japanese coast. General conclusions from a lengthy study of secondary undulations along the Japanese coast. "The general conclusions which have been drawn from the thorough study of the numerous records obtained, are given in the following propositions. In discussing our results we have availed ourselves of the valuable records made by Lord Kelvin's tide gauges at ten different stations. These instruments have been set up at various places on the coasts of the Pacific and of the Japan Sea, and some of them have been in working operation twenty years. (1) On the Pacific coasts, free from any inlet in the coastline, the secondary undulation is quite unnoticable, and of a very irregular nature. (2) On the coasts of the Japan Sea the secondary undulation on the open coast is observable, though the periods of the undulations are not regular. (3) In a bay of considerable area, or in a shallow bay with a narrow opening towards the ocean, the secondary undulation is in ordinary cases imperceptible. (4) In a deep bay or estuary, the breadth of which is not large in comparison with its length, the secondary undulations are most pronounced. (5) In bays or open coasts, which are not far from each other, a common undulation is observed. (6) The secondary undulations in many bays change their periods continuously and through certain ranges. (7) In some bays the periods of the undulation are fairly constant. (8) In many cases the same trains of secondary undulations appear in the same phase with respect to the tidal wave, on consecutive days of ordinary weather. (9) The phases of the prominent, fundamental undulation at different parts of a bay are equal..... (12) In a bay, the periods of the conspicuous undulation observable in the case of a storm, or in that of a seawave of distant origin, are the same as those ordinarily observable in the bay. It has long been believed that the secondary undulation in a bay is the seiche between two opposite sides of the bay; but according to our observations, the phases of the most conspicuous undulation are the same throughout the bay, so that this view cannot be universally true." (R7)

X6. Permanent feature. Bay of Bengal, Indian Ocean. The tidal range is small near the mouth of the Bay, but in the Bay the range is 1-2.7 meters, and this increases rapidly near the end of the Bay. Calculations show that the period of the Bay's natural oscillation is the same as that of the semidiurnal tide. (R7)

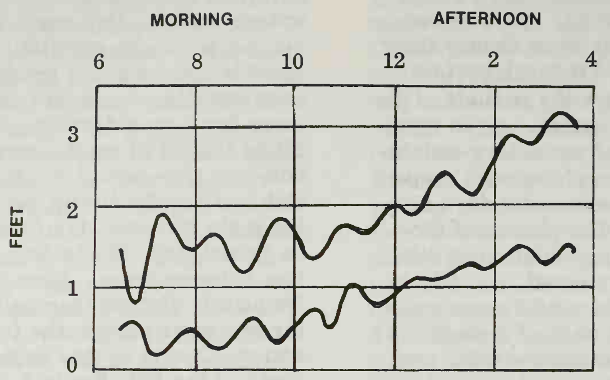
X7. Permanent feature. Madura Strait, Java. Very irregular tides with a strong component possessing an 8-hour period. (R7)

X8. Permanent feature. Port Adelaide, Australia. A remarkable variety of semidiurnal tidal inequalities on successive days. A strong component with a period of 10.9 hours beats with the normal semidiurnal tides. (R7)

X9. Permanent feature. Port Phillip, Australia. Long undulations with a period of 8.3 hours. Seiches in this nearly enclosed bay cannot be this long. (R7) As in the case of other undulations with very long periods, one must search for larger and deeper basins, whose long periods might affect the smaller body of water. (WRC)

X10. Permanent feature. Antarctica. Tidal records made during the British Antarctic Expedition of 1907 revealed large sea seiches with a period of about 3 hours persisting over several months of time. (R8, R9)

X11. Permanent feature. Palawan Island, North Pacific Ocean. "Records of tide observations for that part of the east coast of Palawan lying between the ninth and tenth parallels of north latitude show that the waters washing this coast are peculiarly subject to seiche oscillations. While in most bodies of water seiches occur only occasionally, it appears that here they hold sway for a considerable portion of the time. Slight traces of seiche movement have been noted on tide curves for stations both north and south of the limits mentioned above, but the main strongholds of the seiche seem to be Island Bay, Honda Bay, and the area that lies between them. Here the 'crazy tides' frequently disport themselves without waiting for storm or earthquake to excite them to action. Charts of this region show that the depth of the Sulu Sea is 1,000 fathoms or more over the larger part of its area. Extending out for some miles from the coast under discussion toward this deep water is a relatively shoal area with depths averaging around 20 fathoms. A break in this shelf-like bank occurs off the entrance to Puerto Princesa, where a depth of 200 fathoms approaches close to the shore line. It appears that the seiche oscillation is confined mainly to the relatively shoal water near the coast. That it does not cross the deep waters of the Sulu Sea is shown by the fact that tide records, obtained at a number of places on the east and south shores of this body of water, show no trace of the seiche.....In Puerto Princesa itself, however, the seiche reaches its acme of perfection. This body of water is continuously in a state of rhythmic vibratory motion. Day after day, month after month, its surface rises and falls with a persistent regularity that is surpassed only by the periodic response of the great oceans to the mighty tidal forces of the moon and sun. The period of this vibration is almost exactly one hour and a quarter---one-tenth the average period of a semi-daily lunar tide---and its amplitude varies from a few hundredths of a foot to 3 or 4 feet. Three years of automatic tide-gage records have been obtained at Puerto Princesa wharf for use in connection with hydrographic work in this vicinity. From these gage records, a few portions were selected that were simultaneous with observations showing pronounced seiche oscillations at places along the coast to the north and south of Puerto Princesa. These records show that, at the time when the seiche is noticable at other places along the coast, it has considerable amplitude at Puerto Princesa, and this fact seems to indicate that there is a close relationship between the seiches at the various places. It will be noted also that the periods of oscillation, while differing somewhat at the dif-



Short-period oscillations in the tidal records from Puerto Princesa (X11)

ferent points of observation, are roughly the same for the entire area. In fact, there seems to be a progressive increase in the period from the vicinity of Island Bay northward." Possible causes of the sea seiches around Palawan are barometric changes and strong currents in the Sulu Sea striking the shelves offshore. (R10, R11) More recently scientists have gathered evidence that the Sulu Sea supports a long train of long-period waves (GHW). (WRC)

X12. Permanent feature. Cape Lookout Bight, North Carolina. An irregular seiche of considerable amplitude sometimes persists for several days. (R10)

X13. Permanent feature. Puerto Rico. Fairly regular seiches of small amplitude detected along the south shore. (R10)

X14. Permanent feature. Kauai Island, Hawaii. A continuous oscillation of one to two-tenths of a foot, with a period of about 20 minutes in the bay on the north side. (R10)

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GHS3 Spectacular Tidal Bores

Description. Walls of hissing, frothing water up to 25 feet high that progress up river channels at speeds up to 15-20 miles per hour. The wavefront may be many miles long in broad estuaries. Narrowing as it moves up the narrowing river channel, it may be noticable scores of miles upstream.

Background. Tidal bores are fairly common all over the world, but only a dozen or two are really impressive. The most spectacular are those of the Amazon (the pororoca), the Tsientang River (China), and the Salmon and Petitcodiac Rivers, which empty into the Bay of Fundy, Canada. Those of the Severn (England) and the Seine (France) are not particularly large but are historically famous. Dozens of other rivers boast small bores. Some are mere progressive undulations rather than fearsome walls of white water.

Data Evaluation. Tidal bores are well-described in the literature and have been observed by millions of people. Rating: 1.

Anomaly Evaluation. The science of hydrodynamics adequately explains all major features of tidal bores. This phenomenon is included here for its curiosity value and its similarity to more perplexing progressive waves in the atmosphere and waters. The only suggestion of anomalousness is the tidal bore's occasional elusiveness and unpredictability. At times, when conditions seem ripe, a bore will fail to materialize, or it will be of disappointing size. Rating: 4.

Similar and Related Phenomena. Progressive waves in rivers (GHW4), atmospheric bores, such as the Morning Glory (GWC12).

Examples of Spectacular Tidal Bores

X1. Permanent feature. Amazon delta, Brazil. Eye-witness account of the Amazon's tidal bore from the Araguary, a tributary at the mouth of the Amazon. "Arriving at the mouth of the Araguary, they went down with the tide, and anchored just inside the bar which crosses the mouth of this stream, to await the turning of the tide, which would enable them to pass the shallows, and then carry them up the Amazon. Shortly after the tide had stopped running out, they saw something coming toward them from the ocean in a long white line, which grew bigger and whiter as it approached. Then there was a sound like the rumbling of distant thunder, which grew louder and louder as the white line came nearer, until it seemed as if the whole ocean had risen up, and was coming, charging and thundering down on them, boiling over the edge of this pile of water like an endless cataract, from four to seven metres high, that spread out across the whole eastern horizon. This was the pororoca! When they saw it coming, the crew became utterly demoralized, and fell to crying and praying in the bottom of the boat, expecting that it would certainly be dashed to pieces, and they themselves drowned. The pilot, however, had the presence of mind to heave anchor before the wall of water struck them; and, when it did strike, they were first pitched violently forward, and then lifted, and left rolling and tossing like a cork on the sea it left behind, the boat nearly filled with water. But their trouble was not yet ended; for, before they had emptied their boat, two other such seas came down on them at short intervals, tossing them in the same manner, and finally leaving them within a stone's throw of the river-bank, where another such wave would have dashed them upon the shore. They had been anchored near the middle of the stream before the waves struck them, and the stream at this place is several miles wide. But no description of this disturbance of the water can impress one so vividly as the signs of devastation seen upon the land. The silent story of the uprooted trees that lie matted and tangled and twisted together upon the shore, sometimes half buried in the sand, as if they had been nothing more than so many strings or bits of paper, is deeply impressive. Forests so dense that I do not know how to convey an adequate idea of their density and gloom, are uprooted, torn, and swept away like chaff; and, after the full force of the waves is broken, they sweep on inland, leaving the debris with which they are loaded, heaped and strewn through the forests. The most powerful roots of the largest trees cannot withstand the pororoca, for the ground itself is torn up to great depths in many places, and carried away by the flood to make bars, add to old islands, or build up new ones. Before seeing these evidences of its devastation, I had heard what I considered very extravagant stories of the destructive power of the pororoca; but after seeing them, doubt was no longer possible." (R1, R3, R6) From the descriptions, the pororoca evidently does not appear with every high tide and is, in fact, unpredictable. (WRC)

X2. Permanent feature. Hangchow, China. "...we were surprised by the cries of the natives as they descried to seaward the faint white line which marked the birth of the bore. This was at 12:30 P.M. Bringing our glasses to bear on this line which seemed to be near the meridian of Chishan, a conspicuous hill about twelve miles east by fifteen degrees south from Haining, marking the indentation previously referred to as Bore Shelter Bay, we could see that the bore had formed in two branches. The one on the north side of the channel was considerably the larger and was advancing almost directly up the river, touching the sea-wall with its northern end and the sands with its southern extreme; the other branch was approaching from the southeastward and touched the sands on both sides. The advance line of the first was not so very high, but we could still see it miles away running along the curve of the land, while behind it came a mighty wave, the whole advancing practically at right angles to the northern shore, while the second or southern branch came on almost parallel to the shore and with increasing speed. This latter line curved gradually around and when about five miles from Haining its northern extreme overtook the southern extreme of the first, thus forming a continuous line of white breakers two or three miles long. Where this juncture was effected great waves, white from the force of impact, dashed many feet into the air in mid-stream and seethed all about the point of conflict. This immense upheaval, however, rather quickly subsided, and the flood wave resumed a more or less uniform height, which presently increased as the bore contracted in width, and increased in speed as it conformed to the narrowing channel of the river. With rapidly increasing roar and steady progress this line advanced, and the immensity of the phenomenon began to be appreciated even more than on the previous night. A wall of very muddy water, white-crested and fully ten feet high, was approaching with the speed of a railroad train, breaking over and overwhelming the resisting ebb tide of the river, which in front of the pagoda was still running out with a speed of six or seven miles an hour and fighting every foot of the monster's advance. It was a battle of the flood against the ebb, and the flood, backed by the irresistable power of the ocean's rhythmic pulse, was swallowing up the ebb with an on-rush which must been seen to be fully appreciated." (R2, R4-R6) The above comparison of the bore's speed to a train must be an exaggeration, for 15 miles per hour seems about the maximum for tidal bores. (WRC)

References

R1. Branner, John C.; "The 'Pororoca' or Bore of the Amazon," Science, 4:488, 1884. (X1)

R2. "The Hangchow 'Bore,'" English Mechanic, 49:90, 1889. (X2)

R3. Branner, John C.; "The 'Pororoca,' or Bore, of the Amazon," Popular Science Monthly, 38:208, 1890. (X1)

R4. Darwin, George H.; "Bores," Century Magazine, 34:898, 1898. (X2)

R5. Edmunds, Charles Keyser; "A Visit to the Hangchow Bore," Popular Science Monthly, 72:224, 1908. (X2)

R6. Lynch, David K.; "Tidal Bores," Scientific American, 247:146, October 1982. (X1, X2)

GHS4 Diurnal, Triple, and Quadruple Tides

Description. Tides that follow the moon but which display one, three, four, or more high and low tides each day. With few exceptions, these "non-standard" tides are small. In some instances, these tides shift back and forth between the non-standard rhythm and the more normal semidiurnal tides.

Background. Semidiurnal tides wash the coasts of most of the continents and are thought by most people to be the norm. However, even these common, twice-a-day tides are often "mixed"; that is, one of the daily highs is much larger than the other. Around the Gulf of Mexico and a few other locales, the smaller high tide essentially vanishes, leaving a nearly pure diurnal, once-a-day tide.

Data Evaluation. Small, diurnal tides are common enough, but large, one-a-day tides are very rare, though well-established scientifically. Three-a-day and four-a-day tides have been mentioned briefly in the literature examined, but no details have been offered. Composite rating: 2.

Anomaly Evaluation. One would expect different ocean basins, large seas, and land-protected harbors---all with varying frequencies of natural oscillation---to respond in various ways to the exciting forces of the sun and moon. Putting it simply, some bodies of water will simply not oscillate at the semidiurnal frequency and respond by forming a diurnal tide. These is no anomaly in this if the tidal amplitudes are small. Strong diurnal tides (which are very rare) are not expected from tidal theory. Triple and quadruple daily tides do not present serious explanatory problems, because one can always appeal to secondary undula- or harmonics of the semidiurnal tide in explaining the extra tides. Rating: 3.

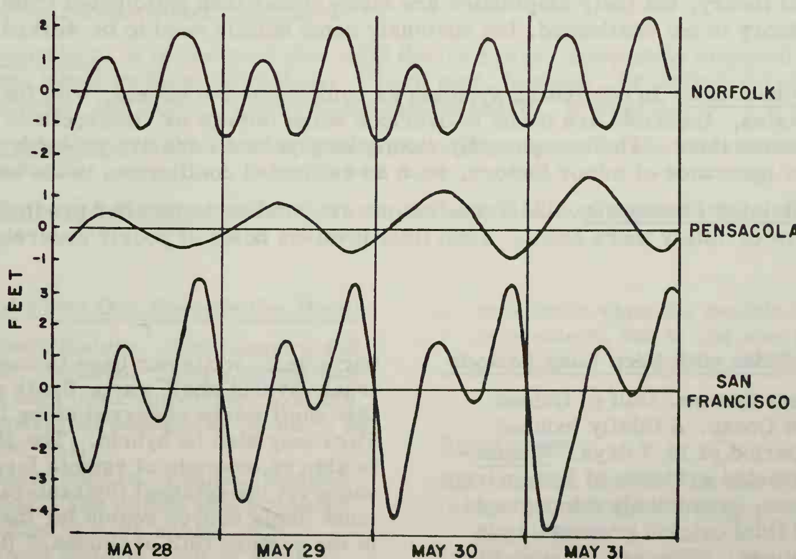
Possible Explanations. Abnormal tidal frequencies can usually be explained using some combination of the following: (1) Secondary undulations; (2) Excitation of the harmonics of the semidiurnal frequency; and (3) The basin's natural frequency of oscillation and other local factors accentuate diurnal response and suppress semidiurnal response.

Similar and Related Phenomena. Secondary undulations (GHS2), tides that follow the sun (GHS1).

Examples of Diurnal, Triple, and Quadruple Tides

X1. Permanent features. Gulf of Mexico, Alaska, China, Philippines, and other scattered localities. Small diurnal (once-a-day) tides that follow the moon; that is the highs and lows advance about 50 minutes per day. (R1) Small diurnal tides are not considered anomalous. (WRC)

X2. Permanent feature. Okhotsk Sea, Russia. "The known range of the tides that flow in and out only once a day has been only a few feet at most. The newly-discovered daily tides of the Okhotsk Sea, however, form waves of notable size. In the month



Semidiurnal, diurnal, and mixed tides (X1) during which the Russian Hydrographic Department made tidal observations at Cape Astronomicheski, at the northeastern head of the Okhotsk Sea, the daily tide on one record-making occasion had a range of 37 feet. Only on a few days during the month did the Russians find two high and low waters occurring at this part of the seashore. The more usual occurrence was a single daily tide, averaging fully 28 feet." (R2)

X3. Permanent feature. Stirling, Scotland, and the Isle of Wight, U.K. Three tides per day are observed at these locations. (R3)

X4. Permanent feature. Courtown, Ireland. At some times, four small daily tides; at other times, a small, irregular semidiurnal tide. (R4)

X5. Permanent feature. Southampton, England. Four tides per day. (R5)

References

R1. Marmer, H. A.; "Variety in Tides," Smithsonian Institution Annual Report, 1934, p. 181. (X1)

R2. "New World Record Found for Height of Daily Tide," Science News Letter, 26: 4, 1934. (X2)

R3. Davis, W. M.; "Tidal Problems," Science, 7:705, 1898. (X3)

R4. Hollis, H. P.; "Abnormal Tides at Courtown," English Mechanic, 104:28, 1916. (X4)

R5. Macbeth, Norman; "The Moon and the Tides: Causation or Companionship," Cycles, 23:288, 1972. (X5)

GHS5 Long-Period Tides of Unexpected Strengths

Description. Tidal components with periods of several days to many months possessing unpredicted strengths.

Data Evaluation. The detection of very-long-period tides, which usually possess amplitudes of only fractions of an inch, require long, high-quality records. Only a few efforts have been made to discern such small tides amidst the noise present in normal tidal records. The analyses are delicate and sometimes contradictory. Rating: 2.

Anomaly Evaluation. The existence of the very-long-period tides described below are predicted by tidal theory, but their amplitudes are much higher than anticipated from theory. Basic tidal theory is not challenged, but obviously some details need to be worked out. Rating: 3.

Possible Explanations. In oscillating systems as complex as the oceans, with their various resonating basins, theorists are bound to overlook some factors or "interactions", as one researcher terms them. The unexpectedly strong long-period tides are probably only the results of our ignorance of minor factors, such as estimated coefficients in the equations.

Similar and Related Phenomena. Tidal predictions are similar to weather predictions, though the former are certainly more exact. Each field involves hosts of poorly understood variables.

Examples of Tides with Very Long Periods

X1. Permanent feature. Gulf of Guinea. South Atlantic Ocean. A tidally induced wave with a period of 14.7 days. "Conclusion. We presented evidence of bottom trapped shelf waves, presumably a topographic shelf wave of tidal origin, propagating in the Gulf of Guinea. They are of particular interest for several reasons. Shelf waves that have been previously reported...have tended to be either purely barotropic or baroclinic, while our case is most likely a truely hybrid shelf wave. Smith suggests that shelf waves observed along the coast of Peru may also be hybrid. The shelf wave is also an example of remote forcing through some yet unexplained tidal interaction. The most likely source region for the wave is in the eastern Gulf of Guinea." (R1)

X2. Permanent feature. North Atlantic Ocean. Abstract. Spectral analysis of a large number of tide records, of length greater than thirty years, shows surprisingly large power at the Chandler Wobble period (fourteen months) in Northern Europe. The amplitudes are 2 to 10 times greater than the equilibrium value. Hints of this pole tide are observed at a few other stations, but at most locations the tide does not appear above the noise continuum. At this low frequency, both the large amplitude and the variation along a coast line present difficulties in hydrodynamic interpretation." (R2)

X3. Permanent feature. Eastern North Atlantic Ocean. "I have recently described the phenomenal appearance in the seas off western Europe of a tidal component with a period of exactly one mean lunar day, namely the 'M_1 tide'. Although only a few mm in amplitude, it is about ten times larger than one would expect from comparison with ordinary diurnal tides, and suggests a resonance response of part of the Atlantic Ocean to forcing functions which are symmetrical with respect to the Equator. The forcing function for the ordinary diurnal tides is antisymmetric, and its components are relatively suppressed, enhancing the appearance of M_1 in this sea area." A large M_1 tide was also discovered at Lagos on the south Portugese coast. (R3)

References

R1. Houghton, Robert W.; "Characteristics of the Fortnightly Shelf Wave along the Ghana Coast," Journal of Geophysical Research, 84C:6355, 1979. (X1)

R2. Miller, Stephen P.; "Observations of the Oceanic Tide at the Frequency of the Chandler Wobble," Eos, 53:1026, 1972. (X2)

R3. Cartwright, D.E.; "Anomalous Tide at Lagos," Nature, 263:217, 1976. (X3)

GHS6 Tides That Precede the Moon

Description. Tides of various types that precede rather than lag the lunar event that supposedly excites them; viz., high tides preceding the moon's meridian passage; spring tides preceding the syzygies; maximum diurnal inequalities preceding the maximum declination of the moon. It most of these situations, the tides lead the purported exciting force by as much as an hour or more.

Data Evaluation. The literature here is very thin, but the authors speak as though the phenomena are well-established. Rating: 2.

Anomaly Evaluation. It is assumed that tidal theory has not adequately disposed of these phenomena, thus labelling them anomalous. There may, however, be undiscovered explanations. See, for example, the rather simplistic suggestion below. Rating: 2.

Possible Explanations. Like the shock wave preceding a missile, the disturbance may lead the exciting force.

Similar and Related Phenomena. Shock waves and many related phenomena in aerodynamics.

Examples of Tides that Precede the Moon

X1. Permanent feature. Port Glasgow and Greenock, Scotland. Tidal records indicate that high tides sometimes lead the moon's meridian passage by as much as two hours. (R1)

X2. Permanent feature. Toulon, Mediterranean Sea. The spring tide precedes the syzygies by 4.75 hours. (R2)

X3. Permanent feature. Gulf of Mexico. The diurnal inequality should reach its maximum when the moon's declination is greatest, but at one spot on the Gulf of Mexico, it leads by 17 hours. (R2)

References

R1. Mackie, David; "On the Tides of Dundee and Glasgow," Report of the British Association, 1837, p. 5. (X1)

R2. Davis, W. M.; "Tidal Problems," Science, 7:705, 1898. (X2, X3)

GHT OCEAN TURBULENCE AND CIRCULATION PHENOMENA

Key to Phenomena

GHT0 Introduction

The oceans are criss-crossed by many ponderous currents of water; some cold, others warm; some near the surface, others running deep. In the Antarctic cold water sinks and then moves north. The warm waters of the Gulf Stream hug eastern North America until they reach Cape Hatteras. Science is beginning to understand these great movements of sea water; but superimposed upon these well-known circulation features are transient events and seasonal movements that are poorly charted and still enigmatic. Why, for example, do the annual El Ninos, those seasonal movements of water down the coast of western South America, push much farther south about every seven years? How do the Gulf Stream rings maintain their identities for several years in a restless ocean? Several such vexing questions have been posed in the literature examined so far. However, the literature of oceanographic research has been merely sampled. This portion of the Catalog of Anomalies will certainly be expanded greatly in the future.

It is also recognized that the subject of "undersea weather" has hardly been touched. Waves, vortexes, and disturbances never seen on the surface have been encountered at great depths. These subsurface phenomena are exceedingly difficult to detect and chart; and much of the research that has been done is classified by the military. Here, too, the Catalog is woefully incomplete.

GHT1 Extraordinary Deep Circulation Events

Description. Large-volume, well-organized disturbances far beneath the ocean's surface. These circulation events consist of powerful transient currents and vortexes, which in some ways resemble atmospheric storms.

Data Evaluation. A single report of a disturbance recorded by an array of deep-water instruments. Undoubtedly more reports such as this one will be found as literature analysis continues. Rating: 2.

Anomaly Evaluation. The sources of these strong transient events are not known. Rating: 3.

Possible Explanation. Disturbances could be generated by turbidity currents resulting from the slumping of huge masses of sediments. Earthquakes and submarine volcanos could also cause transients, but none was associated with the event recorded below.

Similar and Related Phenomena. Gulf Stream rings (GHT8) are much larger in size. As mentioned above, atmospheric weather events (GW) have similar structures.

Examples of Extraordinary Deep Circulation Events

X1. January 24, 1968. About 400 kilometers off northern Baja California, North Pacific Ocean. "Abstract. On 24 January 1968, a transient deep-circulation event was recorded by a triangular array of autonomous current recorders installed 3 meters above the bottom at two of the three positions and at intervals of 3 to 1000 meters above the bottom at the third position in a depth of 3950 meters above the relatively smooth floor of the eastern North Pacific. The event interrupted a 24-hour record of relatively steady but peculiar conditions, lasted for about 1 1/2 hours, and was followed by current directions and speeds that greatly differed from those of the initial period. The event occurred over a volume of the sea of at least 2 kilometers in horizontal dimensions and 1 kilometer thick. Associated with the event were many small clockwise-rotating features extending from 3 to at least 1000 meters above the bottom and a rapidly increasing current velocity at 1000 meters. The event was probably local and may have involved convective motion, internal waves, and the passage of a front. Some of the changes in horizontal velocity may have resulted from the combined effects of upwelling and the earth's rotation." (R1, R2)

X2. General observations. All oceans. Photographs of the ocean floors often show ripples up to 15 centimeters high and a meter apart, indicating currents 40 cm/sec and higher. Water samples from the open ocean sometimes reveal high turbidity, suggesting that violent currents may stir up the sediments on the bottom. Finally, some arrays of current meters measure extremely high velocities (50 cm/sec), which sometimes reverse their directions. (R3)

References

R1. Isaacs, John D., and Schwartzlose, Richard A.; "A Deep Circulation Event," American Geophysical Union, Transactions, 49:699, 1968. (X1)

R2. Schwartzlose, Richard A., and Isaacs, John D.; "Transient Circulation Event near the Deep Ocean Floor," Science, 165:889, 1969. (X1)

R3. Kerr, Richard A.; "A New Kind of Storm beneath the Sea," Science, 208:484, 1980. (X2)

GHT2 Sonar-Detected Subsurface Oceanic Structures

Description. Plumes, spires, walls, and other structures appearing on sonar records that are not solid structures but rather concentrations of particulate matter or thermal discontinuities.

Data Evaluation. Few records of this phenomenon have been found in the literature, although the sonar records are fairly convincing. Rating: 1.

Anomaly Evaluation. The precise nature of the observed structures is not known. If they are composed of particulate matter, how do such aggregates form and maintain their shapes? Rating: 2.

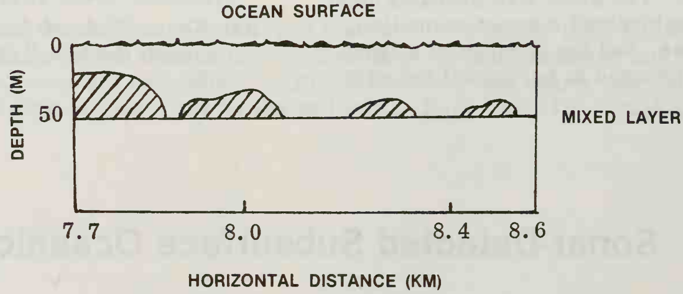
Possible Explanations. Current patterns might create these structures, although the spires and walls seem too stable for this sort of origin. Organized biological activity (minute sea creatures) might form temporary structures and aggregations. Thermal vents, like the so-called "smokers" on the sea floor, might produce thermal plumes thick with particulate matter.

Similar and Related Phenomena. Sea-floor thermal vents; undersea volcanos; and (possibly) the curious plumes of insects occasionally observed over treetops (BI).

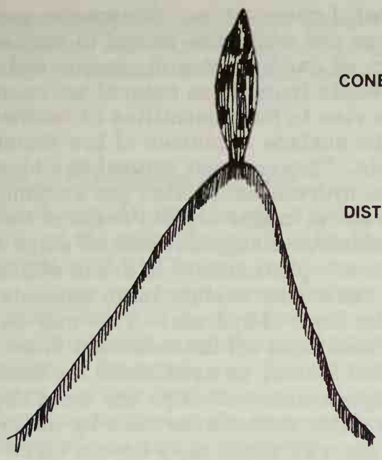
Examples of Sonar-Detected Subsurface Oceanic Structures

X1. Permanent features. Florida Current, North Atlantic Ocean. Peculiar humps or hills of particulate material, thousands of feet long and hundreds high, have been observed in the Florida Current with ultrasensitive 20-kHz sonar. The humps extend from the bottom of the oceanic mixed layer to near the surface. Sediment and plankton probably make up the humps, but the actual constitution and origin of the concentrations are unknown. (R1) Conceivably currents might help concentrate the particulate matter; some sort of organized biological activity is not out of the question. (WRC)

X2. February 11, 1977. South Pacific Ocean. "Whilst passing to the south of Espanola Island in the Galapagos Group we were running our echo sounder; this particular echo sounder gives a very distinct of the sea bed to a depth of 600 fathoms. Between 1130 and 1430 GMT we were receiving a very detailed trace of the sea bed which was extremely undulating, rising in sharp peaks and falling again; this general picture left no doubt in our minds that it was volcanic in origin. We were interested to note that occasionally where the trace reached a peak, in the region where the crater would be expected, there rose a faint but distinctly elongated cone-shaped trace on the echo sounder paper. This we did not take to be solid bottom as the trace of rock could be clearly seen. Within the period, about five of these were noted, some being large and others small, see sketch." Thermal activity was suggested as the cause of the plumes. (R2) The well-known hot-water vents in the Galapagos area do not occur on mountain tops, although



Sonar-detected humps and hills in the Florida Current (X1)



Sonar-detected plume rising over an undersea mountain (X2)

there might very well be a connection. The plumes could also be particulate or biological in nature. (WRC)

References

R1. Proni, John R., et al; "Vertical Particulate Spires or Walls within the Florida Current and near the Antilles Current," Nature, 276:360, 1978. (X1)

R2. Howard, K.E.; "Soundings in a Volcanic Area," Marine Observer, 48:20, 1978. (X2)

GHT3 Nonvolcanic Underwater Eruptions

Description. The large-scale eruption of gases and fluids from the ocean's surface that are apparently unrelated to volcanic activity.

Background. The marine literature contains many accounts of submarine volcanos spewing forth smoke and mud and even creating new bits of land surface. Immense rafts of floating low-density volcanic ejecta are occasionally encountered; so are large tracts of colored water and dead fish. In this category, these rather common manifestations of undersea volcanism are eliminated.

Data Evaluation. The existence of only one eye-witness account of a possible nonvolcanic eruption relegates this phenomenon to a low-confidence category. Rating: 3.

Anomaly Evaluation. From a geological standpoint, a good case can be made for the occasional release of large volumes of gases from the sea floor. In fact, it is rather surprising that more accounts of large gas releases have not be found. A low anomaly rating is in order. Rating: 3.

Possible Explanations. Gas hydrates in sea-bottom sediments may be triggered into releasing trapped gases by earthquakes, turbidity currents, and other undersea disturbances. Accumulations of natural gas stored in pockets under the sea floor may also be released by similar geological activity.

Similar and Related Phenomena. Geysers at sea (GHG1). The (supposedly) mysterious disappearances of ships and planes from areas of the ocean known to be underlain by extensive deposits of gas hydrates (R2). Underwater detonations of nuclear devices. Large-scale releases of natural gas (ES), which might also be accompanied by acoustic phenomena (GSD).

Examples of Nonvolcanic Underwater Eruptions

X1. April 11, 1963. 100 miles north of Puerto Rico, North Atlantic Ocean. The crew of a Boeing 707 aircraft catch sight of a huge water disturbance. "At the 1:30 position, about four or five miles from the path of the jet, the ocean was boiling up in a gigantic hemispheric mound. The copilot described the phenomenon as 'a big cauliflower in the water'. He immediately called the captain and the flight engineer to see the 'cauliflower'. The three crew members watched for about 30 seconds until the sight passed behind the wing of the jet and disappeared from view. The copilot watched the mound of white water growing in both height and diameter, but by the time the other two crew members unlocked their harnesses and climbed over to the right side of the cockpit for a look the mass had begun to fall back. Nevertheless, all three agreed that they had witnessed something of a most unusual nature, and of extraordinary dimensions. Making a rough calculation based on the apparent size of the mound of water as seen from an altitude of 31,000 feet, it appears that the diameter of the mound must have been 1/2 to 1 mile and with a height 1/2 to 1/3 of the diameter." (R1)

General observation. Enormous quantities of gas and water are stored in semisolid form as gas hydrates in oceanic sediments. Blowouts from these natural sediments may give rise to huge quantities of bubbles rising to the surface in plumes of low-density fluids. "Intermittent natural gas blowouts from hydrate-associated gas accumulations, therefore, might explain some of the many mysterious disappearances of ships and planes---particularly in areas where deep-sea sediments contain large amounts of gas in the form of hydrate. This may be the circumstance off the southeast coast of the United States, an area noted for numerous disappearances of ships and aircraft." (R2) The water disturbance seen by the crew of the aircraft might have been a large-scale gas hydrate blowout. (WRC)

References

R1. Durant, Robert J.; "An Underwater Explosion---Or What?" Pursuit, 5:30, 1972. (X1)

R2. McIver, Richard D.; "Role of Naturally Occurring Gas Hydrates in Sediment Transport," American Association of Petroleum Geologists, Bulletin, 66:789, 1982. (X1)

GHT4 Anomalous El Ninos

Description. Sudden, unexpected warmings of the waters of the eastern South Pacific Ocean, particularly along the coast of Peru. Out-of-season El Ninos may begin as early as May rather than the usual November or December. Anomalous El Ninos often commence with the simultaneous warming of much of the South Pacific instead of commencing at the South American coast and propagating westward.

Background. El Ninos occur yearly along northern South America, when a tongue of warm water from the equatorial countercurrent moves south. Roughly every seven years, the El Nino moves much farther south, displacing the cold Peru current and causing the catastrophic destruction of plankton and fish life. In this Catalog category, we are concerned with the anomalies of the El Nino, although it is recognized that the "normal" El Nino is not well-explained.

Data Evaluation. The recent (1982-1983) anomalous El Nino has led to several high-quality studies. Rating: 2.

Anomaly Evaluation. Even the "normal" annual El Nino is poorly understood; the causes of the anomalous seven-year El Nino far less so. The basic fault lies with our poor understanding of the interplay between ocean currents and global meteorology. Rating: 2.

Possible Explanations. The anomalous seven-year El Ninos may be triggered by large-scale volcanic eruptions, which in some way reduce the trade winds.

Similar and Related Phenomena. Lesser-scale warmings of the sea (called "painters") are rather common along the South American coast. Some have suggested that the severe El Ninos may be related to the solar cycle and sun-induced weather changes (GWS).

Examples of Anomalous El Ninos

X1. 1982. South Pacific Ocean. From a discussion of the possible worldwide effects of the eruption of El Chichon in the spring of 1982. "Some are considering the suspicious coincidence of the tropical eruption and the unanticipated appearance of El Nino, the warming of the equatorial Pacific surface waters that can periodically decimate the anchovy population of the eastern Pacific. The coincidence seems particularly suspect to some because this El Nino was rather odd. It began developing in May rather than during October to November, as is usual. According to Eugene Rasmusson of the National Weather Service in Camp Springs, Maryland, the last out-of-season El Nino appeared in 1963. That was shortly after the eruption of Agung, the most recent eruption having a major climatic effect. He also notes that this ocean warming was unique in appearing across the Pacific all at once rather than propagating westward from the South American coast; such unusual behavior caught El Nino forecasters by surprise. The suggestion that the stratospheric warming somehow diminished the trade winds, which in turn leads to the ocean warming, has not been well received. No alternative mechanisms have been offered, but the possibility that one exists is not being rejected out of hand." (R1, R2)

Philander has described the 1982 anomalous El Nino as follows: "In early 1982 anomalous conditions in the western tropical Pacific Ocean were similar to the precursory ENSO (El Nino Southern Oscillation) conditions described above, namely an eastward displacement of the ascending branch of the Walker cell. During the year the anomalous conditions grew steadily in the western and central Pacific Ocean so that there were, and as of November 1982 still are, severe droughts in Australia and Indonesia, heavy precipitation near the dateline, eastward rather than westward winds over the western Pacific and abnormally high sea-surface temperatures in the central Pacific Ocean. These unusual conditions were confined to the western and central Pacific until the early autumn. Only then did the sea-surface temperature start to increase in the eastern tropical Pacific Ocean. The current El Nino, unlike the more common ones, was therefore not an amplification of the seasonal cycle in the eastern Pacific but was completely out of phase with this cycle." (R3)

X2. 1963. South Pacific Ocean. Out-of-season El Nino following the eruption of Agung. (R1)

References

R1. Kerr, Richard A.; "El Chichon Climate Effect Estimated," Science, 219:157, 1983. (X1, X2)

R2. Simon, C.; "El Nino in Progress: A Warmer Pacific and the Winds of Change," Science News, 123:135, 1983. (X1)

R3. Philander, S. G. H.; "El Nino Southern Oscillation Phenomena," Nature, 302: 295, 1983. (X1)

GHT5 The Guinea Tide

Description. A strong, widespread, southerly movement of warm surface water along the African west coast. The Guinea Tide is seasonal, moving south from late September to early May, when it reverses its direction.

Data Evaluation. One report from an oceanographic survey. Rating: 2.

Anomaly Evaluation. The forces that cause this vast annual movement of water are unknown. This ignorance, however, probably reflects only our sketchy understanding of ocean circulation rather than any basic weaknesses in geophysical theory. Rating: 3.

Possible Explanation. None.

Similar and Related Phenomena. The El Nino (GHT4), a similar movement of water along the South American coast.

Examples of the Guinea Tide

X1. Permanent feature. South Atlantic Ocean. "The mysterious water movement or front has come to be known as the Guinea Tide, because it originates in the Gulf of Guinea, below Africa's great western land bulge, at a point close to the equator and approximately on an east-to-west line parallel to the cites of Libreville and Port Gentil in Gabon. It was first noted early in 1966 by scientists attached to France's Office de la Recherche Scientifique et Technique Outre-Mer..... It had apparently gone unnoticed because it travels slowly, advancing only about seven or eight miles per day. Moreover, it is centered in a region that has never before been heavily fished or used as a major shipping lane. When the front gets under way, it is as powerful as any daily oceanic tide, sweeping along a broad area the exact perimeter of which has not yet been charted. It heads southward above the cold Benguela Current, which is not affected, and which flows steadily northward from the lower reaches of the Atlantic. Also flowing north above the Benguela Current is a warmer oceanic stream known simply as the Tropic Water, but the Guinea Tide is powerful enough to push this back southward. Thus, when the Guinea Tide is moving southward, it is traveling opposite to the known counter-clockwise rotational pattern of the South Atlantic Gyre, which is what creates the northward flow of the Benguela Current and the Tropic Water..... The movement of the front apparently starts on the equator in the Gulf of Guinea sometime in late September or early October, Dr. Beardsley says. During November and December it is rather poorly defined, but when it is found the southerly movement is always quite definet. The front seems to stabilize suddenly in January as it keeps heading south, and remains that way through late April or early May, when, for reasons that are so far unknown, it suddenly reverses and heads back north toward the Gulf of Guinea. 'We do not yet know what forces activate or govern the movement of this vast body of water,' Dr. Beardsley says, 'and there may well be factors about it that will never be solved'. (R1)

References

R1. Gebhart, Lee; "Loaded with Tuna," Science News, 93:601, 1968. (X1)

GHT6 Energy Transfer Between Warm Eddies and Incipient Hurricanes

Description. Direct observations of the transfer of energy in the form of heat from specific oceanic structures to tropical storms. The observables are the cooling of surface water and storm augmentation.

Background. The strengths of tropical storms increase as they pass over warm waters; however, the transition to full-fledged hurricanes has always been difficult to predict. Many likely tropical storms fail to attain hurricane status when all conditions seem ripe. Possibly this seeming fickleness of nature is only a consequence of unappreciated small-scale circulation features.

Data Evaluation. One report from an oceanographic survey. Rating: 2.

Anomaly Evaluation. This phenomenon is more unexpected and unappreciated than anomalous. Nevertheless, it may be relevant to more important anomalies. Rating: 4.

Possible Explanations. None necessary.

Similar and Related Phenomena. The anomalous geographical distribution of hurricanes (GHW2).

Examples of Energy Transfer between Warm Eddies and Incipient Hurricanes

X1. August 1978. Gulf of Mexico, North Atlantic Ocean. "Hurricane Anita last August may have drawn part of its power from an eddy of warm Gulf of Mexico water. This is the conclusion of analyses based on detailed oceanographic data taken immediately before and after the storm. The slowly rotating 225-mile-diameter ocean eddy---about a degree warmer than surrounding waters---had been discovered a month earlier by Harris B. Stewart and John Proni of the National Oceanic and Atmospheric Administration. Its continued existence was confirmed on Aug. 28 as the storm was developing. As the storm moved toward the center of the warm eddy, it intensified, reaching hurricane strength as it passed the eddy's western edge. Measurements afterward showed the sea surface had cooled by 4°C." (R1)

References

R1. "Warm Sea Eddy Fed Hurricane Anita," Science News, 113:59, 1978. (X1)

GHT7 Long-Lived, Far-Travelling Oceanic Rings and Eddies

Description. Rotating rings and large eddies of seawater that travel thousands of miles and maintain their identities for one to several years. These features vary from 10 to about 200 miles in diameter and from a few hundred to a few thousand feet in vertical dimension. The temperatures and compositions of the rings and eddies are usually significantly different from the surrounding sea.

Background. Gulf Stream rings have been recognized for several decades. Created when kinks or loops break off the Gulf Stream, they may number roughly a dozen at any one time. Similar rings exist in other oceans wherever swift currents prevail.

Data Evaluation. Long-lived oceanic rings are accepted features of the world's oceans. Rating: 1.

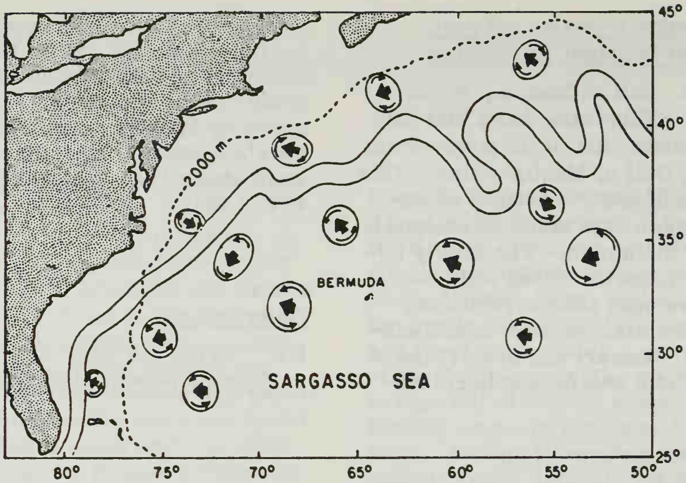
Anomaly Evaluation. The anomalous attributes of the rings and eddies are their long lifetimes and their ability to travel intact across thousands of miles of ocean. Such attributes are unexpected; and they basically reflect our poor understanding of the modes of energy dissipation and propagation in these oceanic structures. Rating: 2.

Possible Explanations. Apparently energy dissipation is unexpectedly low with these rings. Some efficient mechanism also exists to convert thermal potential energy into kinetic energy of rotation.

Similar and Related Phenomena. Large-scale chemical anomalies in the oceans (GHT8) The possible role of warm eddies in triggering hurricanes (GHT6).

Examples of Long-Lived, Far-Travelling Oceanic Rings

X1. General observations. "It now appears that rings are inevitable wherever narrow swift currents exist. Although meandering and ring formation were not really anticipated, from a theoretical point of view they are not very surprising to oceanographers. The observed longevity of rings is more difficult to explain. Unlike weather patterns, such as hurricanes, rings, once formed, have no external source of energy. A hurricane continuously draws in warm moist air from which it can extract large amounts of energy. Thus, the hurricane cannot only maintain itself but it can grow and intensify. A ring cannot grow. It can only maintain its circulation by drawing on the potential energy, which constitutes 95 percent of the ring's total energy, stored in the temperature difference between its core and its surroundings. It is slowly dying from the



Typical distribution of current rings in the North Atlantic (X1)

moment of birth. The mechanism of the dissipation of a ring's energy is not yet clear. Internal friction may tend to draw water from outside into the core of the ring, leading to the eventual erasure of the temperature difference. Glenn Flierl of the Massachusetts Institute of Technology, who devised a computer model of a ring, suggests that while internal friction could be at work, the dominant process may be the leakage of energy from the ring in the form of very slow, long waves. Rings might thus contribute to other physical processes occurring at great distances from the ring itself." (R1)

X2. Long-lived feature. Bahama waters, North Atlantic Ocean. "Recent hydrographic observations from the western Sargasso Sea revealed an anomalously saline water mass ranging from 7° to 12°C which was embedded in the thermocline. The characteristics of this feature indicate that it contained water from the eastern Atlantic and the Mediterranean Sea." This long-lived eddy, dubbed "Meddy", retained its identity while crossing the Atlantic, a distance of about 6,000 kilometers. The central core of this eddy was 20 kilometers in diameter and 200 meters thick. The mode of formation and source of translation energy are unknown. (R2)

References

R1. Kerr, Richard A.; "Oceanography: A Closer Look at Gulf Stream Rings," Science, 198:387, 1977. (X1)

R2. McDowell, Scott E., and Rossby, H. Thomas; "Mediterranean Water: An Intense Mesoscale Eddy off the Bahamas," Science, 202:1085, 1978. (X2)

GHT8 Large-Scale Oceanic Chemical Anomalies

Description. Large-volume, permanent, seasonal, and transient oceanic features possessing chemical properties significantly different than those of the surrounding waters, and for which no obvious explanations exist. The regions affected may extend for hundreds of miles horizontally and thousands of feet vertically.

Background. The permanent currents, long-lived eddies, and fresh-water outpourings of the great rivers insure some chemical inhomogeneity. In this Catalog entry, however, the focus is on chemical differences of unknown origins.

Data Evaluation. Oceanic surveys have detected several unexplained chemical anomalies. The data are sound but scanty. Rating: 2.

Anomaly Evaluation. Once again we have unexpected oceanic features that reflect more the incompleteness of our knowledge about the oceans rather than basic ignorance of geophysical laws. Rating: 3.

Possible Explanations. Biological communities may change the ocean's chemistry over large volumes. Like river influx, water flow from sea-floor vents may produce chemical changes.

Similar and Related Phenomena. As mentioned in "Background" above, many chemical inhomogeneities are fairly well understood.

Examples of Large-Scale Chemical Anomalies in the Oceans

X1. Permanent feature. North Pacific Ocean. "A negative carbon dioxide partial pressure anomaly, with respect to atmospheric pCO, occupies a large area of the North Pacific Ocean with a center just south of the subarctic convergence. The maximum anomaly is about 20 percent and is too large to be accounted for solely by differences in temperature, salinity or calcium carbonate chemistry. Carbon dioxide assimilation by photosynthetic organisms would also contribute to a negative anomaly." (R1)

X2. May 1969. North Atlantic Ocean. "An infusion of low-salinity water has been detected in the area of the Atlantic being studied in the Barbados Oceanographic and Meteorological Experiment. During the first two weeks of May, measurements turned up only normal levels of salinity: 35 parts per 1,000. But later measurements found the salinity to have decreased to 32 to 33 parts per 1,000, which is regarded as a very large change....The area of infusion was at least 500 kilometers wide---the length of one side of the study area---and extended 30 meters deep. The relatively small number of previous measurements in the area during the last 40 years had led the scientists to expect some reduction in salinity during the late spring. The fluctuation is possibly a result of a flow of fresh water from some other source, such as the Amazon River, 1,700 kilometers to the southeast, or it could be due to heavy spring rains." (R2)

References

R1. Curl, H. C., Jr., and Park, P. Kilho; "Biological Origin of Large Surface Carbon Dioxide Anomalies in the North Pacific Ocean," American Geophysical Union, Transactions, 49:697, 1968. (X1)

R2. "Low-Salinity Area in Sea," Science News, 96:15, 1969. (X2)

GHW REMARKABLE WAVE PHENOMENA

Key to Phenomena

GHW0 Introduction

Many mariners tell of "waves from nowhere" that suddenly broke over their ships, sweeping men and equipment into the sea. Great solitary waves are rare; and some, not all, pose problems of explanation. If a solitary wave is merely two or three times larger than the general run of waves, it can be written off as a chance addition of smaller waves of different wavelengths. Single giant waves preceded and followed by relatively calm water are not explained so readily. Submarine disturbances are, of course, possible progenitors. Seismic activity, however, customarily generates waves with very long wavelengths. The typical tsunamis or earthquake generated waves are barely noticed on the deep ocean and rise to catastrophic heights only as they approach shallow water. Solitaries in constricted areas, such as the English Channel, may be the piling up of a storm surge, with nasty weather soon to follow. It is the isolated giant wave, met with in calm weather on a smooth sea, that presents the real enigma.

Small groups of waves and bands of broken sea seem to come and go as mysteriously as the solitary giants. We suppose instinctively that, like ripples on a pond, they are caused by some distant disturbance possibly thousands of miles away. It is true that powerful storms can send heavy surf crashing unexpectedly onto shores thousands of miles from the storm center, but most bands of waves and broken water seem to have little to do with far-off storms. Rather, they are manifestations on the surface of internal waves coursing through the body of the sea. Usually periodic, they probably owe their origins to tidal waters surging over continental shelves and submarine canyons. They are like surface shadows cast by deep and powerful undersea forces.

GHW1 Unexplained Solitary Waves

Description. Giant single waves, rarely two or three together, that measure at least four times the height of the average surrounding wave, and for which no reasonable explanation can be found. These "waves from nowhere" sometimes smash into vessels plying waters that are otherwise calm. These are waves of the open ocean and occur in deep waters.

Background. A few waves in a rough sea are statistically bound to be much larger than others in the area; but waves four or more times the average height are so unlikely that specific physical causes must be sought before writing them off as mere coincidence.

Data Evaluation. Ship captains report large, isolated waves on otherwise calm seas fairly often; but most of the giant waves are observed in heavy seas, where a few exceptional waves are expected statistically. When such explicable cases are filtered out, a dozen or so real anomalies survive. Rating: 1.

Anomaly Evaluation. When out-sized solitary waves occur, one can always claim that an otherwise undetected earthquake, volcanic event, or some other natural undersea cataclysm has transpired---as it probably has. So many natural phenomena can generate giant waves that this phenomenon has a low anomaly content. Rating: 3.

Possible Explanations. Underwater seismic disturbances immediately come to mind, but unless the observer is close to the epicenter seismic sea waves (tsunamis) are difficult to detect. Their wavelengths are so long that they may pass unnoticed on the open sea, although they become highly destructive when they reach shallow waters. Submarine slumping of sediments and the release of natural gas and gas stored in gas hydrates (GHT3) may create surface disturbances. Atmospheric disturbances can send large waves down narrow bodies of water such as the English Channel. Swiftly flowing oceanic currents can steepen the fronts of large waves, making them much more dangerous.

Similar and Related Phenomena. Tidal bores (GHS3); large seiches in lakes (especially the Great Lakes) caused by atmospheric disturbances; landslides bordering the sea (one such landslide in Alaska reputedly caused a wave that reached an elevation of just over 1,000 feet on the opposite shore.

Examples of Unexplained Solitary Waves

X1. 1813. Bay of Biscay, North Atlantic Ocean. "His Majesty's ship Hotspur, in 1813, whilst cruising in the Bay of Biscay, under easy sail, with moderate weather, was in a moment nearly overwhelmed by three successive seas. The quarter-deck bulwarks were carried away, one gun washed overboard, the wheel unshipped, several men lost, and the ship rendered unmanageable, and in imminent danger of foundering, in consequence of the quantity of water shipped. Immediately after, all appeared calm, as if nothing had happened; and it was the opinion of those who witnessed this, that it was occasioned by a momentary and very partial agitation of the sea." (R1)

X2. Circa 1847. Black Sea. "An Austrian steamer of Lloyd's company the Stamboul, was proceeding to Constantinople in a calm state of the weather, and was within an hour's distance of Synope, when suddenly the sea opened under it, assuming the form of a vast tunnel; the waves, in closing, covered it almost entirely, swept the deck, and did the most serious damage. The shock was so violent that several leaks were sprung, and the vessel was sometime in recovering itself from this terrible pressure and getting fairly afloat again. It rose, however, after some pitching, but injured to an extent that if another shock had taken place it would inevitably have been lost with crew and cargo." No earthquake in the area was noted. (R2)

X3. 1881. North Atlantic Ocean. "Solitary waves of an exceptional height have been met with unexpectedly in mid ocean which cannot be accounted for by the wind then blowing. These waves are commonly referred to as tidal waves but this is a misnomer; they are in all probability due to submarine seismic disturbances. In 1881 a solitary wave struck the barque Rosina in the North Atlantic sweeping overboard all hands then on deck. In the same year this unfortunate ship encountered another such wave while both watches were engaged in shortening sail. On this occasion the whole crew were carried away with the exception of a sick seaman lying in his bunk. He was eventually rescued by a passing steamer." (R7)

X4. 1882. South Atlantic Ocean. An unexpected solitary wave hit the Loch Torridon and washed the whole deck watch overboard. (R7)

X5. February 14, 1884. North Atlantic Ocean. "S.s. Faraday.---The wave was visible like a line of high land on the horizon about five minutes before it struck the vessel." (R4)

X6. November 27, 1886. North Atlantic Ocean. "S.s. Westernland.---A huge wave rose to a great height just in advance of the ship. No other similar waves were met with." (R4)

X7. February 18, 1891. North Atlantic Ocean. "H.M.S. Orontes.---While steaming in smooth water a huge wave broke over the vessel forward." (R4)

X8. 1890. North Atlantic Ocean. The Vancouver was badly mauled by a solitary wave. (R5)

X9. June 1892. North Atlantic Ocean. "The Holyrood, in June, 1892, 20°N, 35°W, encountered a solitary sea which looked like a wall of water as it approached; it flooded the decks, but before and after this sea broke, the water was comparitively smooth under a light northeast trade wind." (R5)

X10. September 1893. South Atlantic Ocean. A solitary wave swept three crewmen from the deck of the St. Denis. (R5)

X11. 1893. North Atlantic Ocean. A solitary wave struck the Johann Wilhelm. (R7)

X12. January 1894. North Atlantic Ocean. The Normannia was suddenly struck by a wave as high as the masthead. (R5)

X13. January 31, 1926. North Atlantic Ocean. A tremendous wave with an estimated height of 80 feet suddenly piled up ahead of the S.S. Empress of France. It swept over the ship doing much damage. (R6) The average height of the waves was not mentioned. (WRC)

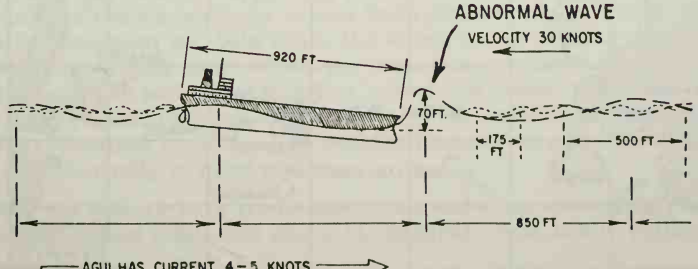
X14. February 1933. North Pacific Ocean. "...the highest wave reliably recorded was measured from the USS Ramapo, a 478-foot naval tanker, while running between Manila and San Diego in February, 1933. A wind of about 60 knots was blowing from astern, and huge seas had been running. The seas were not breaking; there was no rolling and easy pitching. The longest period was nearly 15 seconds, from which the wavelength may be calculated as about 1,100 feet and the wave speed as more than 50 knots. The watch officer later noticed an increase in wave heights in a succession of waves at 80, 90, 100, and 107 feet, and finally the enormous height of 112 feet. The last estimate, though at first unbelievable, appears fairly reasonable, since the ship was not listed, her stern was in the trough, and the officer saw the crests astern in line with the crow's nest and the horizon, at the time of observation. Knowing the length of a line from eye to crow's nest and the angle made with the ship's horizontal, it was a matter of simple trigonometry to calculate the wave height. Obviously a wave of such dimensions could not result from a storm with the usual duration and fetch. It turned out that the storm was unusually widespread, with an unobstructed fetch of thousands of miles and a duration of seven days. It is also possible that two or more wave trains of different wave lengths came together. When their crests coincided, an unusually high wave would be formed by their combination."(R13) Due to the severity of the storm and the possibility of additive waves, this 112-foot wave may not be anomalous, but it is of sufficient interest to record in any event. Note that the probability of encountering above average waves is discussed toward the end of this section. (WRC)

X15. August 5, 1968. Indian Ocean. From the s.s. Esso Lancashire off Durban. "At 0845 GMT the vessel entered a wave at an altitude of approx. 20 ft and emerged seconds later very much the worse for wear. If Cdre. W.S. Byles, R.D. has any idea where 'The One from Nowhere' went, we found the wave that should be with his trough! The wave passed unbroken over the monkey island (a height of about 60 ft) and we struck it well above the trough. It was preceded by a wave slightly larger than usual and we rode that one fairly comfortably but the wavelengths to the big one appeared much less and we just did not make it." The log for 0745 noted swell at 20 foot heights. Adding the 60 feet of the monkey island to the 20 feet above the trough gives a wave with a height of 80 feet, or four times the average wave height. (R11)

X16. Frequent occurrence. The Indian Ocean. "The abnormal formations that develop off the southeast coast of Africa are made up of two elements: local waves and those coming up from the Southern Ocean, a fetch that sometimes reaches 1,200 miles and brings fully developed waves by the time they reach the Port Elizabeth area. Although the lengths of the local waves and the long-distance waves differ greatly, they temporarily come together, increasing to an overall height, sometimes reaching the height of a six-story building, and creating correspondingly deep troughs. Another interesting fact should be noted. As ships head in a southwesterly direction and start edging toward the rim of the continental shelf, beyond the 100-fathom line, the sea conditions become noticeably heavier. It is in the over-100-fathom depths that most of the damage occurs.....On September 25,(1973), Svealand, on her maiden voyage, was experiencing gale-force, southwesterly winds with waves running from 30 to 40 feet in height. At 1647 hours on the same day, the forward part of the supertanker slid into a long deep trough. Before the bow could lift, the oncoming cliff of water smashed down on the first two hatches setting them down bodily by 2 feet and tearing them open. Two of the ship's crew were injured. At the moment the superwave struck Svealand the wind was howling out of the southwest at a speed of between 48 and 55 knots, the current was flowing southwest at 4 to 5 knots, and the ship was making 3 knots." The article points out that the Agulhas Current acts in a way to steepen the oncoming wavefronts. This combined with heavy seas and the addition of two wave trains probably accounts for the serious superwave problem off the African coast. Note that X15's wave was probably generated by this mechanism. (R15, R16, R19-R22) The edges of the continental shelves may influence wave heights if their wavelengths are comparable to the shelf's depth (roughly 600 feet, on the average). (WRC)

X17. No date given. English Channel, North Atlantic Ocean. "The time was evening. He was a few hours out from London in the English Channel, in a 900-ton ship, of which he was the chief officer. The sky was murky, but not absolutely cloudy, and the Channel waters were calm, though there was a fresh breeze blowing from the west at such a rate as to compel them to sail under a reefed mainsail and double-reefed topsails. On their lee was a brig. 'My captain and I,' says Captain Parselle, 'were standing on deck. I had given orders for the watch to be called, and they were assembled on the poop deck. The captain said, Mr. Parselle, I think the lighthouse ought to be visible by this time, meaning the Eddystone. Suppose I go aloft and look, I answered. I went up the rigging till I got about 60 feet aloft, and suddenly, when just in that perilous position, I heard a terrible shout from the deck. I looked down to see what was the matter, and just as I did so a mounatin of water struck us amidships. It picked me right off my feet, and hurled me clean through the rigging, and flattened me against the mast, whence I fell into the maintop. The rest of what happened I discovered after my recovery. The wave took off every strip of rigging and canvas, all the yards, boats, and arms, and left the ship with only her masts standing.' The brig which had been lying to leeward had been stripped clean to the deck, masts and all---as clean as if an army of carpenters had been at work. The watch had been swept overboard, and every man of them lost. A sea wave such as this is as distinct from the sea waves ordinarily encountered as a cyclone from an ordinary wind storm." (R3)

X18. No date given. North Atlantic Ocean.



Tanker encountering a giant wave off the African Coast (X16)

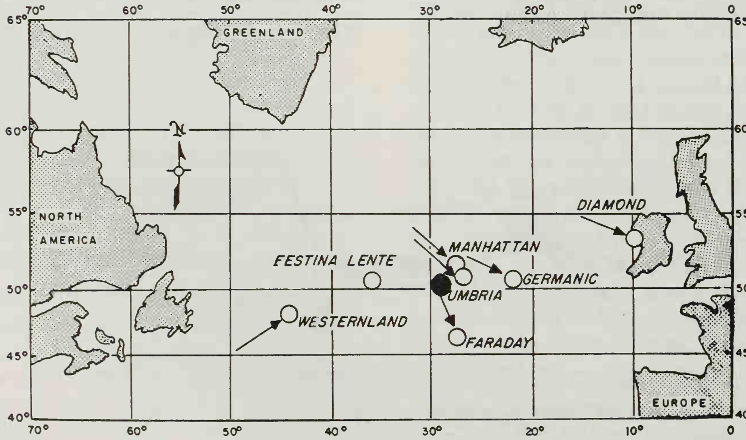
The S. S. Rheinland was temporarily submerged by a solitary wave. Only the funnel and masts could be seen. (R7)

X19. Mathematical analysis of the frequency of occurrence of giant waves. "Although such events happen only rarely, this does not mean that their likelihood of occurrence is not predictable. There are two aspects of this problem. One concerns what happens on a sea when a large number of wave components each with its own period and height, are traveling along together at slightly different, but constant, speeds. As the components continually get into and out of step with each other they produce groups of high waves followed by brief intervals of relatively quiet water which are characteristic of all sea waves. Every now and then, just by chance, it so happens that a large number of these components get into step at the same place and an exceptionally high wave ensues. The life of such a wave is only a transient one, being not much more than a minute or two. . . . the probability of occurrence of any such wave is finite and can be predicted; its calculation has the apparently contradictory title of Statistics of a Stationary Random Process. Using this theory, it has been shown that whilst one wave in 23 is over twice the height of the average wave, and one in 1,175 is over three times the average height only one in over 300,000 exceeds four times the average height." (R8, R9, R14) Of course this theory cannot satisfactorily explain the appearance of large solitary waves on a relatively calm sea. (WRC)

X20. Analysis of abnormal waves in the North Atlantic. After studying the locations where eight giant waves were encountered, the ships' courses and speeds, and the directions of the waves, the author suggested that the Faraday Reef, located in the central North Atlantic, may help create these waves. (R4)

X21. Analysis of abnormal waves in the North Atlantic and North Pacific. Unique heavy sea phenomena may be created in the vicinity of submarine canyons when the length of the waves are of the same magnitude as the water depth. (R12)

X22. March 31, 1883. English Channel. "The Weymouth and Channel Islands Steam Packet Company's mail steamer Aquila left Weymouth at midnight on Friday for Guernsey and Jersey on her passage across Channel. The weather was calm and clear, and the sea was smooth. When about one hour out the steamer was struck violently by mountainous seas, which sent her on her beam ends and swept her decks from stem to stern. The water immediately flooded the cabins and engine room, entering through the skylights, the thick glass of which was smashed. As the decks became clear of water, the bulwarks were found to be broken in several places, one of the paddle-boxes was considerably damaged, the iron rail of the bridge was completely twisted, the pump was broken and rendered useless, the skylight of the ladies' cabin was completely gone, and the saloon skylight was smashed



Locations of eight ships that encountered giant solitary waves in the North Atlantic (X20) to atoms.... Five minutes after the waves had struck the steamer the sea became perfectly calm." (R17, R18)

X23. September 1943. North Atlantic Ocean. "In September 1943, the Queen Elizabeth, sailing across the Atlantic as a troopship, was hit by one of these 'freak' waves off Greenland. One witness on the bridge said that the giant ship was lifted out of the water like a toy and thrown deep into a wave. Fittings and equipment attached on the forecastle were torn off and thrown against the bridge, smashing every glass pane." (R20)

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R22. Swetnam, D. M.; "Freak Waves," Marine Observer, 49:12, 1979. (X16)

GHW2 Periodic Bands of Waves

Description. Moving, periodically appearing packets of white-capped waves or choppy water. The intensity of the phenomenon varies from place to place. In its best-developed form, as seen in the Andaman and Sulu Seas, the waves in the packets may be several feet high and announce their coming as an advancing white line on the horizon and an increasing roar. Satellite photographs and radar imagery reveal that these bands may stretch for hundreds of kilometers. Each packet consists of several bands a few hundred meters wide, separated by several hundred meters. The packets themselves recur at the local tidal frequency; that is, semidiurnally in most places.

Background. Deep-sea sailors have frequently remarked these unexpected seething bands of water, often neatly raised a few feet above the general ocean level, calling them "tidal rips."

Data Evaluation. Records of periodic bands of waves go back almost 200 years, and they are frequently discerned on satellite photos. Rating: 1.

Anomaly Evaluation. These regularly appearing, travelling disturbances are thought to be surface manifestations of internal waves or "solitons," which though well-described theoretically have been little-explored in the natural world. Even if internal waves are the correct explanation of wave bands, some mechanism for periodically generating solitons must be found. Here, too, likely candidates exist (see below). In sum, then, this rather spectacular phenomenon is only mildly mysterious. Rating: 3.

Possible Explanations. Internal waves or solitons initiated when the surge of tidal water encounters continental shelves and/or submarine canyons incised in the shelves. It is also possible that sea mounts and other submerged structures may contribute.

Similar and Related Phenomena. Slicks and calms (GHC2) may be the surface manifestations of internal waves in small, shallow bodies of water; the "crazy tides" of Palawan Island in the Sulu Sea (GHS2-X11); the huge waves common along the south east coast of Africa, to which internal waves established by the continental shelf may contribute (GHW1).

Examples of Periodic Bands of Waves

X1. 1814. Strait of Malacca, South Pacific Ocean. "In his Majesty's ship Minden, in 1814, a number of singular Ripples were observed between the north end of Sumatra and the Nicobar Islands; and also between that line and Pulo Penang, or Prince of Wales' Island. None of these islands, however, were in sight; and there were no soundings. These ripples varied from two to five miles in length, and from two to four hundred yards in breadth: their direction was nearly north and south; they were always first descried in the west, or southwest; from that quarter they approached and passed the ship, and then went off to the east or north-east. In their general appearance they resembled the waves of the sea breaking on a shallow sandy shore. The waves forming the ripple, did not tumble against one another irregularly, but curled and broke in the direction towards which the whole ripple was advancing. When the sea breaks on a sandy beach, and forms what is called Surf, the waves stretch along parallel to the shore, and when they break, roll in upon it, one after the other; but in these ripples, the waves were not so continuous, and, when they broke, the water, instead of rolling along like surf, splashed up perpendicularly to a considerable height. Some of the ripples were very gentle, so that the surface of the sea was scarcely whitened by them, their approach being indicated only by a faint noise. Others were heard several miles off, and advanced towards the ship, boiling and foaming in an extraordinary manner. Some of them not only dashed the water many feet up the side, but actually shook the ship in a very sensible degree.

As we approached the line joining the north end of Sumatra and the Nicobar Islands, the ripples became more frequent and more violent. During the 5th of September, one passed the ship about every quarter of an hour. The wind at this time was between north-east and east, very light and variable, and sometimes calm; which rendered the effect of these ripples during the stillness of the night not a little striking. At first, a low hollow sound was heard, like that caused by a surf on a distant coast: it gradually became louder and louder; till at length a long foaming streak was discovered advancing rapidly towards the ship, which it soon surrounded, and then all was noise and commotion. This lasted for a few minutes, when the ripple moved past to the north-east, its sound becoming fainter and fainter; and it occurred often, that just as one ceased to be heard, another was perceived, and so on during all the night.....During one evening the following curious phenomenon was observed. Whenever the ship entered one of the ripples, the wind immediately freshened, and at the same time changed its apparent direction; but, upon quitting the ripple, the wind invariably resumed its original velocity and direction." (R1)

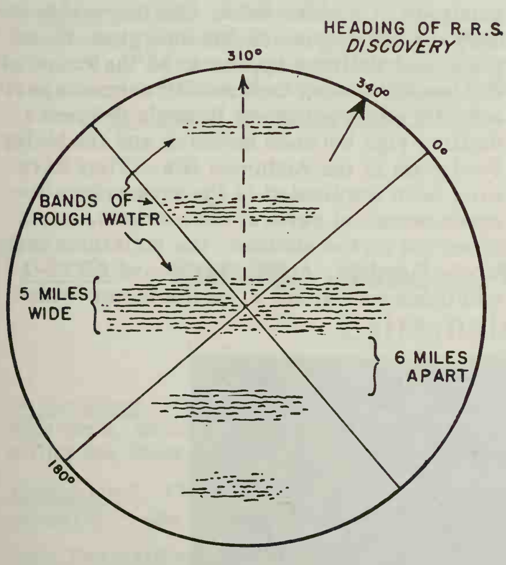
X2. December 29, 1884. North Atlantic Ocean. "The commander of the British steamship Bulgarian reports that on Dec. 29, in latitude 49° north, longitude 34°30' west, at two P. M., while the sea was smooth and the wind moderate from the south and west, he ran through a regular bore. The water boiled and seethed. The surface of the bore was about two feet above the general level of the ocean, and its extent about six miles long and from three to five miles wide, moving to the north-east. This is a very unusual phenomenon for such a place." (R2)

X3. July 27, 1961. Red Sea, Indian Ocean. "At 1930 GMT the wind veered from 330° to 060° and increased to force 4; the air temp.

dropped from 89°F to 86° and a shower was seen near the ship. A sudden swell, 5 ft. in height, came in from 300° with a period of 5 sec. It arrived in four or five lines at a time, then died down for about 30 sec to 1 min., after which interval it moved in again. This cycle kept repeating, though with decreasing height of waves, until 2120." (R4)

X4. March 1963. Andaman Sea, Indian Ocean. "Alternate bands of rough and smooth water passed the R. V. Anton Brun at four oceanographic stations in the Andaman Sea in March 1963 while that ship was operating under the National Science Foundation Program in Biology for the International Indian Ocean Expedition. At one of these stations a low roar accompanied by breaking whitecaps was observed as the bands passed the ship in a flat calm sea." (R6)

X5. March 28, 1964. Indian Ocean. "1930-2000 GMT. Bands of breaking waves of height 2 ft and period 1 sec, about 1/2 mile in width and 6 miles apart were observed by radar, heading in a 310° direction. When the bands passed the ship, which was hove-to, the wind did not change in direction or



Groups of waves detected on radar (X5)

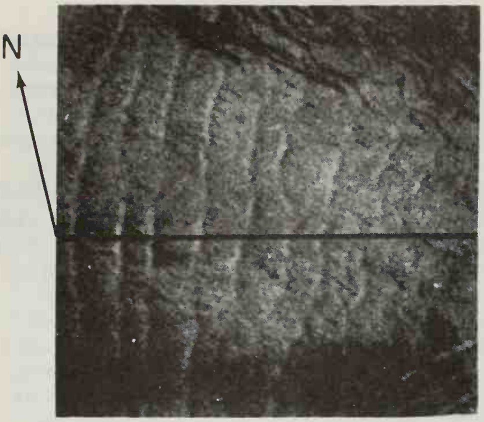
increase in force. The swell died down completely. There were five bands in all; the first and last being comparatively weak while the middle one was the strongest. They had the appearance of waves breaking on a flat sandy shore." (R5)

X6. June 12-13, 1964. North of Sumatra, North Pacific Ocean. "On the morning of June 12, 1964, distinct zones of whitecaps ranging from 200 to 800 m in width and stretching from horizon to horizon (approximately 30 km) in a north-south direction were observed in the Andaman Sea north of Sumatra. At least five of these zones, with a spacing of about 3200 m between each zone, were observed. The observed zones or bands of choppy water had short, steep, randomly oriented waves with heights of about 0.3 to 0.6 m. Each band stood out distinctly in an otherwise undisturbed sea. A 4-m/sec NNW wind and a surface water temperature of 29°C were observed, but neither changed significantly as the ship crossed the bands of choppy water. Detailed salinity measurements were not made while crossing the bands; however, routine bi-hourly salinity samples showed a maximum regional salinity gradient of 0.03% per km. Later in the day, several other bands of similar dimensions, but having smaller waves, were observed.

On June 13, similar north-south trending bands of choppy water were seen farther to the west in the Great Channel, near 06°09'N, 94°37'E. Ten bands, each approximately 200 m wide and 800 m apart, were observed. In some instances, the water between the bands of choppy water had a slicked appearance despite a 9-m/sec SSW wind. Similar slicks were not apparent on the preceding day when the bands of choppy water were farther apart. Boundaries of the choppy water were all well defined.....The bands were computed to be moving eastward at 2.6 m/sec." Bathythermograph records indicated that internal waves with maximum heights of 82 meters were the probable cause of the surface disturbances. (R6)

X7. July 24, 1973. New York Bight, North Atlantic Ocean. Images taken by Landsat-1 show wave packets, convex in the direction of propagation, with wavelengths on the order of 500 meters and periods of 15 minutes. Amplitudes are 5-10 meters. Similar waves have been recorded from space at a wide variety of locations all around the world. They are believed to result from internal waves excited by tidal action at the edges of the continental shelves. (R8, R15)

X8. August 15, 1975. Alaskan coast, North Pacific Ocean. Periodic striations recorded by synthetic aperture radar on an aircraft. The leading wavelengths were about 500 meters, decreasing to 120



Internal waves 1 kilometer apart photographed off New York by a satellite (X7)

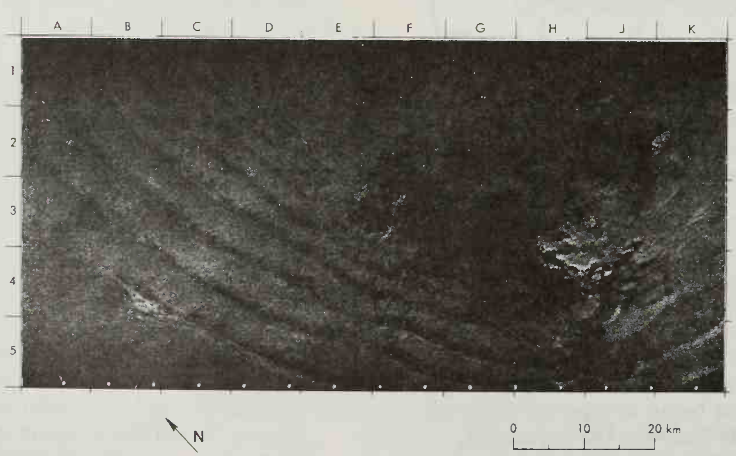
meters at the rear of the packet. Crest lengths ranged up to 10 kilometers. The packets were separated by about 2 kilometers. The bands were located about 5 kilometers inshore from a 300-meter-deep submarine canyon. (R8, R9)

X9. Circa 1939. Gulf of California, North Pacific Ocean. Data from 50 oceanographic stations revealed internal waves about 65 feet in amplitude, with periods between 6 and 7.5 days. (R3)

X10. No date given. Australian waters, South Pacific Ocean. Observations from an aircraft revealed whitecaps being formed sporadically---the interval between the appearance of successive whitecaps was 8-10 seconds. (R7)

X11. No date given. North Atlantic Ocean. From shipboard, whitecaps were seen to form about every 12.2 seconds, whereas the period of the larger waves was only 8.7 seconds. (R7)

X12. Permanent features. Andaman Sea, Indian Ocean, and Sulu Sea, North Pacific Ocean. "Peculiar striations more than a hundred kilometers long, visible on satellite pictures of the surface of the Andaman and Sulu Seas in the Far East, appear to be of interest in fields as far removed from oceanography as quantum field theory. A recent report of underwater current and temperature variations associated with such surface phenomena in the Andaman Sea, by Alfred Osborne, a physicist at Exxon Production Research (Houston), and Terrence Burch, an oceanographer with EG&G Environmental Consultants (Waltham, Mass.), suggests that these striations mark the propagation of 'solitons,' exotic solutions of nonlinear wave equations that have captured the interest of mathematical physicists studying a broad range of phenomena spanning 22 orders of magnitude in size. The surface striations seen in the satellite pictures are interpreted as secondary phenomena that accompany the passage of 'internal solitons,' solitary wavelike distortions of the boundary between the warm upper layer of sea water and the cold lower depths. These internal solitons are traveling ridges of warm water extending downward hundreds of meters below this thermal boundary. Carrying enormous energies, these presumed solitons appear to be the cause of the usually strong underwater currents periodically experienced by Exxon's deep-sea drilling rigs between Sumatra and the Malay Peninsula in the Andaman Sea. They have even been implicated in the mysterious disappearances of several submarines.... As observed on the surface, the striations seen by the Landsat, Apollo-Soyuz and ERTS-1 satellites turned out to be kilometer-wide



Internal wave train in the Andaman Sea as seen by a satellite (X12) bands of extremely choppy water stretching from horizon to horizon, followed by about two kilometers of water 'as smooth as a millpond.' These striking bands of agitated water are called 'tide rips,' because seamen who have observed them in the past erroneoudly took them to indicate tidal movement over uncharted shoals. The tide rips reached the research vessel at intervals of about an hour (corresponding to spacings of 5 to 10 km), until a packet of 4 to 8 such bands had passed. This spectacle repeated itself with the regularity of the semidiurnal tidal period." (R12) Several other reports cover this research in the Andaman and Sulu Seas. (R10, R11, R13, R14)

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GHW3 Sudden, Unexpected Onset of Extremely High Surf

Description. The sudden arrival of extremely high waves during calm, fair weather. Such high seas, unannounced by any winds or bad storms within hundreds of miles, frequently afflict the West Indies, western South America, and India.

Background. The absence of any warning makes these sea surges very dangerous to life and property---one minute all is calm, the next minute immense waves hit the shores.

Data Evaluation. Several scientific accounts of this phenomenon have been found, as well as some attempts to correlate the high surf with intense storms thousands of miles away. Rating: 1.

Anomaly Evaluation. Some episodes of unexpected high surf have been positively correlated with very distant severe storms; other events have not been connected with any specific meteorological disturbance. Since ocean weather is not well-mapped, it is quite possible that all unannounced sea surges may be attributable to distant storms. For this reason, a low anomaly rating is reasonable. Rating: 4.

Possible Explanations. Distant, severe storms.

Similar and Related Phenomena. Earthquake-caused tsunamis, which usually involve just a few large waves rather than hours of high surf; giant solitary waves (GHW1).

Examples of the Sudden, Unexpected Onset of Extremely High Surf

X1. December 2-3, 1951. Puerto Rico and Barbados, North Atlantic Ocean. "On December 2-3, 1951, very rough surf occurred along the northern coast of Puerto Rico and the western coast of Barbados. Again, on December 5, 1951, heavy seas pounded the western coast of Barbados. During the morning of December 2, 1951, the seas were calm along the northern Puerto Rican coast; but shortly after noon a rapid agitation of the seas was noticeable, and by 3 p.m. local time mountainous waves lashed the coasts. The entire day was calm and sunny, and the mildness of the weather contrasted impressively with the wildness of the seas. Similar calm weather prevailed during the high seas in Barbados. In both islands there was considerable damage to houses, roads and small fishing craft." (R2)

X2. August 17, 1952. Near Puerto Rico, North Atlantic Ocean. "On August 17, 1952, I was marooned for twelve hours on the small, uninhabited island of Desecheo, some fifteen miles off the northwest coast of Puerto Rico. Suddenly, at about 4:30 p.m. local time, the sea withdrew along the western coast, sea-level being lowered perhaps 10 ft. There was a dull, muffled sound, followed by a remarkably rapid churning of the seas towards the west-northwest. Three hours later, seas were still very high, and it was next morning before I could be brought from the island. It was very warm, sunny and balmy all day. Later, it was discovered that rough seas had occurred along both coasts of Mona Passage." (R2)

X3. December 3-4, 1952. Barbados. High surf, as in X1 and X2. In all cases (X1-X3) seismological records and weather maps of both the North and South Atlantic were examined for clues to the high surf. Apparently there were no quakes or distant storms that could be blamed. (R2)

X4. April 4-6, 1958. Barbados, North Atlantic Ocean. High surf, severe sea surge. (R3)

X5. October 24-28, 1958. Barbados, North Atlantic Ocean. Severe sea surge, Both X4 and X5 were correlated with storms in the North Atlantic. (R3)

X6. June 1960. New York and New Jersey shores. "With virtually no warning at all, freakish tides and fourteen feet high waves tore at the Atlantic beaches of Long Island and New Jersey early in June, 1960. Great areas were inundated and, when the waters retreated, they carried much sand and soil with them, leaving vistas of miniature hills and valleys along the shore. Fortunately, lifeguards were able to clear the beaches in time, so no lives were lost during this period." Waves attributed to distant storms. (R4)

X7. July 25-26, 1968. Valparaiso, Chile. "Suddenly and without warning, tidal waves 15 to 18 feet tall rolled into the Chilean coastline near the capital city of Valparaiso on July 25 and 26. The huge waves were apparently caused by a sea surge far offshore. Although much coastal property and many ships were damaged, there were no personal injuries reported. The question that needed answering, however, was what caused the sea surge? Some reports indicated the waves were associated with seismic phenomena; other theories attributed the waves to a storm far out at sea. Today, however, their origin remains a mystery." (R5)

X8. General observations. Saint Helena, South Atlantic Ocean. Sudden onsets of heavy swell at St. Helena may be due to distant storms. (R6)

X9. General observations. Ceylon and India are often subjected to huge rollers from Indian Ocean storms. (R9)

X10. General observations. West coast of South America. Long history of heavy "surf days." (R9)

X11. General observations. East coast of South America. High, episodic surf called "resacas." (R9)

X12. General observations. West coast of Ireland. "Death waves" supposed the precursors of storms. (R1)

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GHW4 Downstream Progressive Waves in Rivers

Description. Walls of water several feet high that advance rapidly downstream in shallow rivers. The phenomenon occurs in rivers subject to sudden influxes of water due to heavy rains upstream. The progressive wave, however, travels much faster than the flood waters themselves.

Background. Progressive waves moving downstream are analogous to tidal bores moving upstream.

Data Evaluation. An occasional phenomenon in several shallow rivers, but literature on the subject is almost nonexistent. Rating: 2.

Anomaly Evaluation. Wave theory adequately explains this phenomenon; and it is included only for its novelty. Rating: 4.

Possible Explanations. Downstream bores are gravitational waves that outrun the surge of flood waters into shallow streams.

Similar and Related Phenomena. Tidal bores (GHS3).

Examples of Downstream Progressive Waves in Rivers

X1. General observations. "When the upper reaches of a river are swollen by rains, room is made for the flood by the gravitational rise of the water farther down-stream. As in deep rivers the rate of propagation of a long wave is many times greater than the velocity of flow, the effect of this wave-transmission is to diminish the initial inequality of slope caused by the rain-water, and no wave is visible. The fact that in the lower reaches the level of the river rises before the arrival of turbid waters, alone attests the fact that flood-water has caused a progressive wave. In certain rivers, however, of small depth (therefore propagating a wave slowly) and subject to sudden accessions from swollen tributaries, the 'first rise' of water in the lower reaches frequently takes the form of a steep-fronted wave, or bore, travelling downstream. On the Tees the phenomenon is called a roll-wave. Mr. F.R. Glyn, F.R.G.S., from whom I first received an account of the phenomenon, describes it as 2 or 3 feet high, reaching from bank to bank. He observed it on no less than six occasions during the course of one summer and autumn. It is a source of considerable danger to anglers, coming as it does wholly without warning and travelling at a considerable speed, viz. the speed of the stream plus the speed of a long wave in water of the actual depth. A similar wave is known at Aysgarth on the Ure, which has also been described to me by an eye-witness as '2 or 3 feet high.' ....On the Swale, the roll-wave just above Richmond (Yorks.) has been described to me by an eye-witness as apparently about 4 feet high. The upper portion of the Tyne is also subject to these waves. Roll waves are said to be known also on the river Wye as a sequel of rains in the upper reaches, and in the rivers among the foothills of the Himalayas they are not uncommon." (R1)

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THE STRANGE PHENOMENA OF EARTHQUAKES

A sensory channel most humans find hard to ignore is that of physical motion; a category that includes shock, vibration, and gross physical motion. Short, sharp shocks are sensed kinesthetically, like bumps on a highway. The frequent tilting effects of earthquakes, though, disturb one's sense of balance and induce disorientation. Whatever the mode of detection, the onset of physical motion of the earth's crust signals the existence of powerful local forces and thus the possibility of a variety of strange phenomena.

The physical motion accompanying an earthquake should not occupy all of our attention here. Rather, it is the remarkable spectrum of parallel events occurring before, during, and after the quake proper that makes up most of this section of the Catalog of Anomalies. The entries fall into two main categories: (1) Those phenomena that are apparently caused by the earthquake, such as the expulsion of solids from the crust; and (2) Those external forces that seem to affect earthquake frequency, such as solar activity. The mysteries, then, are not the shock and heaving of the quake itself, but rather the curious effects and correlates that surround the event in time and place.

A major earthquake disrupts the balance of terrestrial forces from deep in the rocky mantle to high in the ionosphere. As the earth's surface vibrates---not unlike the skin of a drum---great sea waves (tsunamis) and atmospheric pressure waves spread out rapidly from the epicenter. The sea waves may travel 10,000 miles, while the air waves may penetrate into the charged layers of the ionosphere, upsetting terrestrial communications. A truly great quake is felt globally.

Near the epicenters of big earthquakes, unusual phenomena abound. Loud groans, explosions, and grinding noises are emitted by the rending strata. Less common are flames issuing from the ground, moving lights and sky glows. These "earthquake lights" have already been cataloged (GLD8), but miscellaneous electromagnetic effects are included here. The same pressures within the crust that generate piezoelectricity force up geysers of hot water, sand, and even coal.

Scientists have long been intrigued by the apparent ability of many animals to sense the coming of an earthquake long before humans hear the grating roars and feel the heaving ground. In Japan and China, fish, pheasants, and other animals are valued for their ability to detect earthquake precursors. Exactly how they do this is still a matter of conjecture.

Some people still swear that "earthquake weather" exists, even though most of the greatest quakes were not preceded by the hot, sultry forboding calm that legend tells us presages a big convulsion. Still, there are startling correlations between earthquakes, heavy rainfall, fogs, wind gusts, and other weather phenomena. It is understandable how the dust raised by an earthquake might increase rainfall and how ionized aerosols squeezed out of the crust might lead to the condensation of fog, but cause-and-effect relationships between quakes and other weather phenomena are harder to discern.

Many other earthquake-related phenomena have been observed, as the following pages will demonstrate. Large earthquakes release so much energy that almost all geophysical parameters are shaken a bit.

GQB ANIMAL RESPONSE TO EARTHQUAKE PRECURSORS

Key to Phenomena

GQB0 Introduction

Many animals and, to a lesser extent, humans seem to be capable of sensing some earthquake precursors, such as minor ground movements, released gases, and changes in electrostatic and electromagnetic fields. Actually, the only reason for supposing that precursors may be sensed is that animals occasionally behave in strange ways prior to quakes and a few humans claim to experience vague sensations before and during the shocks. So prevalent are the stories of unusual animal behavior that some scientists, particularly in China, have considered employing them as earthquake predictors, along with more conventional physical measurements. Despite this increased interest, the exact nature of the precursors and the means by which they are sensed are matters of conjecture.

GQB1 Anomalous Animal Activity before Earthquakes

Description. General animal restlessness and unusual behavior prior to earthquakes. The range of observed anomalies is immense, involving many facets of behavior; such as fear, agitation, and vocal sounds. Mammals, birds, insects, and fish are among the life forms indulging in abnormal prequake activity. Dogs bark and howl, cats leave their homes, horses refuse to proceed or kick down their stalls, birds desert the epicenter-to-be, etc. Abnormal behavior usually precedes the quake by only a few minutes or hours, although lead times of a few days have been reported.

Background. Even the ancients recorded anomalous animal activities prior to earthquakes; and the phenomenon is well-established in folklore. Evidently humans cannot discern the precursors that animals apparently can. Although a certain human irritability before earthquakes has been claimed---sensations analogous to those associated with the foehn and other hot, dry winds.

Data Evaluation. Reports of this phenomenon are rather common, even in the scientific literature, particularly in the late 1970s. The reports, however, are almost all after-the-fact testimonies and hgihly suspect. Almost every convulsion of nature brings forth stories of how this or that animal behaved strangely just before the event---all in retrospect. In recent years, observer networks have been established in quake-prone areas, especially in China, where the subject is taken more seriously. Special interview techniques have also been developed. Even with more scientific approaches, abnormal animal behavior prior to earthquakes continues to be reported. Rating: 2.

Anomaly Evaluation. It is recognized that animals in general have more acute senses than humans. The anomaly here is that we have not been able to identify what, if anything, the affected animals are detecting. If it is simply a matter of supersensitivity to sound or smell, the anomaly is a minor one. The sensing of electromagnetic forces would be somewhat more interesting to the anomalist. If an unrecognized sensory channel is involved, we would have a first-class anomaly. No one knows at present. Rating: 2.

Possible Explanations. Animals detect precursor sounds and/or vibrations, or gases (possibly electrically charged) emitted from the earth, or electromagnetic forces.

Similar and Related Phenomena. Human malaise and irritability due to foehns, infrasonic waves, and the so-called "earthquake weather." Electromagnetic navigational capabilities of animals, including humans (B).

Examples of Anomalous Animal Activity Prior to Earthquakes

X1. 373 BC. Helice, Greece. "The idea that animals panic before earthquakes goes back at least as far as recorded history. The first precise description dates from 373 B.C. and concerns the city of Helice, in Achaia, the region of ancient Greece bordering the Gulf of Corinth. Helice was struck that year by an especially violent earthquake and was swallowed forever by the sea. Five days before, the historian Diodorus, whose works are based partly on authors now lost, reports that animals there, including rats, snakes, weasels, centipedes, worms, and beetles, migrated in droves along the connecting road toward the city of Koria." (R9, R31)

X2. March 19, 1750. London area, England. Dogs howled and fish threw themselves out of the water. (R2)

X3. February 5, 1783. Messina, Italy. Geese cackled; dogs howled so unbearably that they had to be shot. (R9, R23)

X4. 1805. Naples, Italy. "In the Neapolitan earthquake of 1805, these anticipatory signs were most remarkable in relation to the life of the animal world. An Italian writer, quoted in Mr. Wittich's 'Curiosities of Physical Geography,' says: 'I must not omit in this place to mention those prognostics which were derived from animals. They were observed in every place where the shocks were such as to be generally perceptible. Some minutes before they were felt, the oxen and cows began to bellow, the sheep and goats bleated, and, rushing in confusion one on the other, tried to break the wicker-work of the folds; the dogs howled terribly, the geese and fowls were alarmed and made much noise; the horses which were fastened in their stalls were greatly agitated, leaped up, and tried to break the halters with which they were attached to the mangers; those which were proceeding on the roads suddenly stopped, and snorted in a very strange way. The cats were frightened, and tried to conceal themselves, or their hair bristled up wildly. Rabbits and moles were seen to leave their holes; birds rose, as if scared, from the places on which they had alighted; and fish left the bottom of the sea and approached the shores, where at some places great numbers of them were taken. Even ants and reptiles abandoned, in clear daylight, their subterranean holes in great disorder, many hours before the shocks were felt. Large flights of locusts were seen creeping through the streets of Naples toward the sea the night before the earthquake. Winged ants took refuge during the darkness in the rooms of houses. Some dogs, a few minutes before the first shock took place, awoke their sleeping masters, by barking and pulling them, as if they wished to warn them of the impending danger, and several persons were thus enabled to save themselves.'" (R3, R4, R9) The foregoing anecdotal evidence is rather typical of this phenomenon before specific observation networks and interview techniques were established. (WRC)

X5. November 1812. Kentucky. From Audubon's journals. "I was jogging on one afternoon, when I remarked a sudden and strange darkness rising from the western horizon. Accustomed to our heavy storms of thunder and rain I took no more notice of it, as I thought the speed of my horse might enable me to get under shelter of the roof of an acquaintance, who lived not far distant, before it should come up. I had proceeded about a mile, when I heard what I imagined to be the distant rumble of a violent tornado, on which I spurred my steed, with a wish to gallop as fast as possible to a place of shelter; but it would not do, the animal knew better than I what was forthcoming, and instead of going faster, so nearly stopped that I remarked he placed one foot after another on the ground, with as much precaution as if walking on a smooth sheet of ice. I thought he had suddenly foundered, and, speaking to him, was on the point of dismounting and leading him, when he all of a sudden fell a-groaning piteously, hung his head, spread out his four legs as if to save himself from falling, and stood stock still, continuing to groan. I thought my horse was about to die, and would have sprung from his back had a minute more elapsed, but at that instant all the shrubs and trees began to move from their very roots, the ground rose and fell in successive furrows, like the ruffled waters of a lake, and I became bewildered in my ideas, as I too plainly discovered that all this awful commotion in nature was the result of an earthquake..... The fearful convulsion, however, lasted only a few minutes, and the heavens again brightened as quickly as they had become obscured; my horse brought his feet to their natural position, raised his head, and galloped off as if loose and frollicking without a rider." (R8) This quake was one of the early ones in the catastrophic New Madrid series. (WRC)

X6. February 20, 1835. Concepcion and Talcahuana, Chile. "It was towards noon, beneath a clear and almost cloudless sky, with the sea-breeze freshly blowing; that the cities of Conception and Talcahuana, on the coast of South-America, were desolated in the year 1835. At ten o'clock, two hours before their ruin, the inhabitants remarked with surprise, as altogether unusual, large flights of sea-fowl passing from the coast towards the interior; and the dogs at Talcahuana abandoned the town before the shock which leveled its buildings was felt. Not an animal, it is believed, was in the place when the destruction came." (R3, R5, R6, R9, R23)

X7. October 18, 1844. Peru. Before the shock, dogs began to bark, and beasts of burden steadied themselves. (R1)

X8. November 11, 1855. Tokyo, Japan. Wild cats cried; rats disappeared. (R23)

X9. 1880. Tokyo, Japan. Cats tried to escape from houses; foxes barked; horses tried to kick down their stalls. (R5, R6)

X10. February 23, 1887. Italy. "The largest collection of these reports bearing on the reactions of animals can be found in 'The Ligurian Earthquake of February 23, 1887,' written by Mercalli and Torquato Taramelli. Under the heading 'Physiological Phenomena in Animals,' the following information appears: 'In more than 130 localities, as far as it is known to us, a condition of unrest and fear among domestic animals was noted which expressed itself in unusual cries, restlessness, flying by fowl, attempts to flee into the open, etc., generally a few minutes before the earthquake.' Among the two dozen detailed reports are five that mention expressly that the paniclike reactions of the animals were observed only a few seconds before the earthquake." (R31)

X11. April 18, 1906. San Francisco, California. Dogs barked the night before. A few seconds before the shock, horses and cows snorted and stampeded. (R23)

X12. October 20, 1907. Karatagh, central Asia. The evening before, dogs howled, cattle bellowed with fright, horses stampeded. (R9)

X13. July 3, 1910. Landsberg, Germany. Two minutes before the quake, all bees left their hives in excitement and returned 15 minutes later. (R23)

X14. March 3, 1933. Sanriku, Japan. One week before the shock, all rats disappeared; 2-3 days before, rats and cats were unusually quiet (?); a day before, seagulls left their usual habitat; several hours before, a duck avoided its usual sleeping place. (R23) Obviously, such "soft" data cannot be of much help. (WRC)

X15. March 10, 1933. Long Beach, California. A flock of Brewers blackbirds became uneasy before the quake. (R13)

X16. 1966. Hopei Province, China. Before the magnitude 6.8 quake, all the dogs near the epicenter deserted their kennels and thus survived. (R24)

X17. 1966. Tashkent, Russia. An hour before the quake, there was a mass migration of ants carrying their eggs. (R14)

X18. July 18, 1969. Tientsin, China. "Unusual behavior was observed in seagulls, sharks, and five species of fish in the sea a few days before the magnitude 7.4 earthquake in the Pohai Sea on July 18, 1969. Advance warning was issued by the Tientsin

People's Park based on the variations in behavior of the zoo's Manchurian tigers, giant pandas, yaks, deer, loaches, and other animals. Two hours later the earthquake struck." (R23, R24). Note that rural peoples are much more sensitive to the behavior of wild and domestic animals than inhabitants of industrialized areas. (WRC)

X19. February 4, 1975. Haicheng, China. "Some instances noted at this time (before the earthquake) were of snakes being found frozen on the road....geese flying, chickens refusing to enter their coop, pigs rooting at their fence, cows breaking their halters and escaping, and goats as well as cows being unusually restless. Rats appeared to behave as though drunk. Three well-trained police dogs howled, refused to obey commands, and kept their noses close to the ground as though sniffing." (R16, R20, R26) "In the Anshan city park aviary, there were over 100 birds. Many of them picked up their eggs and flew out of their nests. While they were flying their eggs fell and smashed.... A dog had given birth to puppies earlier in the day. After 1700, the mother picked up the puppies in her mouth and ran outside with them. She had to hit against the door twice to get it open. The owner thought that this was strange and immediately remembered the announcement of the earthquake prediction. He went outside and the earthquake occurred 4 or 5 minutes later." (R33)

X20. June 1975. Stanford, California. "Acting on a suggestion by Bruce Smith of the US Geological Survey Drs Kraemer and Levine analysed the course of chimpanzee behavior at the Stanford Outdoor Primate Facility before and after 25 minor earthquakes which, Smith told them, had occurred in the vicinity between 19 June and 24 June. The Stanford researchers found that the chimps' behavior changed on the days before two of the largest earthquakes in this period. One took place 19 June and registered 3.1 on the Richter scale. The other earthquake occurred 24 June and measured 2.0. The chimps were restless and spent more time on the ground than usual. The changes were 'so significant it seems unlikely they were due to chance' said Dr. Kraemer." (R15, R18, R23)

X21. 1975. Oroville, California. Magnitude 6.0. Many accounts of anomalous behavior of farm animals from minutes to weeks before the event. (R20)

X22. May 6, 1976. Friuli, Italy. "The most remarkable animal behavior effects (the quake occurred at 2100 LT) were the following. Deer formed flocks---in the late afternoon, a flock of 15 deer came down from the mountains and close to the village, crowding together with apparently no interest in grazing---an event never before seen in this area. Cats left the houses and the village---at the time of the quake no cat was apparently left in the village. They did not return until two days later (there were many aftershocks). In three cases, cats dragged kittens outdoors and bedded them in green vegetation. Before fleeing from an apartment a cat was seen to move its ears convulsively for some time. Mice and rats left their hiding places---on one farm mice and rats were observed running around before the quake. People were annoyed and surprised as all their five cats were missing. Fowls refused to roost a few hours before the quake. People fleeing from their houses during the quake found their fowl already scattered in the garden. The animals had apparently forced their way out from the pen before the disaster. On one farm, several minutes before the quake, the fowl made such a noise that farmers thought a fox had entered the chicken house. Cattle panicked in their barns---according to many reports, cattle showed clear signs of fear 15-20 minutes before the quake. The animals started to bellow, tear at their chains and paw their boxes. Dogs barked without apparent reason. This behavior started 20 min before the quake.....Birds emitted calls at unusual times---one person heard a cuckoo, never normally heard at night. Caged birds started to fly---in six places people observed that 10-15 min before the earthquake birds became restless and occasionally emitted calls. Then they began to beat their wings and finally started to fly." One canary kept wetting its plumage. (R20, R21, R23, R31)

X23. July 28, 1976. Tangshan, China. Chinese scientists collected 2,093 reports of unusual animal behavior preceding this devasting quake. "Some of the observations involved goats that did not want to enter their stables, cats or dogs that hauled their young into the open, pigs that squealed strangely, excited chickens that fled from their roosts in the middle of the night, rats that left their nests, and fish that flitted around in the water." (R24, R31)

X24. November 24, 1976. Turkey. Before the quake, widespread barking and howling of dogs. (R17)

X25. November 22, 1977. Willits, California. "Abstract. Following two moderate earthquakes, reports of the behavior of animals prior to the earthquakes were gathered using a standardized interview schedule. This schedule was developed to maximize the reliability and validity of the reports through application of accepted social science methodology. Interviews with 50 households near Willits, California, produced 17 reports of unusual animal behavior prior to that earthquake. Only one of the thiry-five interviewees who experienced a similar earthquake near Ovando, Montana, reported unusual animal behavior prior to the earthquake. The difference in the frequency of positive reports and the content of the positive reports from Willits support the inference that a number of animals at Willits were responding to physical precursors which were absent at Ovando. The behavior reported at Willits was unusual in the sense that there was no immediate explanation for it, but it was not bizarre. On the contrary, it was always behavior typical of that species when motivated by general anxiety. Unusual behavior was often reported on only one or a few animals at a particular location so that even at Willits most animals were described as having behaved normally." A later paragraph in R25 was more specific. "The following instances of species-specific anxiety reactions are among the reports of unusual behavior recorded at Willits. A normally calm Arabian gelding was found kicking at the sides of its box stall approximately 3 hours before the earthquake. After attempting to quiet the horse, the owner released it into a paddock where it continued to move about nervously; horses in the neighboring stalls were calm the whole time. A cat that normally entered the house about 7:30 in the morning to eat and find his place to sleep, continually paced and repeatedly entered and left the house that morning: behavior so unusual for this cat that the owners discussed it hours before the shock. A two-year old Doberman Pinscher, which normally ran about indoors or slept during the morning, remained in her owner's presence almost continually from 8 AM until the earthquake, sometimes whining, pacing, and acting nervous and excited, at other times resting her head in her owner's lap. The owner wondered aloud to her husband if she should give the dog a tranquilizer." (R22, R25, R26, R28, R30)

X26. General observations. "Anecdotal reports by non-scientists from many parts of the world contain many similar observations of animal behavior before earthquakes. These observations come from people who could not possibly have had contact with each other or have read reports from other areas. This lends credibility to the observations, and provides a large body of evidence supporting the contention that animals do sense something before earthquakes. Apparently the response of animals is not restricted to a single species or genus, but spans a very wide spectrum of biological forms which suggests that there is either more than one stimulus or a universal one that can be detected by a wide variety of organisms. Furthermore, with the possible exception of reports of snakes coming out of the ground in mid-winter, few of the responses reported are truly 'abnormal' or extreme. Most involve normal forms of activity which take place either at elevated levels or at unique times. Thus the term 'abnormal behavior' is somewhat misleading." (R19)

X27. General observations. Birds are particularly sensible of its approach, especially ducks and geese. Dogs howl, horses neigh, swine grunt, and asses bray, all showing at the same time great restlessness and uneasiness. During the shock horses and oxen stretch out their legs to avoid being overthrown." (R7)

X28. General observations. While studying an earthquake swarm in the Mojave Desert in 1979, scientists noted that some local dogs barked regularly when they heard the booming noises made by the quakes. Comparing human and canine responses and the tremors recorded by a seismograph indicated that the dogs often barked when humans heard nothing. The seismograph, however, confirmed that a quake had occurred. (R27)

X29. General observations. The following observations were attributed to the Journal of Comparative Psychology. "In one case a mother cat fetched her young ones as if seeking human help. Even hares appear to be altered as to show no fear of humankind. Horses are extraordinarily affected, sometimes throwing off the rider, even when the latter had not himself felt the tremor of the earth..... Crocodiles, which are ordinarily as mute as lizards, go roaring down out of the bed of the river to take refuge in the primeval forest, a thing actually seen by Alexander von Humboldt. In Cuba a tame house snake is kept which flees into the open before every earthquake, thus giving warning to the house dwellers. Bees are extremely sensitive to earthquakes, leaving their hives in great excitement long before the shock is felt, quieting down only after the earthquake has passed over."(R11)

X30. General observations. Japanese observations of pheasants reveal them to be extremely sensitive to tremors, regularly crowing just before or during the tremors recorded on seismographs. (R10)

X31. General observations. "Two Japanese seismologists, Dr. Shinkishi Hatai and Dr. Noboru Abe, observed that catfish (Siluridae) in natural conditions showed signs of restlessness about six hours before earthquake disturbances were registered on their recording apparatus. Since catfish are, ordinarily, placid unresponsive creatures, experiments were made to test this seeming responsiveness. Catfish placed in an aquarium were tested three times a day by tapping on the supporting table. When no earthquake was impending, the fish moved lazily or not at all; but about six hours before a shock the fish jumped when the table was tapped, and sometimes swam about agitatedly for a time before settling down upon the bottom again. Several months' testing showed that in a period when 178 earthquakes of all degrees of severity had been recorded, the fish had correctly predicted 80 per cent of the shocks. They showed no discrimination in their movements between slight local shocks and more serious distant shocks. The experimenters think that the catfish are made sensitive through electrical changes in the earth, since it was only when the aquarium was electrically earthed, through the drain-pipe, that they responded to a coming earthquake." (R12, R20)

X32. General observations. Some species of fish are remarkably sensitive to pressure waves below 50 Hz, so much so that they can probably detect earthquakes 1 to 3 Richter magnitudes lower than humans. (R29)

X33. General observations. After studying the accounts of thousands of quakes while assembling his huge catalog, Mallet makes these observations. "Effects on Animals. Hamilton says that during shocks, horses and oxen extended their legs widely to avoid being thrown down (an evidence of the velocity of the shock), and that hogs, oxen, horses and mules, as also geese, appeared to be painfully aware of the approach of the earthquake of Calabria; and the neighing of a horse, the braying of an ass, or the cackling of a goose, even when he was making his survey, drove the people out of their temporary sheds in expectation of a shock. All birds appear sensible of its approach, but geese, swine, and dogs more remarkably than any other animals; the geese quit the waters before the earthquake and will not return to it. Can it be that with their heads immersed they are able to hear the first distant muttering, while these are yet inaudible to those who hear through the air, and not as in their case through a liquid? Von. Hoff notices 'a presentiment (vorgefuhl) which it was thought had been remarked in particular species of animals shortly before an earthquake. Even men have sometimes, a short time before such occurrences, felt a tendency to headache, giddiness (vertigo), and an inclination to vomit. It has been remarked, that at such times domestic animals showed a decided uneasiness, dogs howled mornfully, horses neighed in an unusual manner, and poultry flew restlessly about. The latter phenomena might be easily produced by mephitic vapours, which often ascend to the surface of the earth before the breaking forth of the earthquake.' The Circicelli, (possibly our Sand-eels,) a little deep-water fish, like our white bait, which usually lies buried in the sand, Hamilton says, 'came up to the surface with many others, and were caught in multitudes;' this might arise either from actual heat of the sea-bottom and water close to it, or from it being fouled by the commotion or by exhalations into it; or they may have been startled by the vibrations, as trout are when one stamps violently on a river bank." (R32)

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GQB2 Human Sensations Experienced before and during Earthquakes

Description. Sensations of giddiness, nausea, and disorientation prior to and during earthquakes. Less specific reactions include a vague uneasiness and feeling of impending calamity.

Data Evaluation. The few reports that have been collected are very subjective and set down after the event itself. No studies exist of human sensations prior to quakes---such studies could well be made in quake-prone areas. The problem is that the solicitations of experiences after almost any important natural event will elicit claims of foreboding and statements such as "I knew something was going to happen." In addition, a large earthquake can induce psychological reactions which surface as claims of nausea felt during the event.

Rating: 3.

Anomaly Evaluation. As described below, several physical conditions may occur prior to a quake which could conceivably affect human senses. In consequence, this phenomenon must be given a low rating; however, there is always a remote possibility that precognition is involved, in which case an upward revision of the anomaly rating would be in order. Rating: 3.

Possible Explanations. Low-frequency, wave-like motion of the ground, which induces the symptoms of seasickness; the release of gases, including ionized molecules, which affect human nerve centers; an electrical state of the atmosphere, such as very high voltage gradients.

Similar and Related Phenomena. The reactions of animals before and during earthquakes (GQB1); earthquake weather (GQW); human sensitivity to electrostatic and electromagnetic fields (BH).

Examples of Human Sensations before and during Earthquakes

X1. 1822. Copiapo, Italy. "A correspondent of Captain Basil Hall, who was in the earthquake of Copiapo, in 1822, describes the effect on the mind as something which begins before any other sign of the earthquake has manifested itself at all---an anticipatory horror, which is even more marked in the case of the lower animals. 'Before we hear the sound, or at least are fully conscious of hearing it, we are made sensible, I do not know how, that something uncommon is going to happen; everything seems to change color; our thoughts are chained immovably down; the whole world appears to be in disorder; all nature looks different to what it is wont to do; and we feel quite subdued and overwhelmed by some invisible power, beyond human control or apprehension.'" (R3) This vagueness is typical of many reports of earthquake sensations. (WRC)

X2. October 14 and 23, 1839. Scotland. "A feeling of nausea was experienced by many individuals, and which is variously described as resembling 'sea-sickness,'---'sickness, like that felt before fainting'---'uneasy sensation, which I can compare only to the first disagreeable feelings which usually precede a fit of sea-sickness,'---'a most peculiar sickish sensation, such as I never felt before. Headaches were produced, as attested by the Rev. Mr. Walker on the 12th October, by Mr Rutherford, W.S., on the 14th October 1839, and by Mr Young of Crieff, on the 23rd October 1839, all of whom ascribe these as the effects of shocks which occurred on these days. Nervous sensations of a more indefinite kind are spoken to by various individuals. On the 14th October 1839, at the moment that the shock occurred, an individual, though he was not aware of its occurrence, experienced 'an unusual feeling, which led him to suppose that some illness was impending.' Mr Robertson, who felt the shock of 16th October at Glendevon, on the north side of the Ochils, says,---'I remember having just before, felt as if some strange presence had been silently gathering round me, and could not be shaken off.' Mr Laurie, the parish schoolmaster of Monzie, says, 'the shock of the earthquake on 23rd October, affected the nerves disagreeably, and left a painful impression. It reminds me vividly of the shock from an electric machine.' The conviction of there having been an electrical discharge, was decidedly entertained by a number of individuals. Thus, at Alva, near Tillicoultry, two clergymen felt as if electrified. Mr Jeffrey, who felt the shock in the Carse of Falkirk, says,---'I may mention a circumstance which I have not seen taken notice of in any account of the late earthquake, and it is, that I am convinced it was accompanied with an electric shock. I was perfectly calm and collected at the time when it came on, and never had any doubt of what it was, nor was I at all alarmed for the consequences. But the feeling produced upon my body, was exactly similar to what an electric shock has in other circumstances had upon me.' Mr Stein, surgeon at Menstrie, near Stirling, says, 'I think the atmosphere (on the 23rd October 1839) was highly charged with electricity, both before and at the time when the shock occurred.' He speaks of 'the slightly reddened or lurid appearance of the atmosphere towards the S. and SE., particularly observable for several evenings preceding the shock of the 23rd." (R1)

X3. April 9, 1970. Manila, Philippine Islands. "The reactions of a large circle of acquaintances seem to have been remarkably similar, especially on the morning of 9 April before the second major tremor;

not only were sleeplessness, headaches and giddiness experienced---of the kind reported by Mr Wallace---but, in some instances, nausea of the kind experienced in a cross-Channel steamer in an irregular sea. Like myself, many of my friends live in elevated apartments where earth movements are exaggerated, but some of the sufferers live in bungalows at ground level." The author then speculates that the sensations of nausea may have been stimulated by ground waves with frequencies less than 1 Hz. (R4)

X4. General observations. "The atmospheric changes preceding strong earthquakes are apparently also felt by sensitive people. The term 'earthquake weather' is known in Europe, South America and in western US. It is associated with an unusually warm and oppressive weather situation. The reported physiological reactions are comparable to those felt during Foehn, Scirocco or Sharav, which are known to have been accompanied by high concentrations of positive air ions." (R5)

Claim that some earthquakes are preceded by a slight breath of wind which, in the frequent calms before quakes, can be felt on the face by sensitive persons. (R2)

In summarizing his findings, based on his preparation of an immense earthquake catalog, Mallet observed as follows: "Nausea at the Moment of Shock.---The curious effect of earthquake shock upon human beings, and if accounts are to be credited, also upon some domestic animals, is deserving of more attention than it has yet received. The fact itself, as respects human beings, admits of no doubt. I have direct testimony of the boys of a large boarding-school being suddenly awakened at night by one of the North American shocks, and the greater number suffering from immediate sense of nausea, amounting to vomiting in many cases. In the late earthquake at Naples (Dec. 1857) many instances were related to me by the sufferers. The question arises, Is the nausea an effect of the sudden disturbance of the nervous system by alarm, &c., or is it due to the movement itself, and analogous to sea-sickness? There are great difficulties in the way of either solution. Those most likely to suffer severely from nervous alarm, do not seem to be those most usually affected. The direct movements are very generally too sudden, sharp, and of too little duration, to admit of the second explanation. The facts, however require to be more numerous, and to be scientifically collected and classified as soon after the occurrence as possible, and are commended to such physiologists as may be favourably circumstanced for the observation in earthquake regions." (R6, R7)

Biologist Marsha Adams claims that bleeding anomalies precede powerful earthquakes. The staff of a San Jose clinic maintain they can predict earthquakes by virtue of sharp increases in emotional disturbances and reactions to anthesthetics. Some subjects seem to be able to predict a quake from the onset of fatigue, chills, headaches, nausea, and other physiological symptoms. (R8)

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GQG EARTHQUAKE GEOGRAPHICAL ANOMALIES

Key to Phenomena

GQG0 Introduction

The prevailing theory of plate tectonics (nee continental drift) views the physically interacting edges of the moving crustal plates as the loci of most earthquakes and volcanic activity. Generally, these plates have tortuous boundaries with little overall geometric plan, although some trace out long curves. In this section, the earthquake phenomena presented suggest highly geometric, global patterns that are at variance with expectations from plate tectonics.

GQG1 Seismic Activity Occurring on Great Circles

Description. The tendency of earthquakes and volcanos to occur along great circles, including the apparent sympathetic seismic activity at antipodal points.

Background. The so-called Rouse Belts, described below in X2, received much publicity in 1968 in popular science publications. So far, no followups, pro or con, have been uncovered in the professional literature. The same is true for other suggested global patterns of seismic activity.

Data Evaluation. No thorough scientific studies of the purported phenomena have been found. Except for the Rouse Belts, the data consist of almost casual observations. Rating: 3.

Anomaly Evaluation. The confinement of most earthquakes to a few great circles would suggest some global pattern reminiscent of the Tetrahedral Earth and similar geometric visions. This sort of pattern, if borne out in actuality, and the possibility of sympathetic antipodal earthquakes would be counter to current theories, which emphasize plate edges as the primary loci of seismic activity. Rating: 2.

Possible Explanations. The boundaries of the earth's plates occasionally trace out long arcs that resemble but are not truly great circles. Thus, the tendency of quakes to occur along great circles may be illusory and disappear with more thorough analysis. Sympathetic seismic activity at the antipodes of major quakes might be caused by some sort of focussing of earthquake waves.

Similar and Related Phenomena. The Tetrahedral Earth and other "plans" of the earth (E).

Examples of Seismic Activity Occurring on Great Circles

X1. August 26-27, 1883. Cayman Islands, West Indies. Seismic activity simultaneous with the eruption of Krakatoa in the East Indies. The two sites are antipodal. (R1, R5) Although much is made of the antipodal relationship in this report, mere coincidence seems just as likely as the inferred sympathetic reaction. (WRC)

X2. General observations. "In Nature of October 14 (p. 570) you published a letter from Prof. O'Reilly regarding the great earthquake of Carolina, and drawing attention to the tendency of earthquake lines to assume the direction of great circles. So far his observations were identical with a theory I had myself elaborated, and which I embodied in a paper written at the beginning of the year 1884, now in the hands of the Committee of the Geological Society of London, but never presented to the Society. So long ago as that period I had drawn attention to what I pointed out as the two principal earthquake great circles---one, the Japan and Rocky Mountain system, with one of its poles 170° W. long., 25° S. lat.; the other, the Himalayic, with its north pole approximately in 45° N. lat., 160° W. long. The former has been frequently described, and Scrope suggested a theory to explain its occurrence. The latter is little less remarkable, and is at the moment even more interesting, as, with the exception of the Carolina earthquake, all the great earthquakes and volcanic eruptions of the last five years may be referred to it. I may instance the cases of Krakatoa, Kashmir, the Caucasus, Spain, Cotopaxi, New Zealand, and the recent Mediterranean disturbance, all of which occurred within a few degrees of the line or actually on it. Now it is remarkable that this line is marked through a considerable portion of its course by the presence of disturbed Miocene rocks, so much so that I have felt justified in calling it the Miocene line."(R2)

"Earthquakes by and large never move straight up and down. Instead, they strike up at earth's crust at an angle. What started the hypothesis was doctoral candidate George E. Rouse's observation that deep quake zones around the planet---called Benioff zones---all seem to lie at surprisingly similar angles of about 60 degrees. Wondering why this should be so, he decided to see what would happen if he projected the Benioff zones into imaginary planes passing all the way through the globe. Using a $1.50 toy globe, Rouse began his first circle at a point of relatively mild seismic activity in Chile. To his surprise, the completed circle also passed through a very active zone in Turkey, the site of a recent quake in the Pyrenees Mountains between France and Spain and another seismically active spot in Venezuela. Intrigued, he drew 15 more circles, beginning at different deep quake zones, and a striking conclusion appeared: Not only was the plane of every circle tangent to the outer core of the earth, but where the planes emerged, they coincided with the Benioff zones of other quake areas, and with volcanic and other seismic areas. With 16 circles, in fact, Rouse found he had included most of the major seismic features of the globe; five more brought the total to over 90 percent. With the original 16 circles, there are 19 points on the globe at which three circles intersect. 'All but five of these trisections occur at zones of major seismic or volcanic activity,' says Dr. Ramon E. Bisque, a professor of geochemistry who is now helping Rouse with his research.'" (R3, R4)

X3. General observations. A surprising number of quakes occur in pairs and triplets, positioned symmetrically on the same latitude. For example, ten symmetrical pairs were noted in the period 1899-1905 out of 126 total quakes. (R6)

X4. Occasional occurrence. Numerous examples of roughly antipodal earrhquakes are said to exist, although not simultaneous, as in X1. Separated in time by only a few days, they may be related to readjustments of the earth's axis. In the sense that one quake may stimulate the second, they are sympathetic. (R7)

References

R1. Forel, M.; "Le Cataclysme de Krakatoa Extendu aux Antipodes," L'Astronomie, 4:383, 1885. (X1)

R2. Kingsmill, Thomas W.; "Earthquakes," Nature, 35:319, 1887. (X2)

R3. "The $E = mc^2$ of Solid Earth Theory," Science News, 93:301, 1968. (X2)

R4. Small, William E.; "'Giant Step' toward

a Unifying Theory of Geophysics?" Scientific Research, 3:39, June 10, 1968. (X2)
R5. Roulet, Edmund, and Forel, F. A.; "Underground Noises Heard at Caiman-Brac, Carribean Sea, on August 26, 1883," Nature, 31:483, 1885. (X1)
R6. Gill, H. V.; "Some Recent Earthquake Theories," Nineteenth Century, 63:144, 1908. (X3)
R7. Nagaoka, H.; "Variations of Latitude and Great Earthquakes," Nature, 130:541, 1932. (X4)

GQG2 Earthquake-Prone Areas Uncorrelated with Geological Structures

Description. Centers of earthquake activity that do not appear to be associated with any faults or other geological features that might be the causes of enhanced seismic activity.

Data Evaluation. Only a single news release, but it is from a prestigious organization. In general, though, earthquake "hot spots" in the eastern U.S. seem widely recognized, but they are rarely treated as specifically as in R1. Rating: 2.

Anomaly Evaluation. The persistence of high levels of seismic activity in certain areas in the eastern U.S. (and presumably other areas elsewhere on the earth) represents a substantial geological mystery. Whatever causes these sometimes catastrophic quakes is buried deep beneath the crust. Rating: 2.

Possible Explanations. Deep fault zones without surface expression; deep movements of magma.

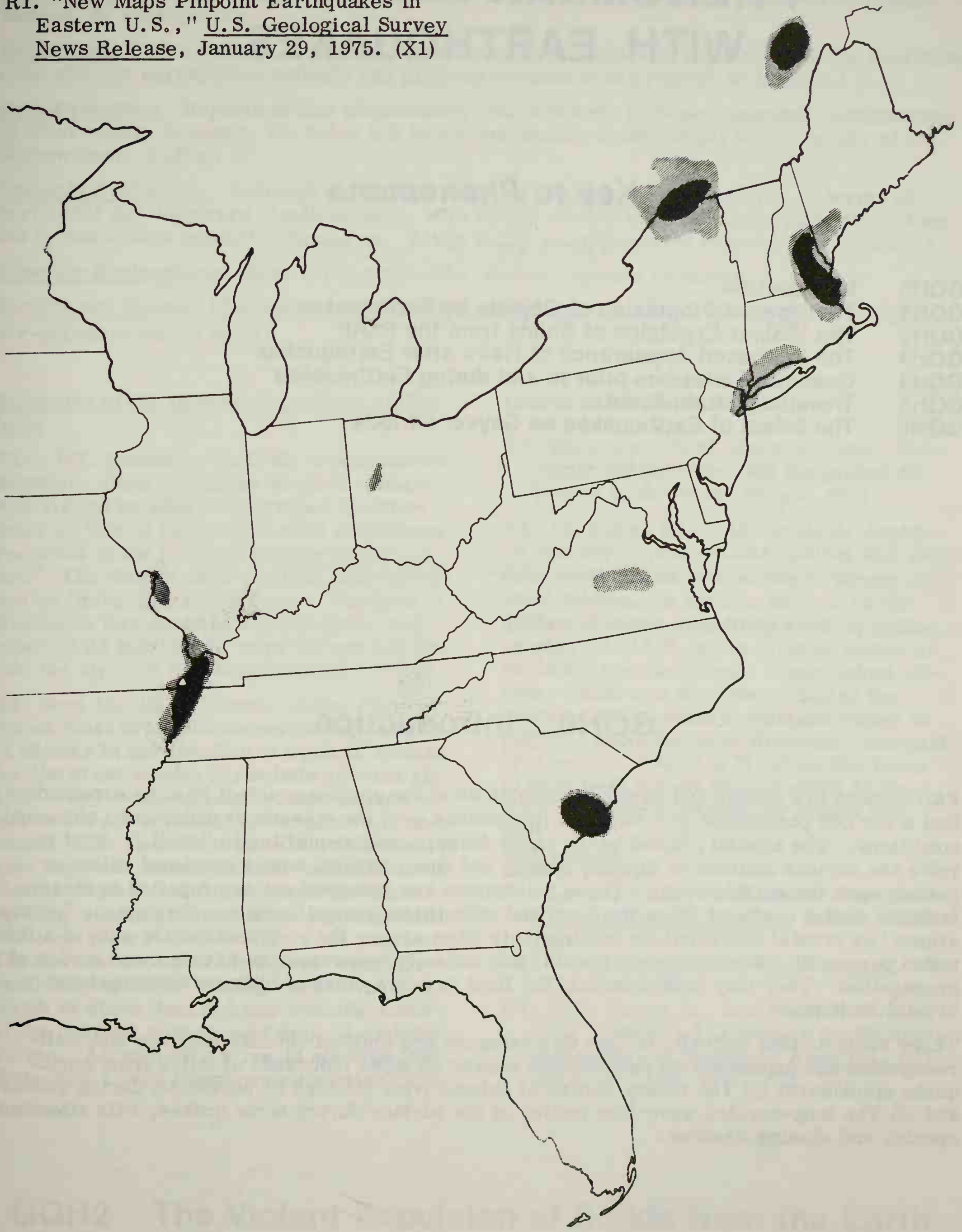
Similar and Related Phenomena. None.

Examples of Earthquake-Prone Areas with No Correlated Geological Structures

X1. General observations. Eastern U.S. The following comments are from a news release announcing a report on earthquakes in the eastern U.S. "According to James F. Devine, geophysicist, U.S. Geological Survery National Center, Reston, Va., and co-author of the report, 'The sources of earthquakes in the East are not nearly as well known or understood as are the sources of earthquakes in the Western U.S. Among the obvious reasons for lack of knowledge are the facts that eastern earthquakes occur less frequently, are generally smaller, and are thought to occur at greater average depths than they do along the West Coast. Also, eastern earthquakes appear to produce only vibratory ground motion and not the actual differential ground displacement of the Earth's crust that is so evident along the West Coast. Apparently as a result of all these factors, earthquakes have produced little evidence of surface fault movement east of the Rockies in at least recent geologic time. As a result, we usually have only secondary geologic effects, such as sand boils and ground slumping, to aid us in our seismic studies. On the other hand, major earthquakes in the East have been felt over a much greater distance than similar-sized earthquakes in California,' the USGS scientist said, 'For example, the three large earthquakes near New Madrid, Mo., in 1811-1812 were felt in Boston, Mass., and New Orleans, La., and the 1886 Charleston, S.C., earthquake was felt in Des Moines, Iowa, and Providence, R.I.'.....In some areas of the Eastern United States, earthquake activity appears to be associated with known tectonic structures, such as in the Mississippi embayment trough and in the Appalachian Mountains. In many other areas, seismicity, usually of low level, is so scattered that no localized faults or other structures are indicated. In a few places, such as central Virginia, central New England, and most notably in the vicinity of Charleston, S.C., the sources of seismic activity of intermediate or even high levels remain a geologic mystery and cannot, in the light of present information, be considered localized along known structures." (R1)

References

R1. "New Maps Pinpoint Earthquakes in Eastern U.S.," U.S. Geological Survey News Release, January 29, 1975. (X1)



Earthquake "hot spots" in the eastern United States (X1)

GQH UNUSUAL DYNAMIC PHENOMENA ASSOCIATED WITH EARTHQUAKES

Key to Phenomena

GQH0 Introduction

Earthquakes are sudden and powerful distortions of the earth's crust; it is to be expected that a few odd phenomena will manifest themselves near the epicenters under such abnormal conditions. The handful offered below range from paradigm-shifting to "droll." Most involve the curious motions of liquids, gases, and finely divided solids contained within or resting upon the earth's crust. These substances are squeezed out or propelled in bizarre fashions during quakes. More profound and scientifically significant are the curious "strain events" or crustal deformations inching their ways across the continents at the rate of a few miles per month. Such "seismic ghosts" are not fully understood as to origin and modes of propagation. They may in fact be only the first in a new class of hitherto unappreciated crustal motions.

Three subjects that logically fit into this category are omitted because they are now well-recognized and explained: (1) Seiches that appear on lakes thousands of miles from earthquake epicenters; (2) The rotary motion of objects (viz. statutes on pedestals) during quakes; and (3) The long-derided wave-like motion of the surface during some quakes, with attendant opening and closing fissures.

GQH1 The Upward Propulsion of Objects by Earthquakes

Description. The upthrow into the air of loose objects, to heights of at least several centimeters, by earthquakes.

Background. It was decided to include this phenomenon because of the dispute in the literature over whether earthquakes actually can produce vertical accelerations as high as 1 g.

Data Evaluation. Reports of this phenomenon are rare and, in some instances, exaggerated. In other cases, however, the holes left by ejected stones testify amply to the reality of the phenomenon. Rating: 2.

Anomaly Evaluation. Although earthquake motions are generally considered in terms of horizontal and downward displacements, with minor upward accelerations, geophysics does not forbid violent upward components. Little if any anomalousness exists here. Rating: 4.

Possible Explanations. Rare but permissible, violent, upward impulses.

Similar and Related Phenomena. The energetic expulsion of solids from the ground (GQH2). Air-pressure waves (GSW).

Examples of the Upward Propulsion of Objects

X1. 1797. Ecuador. "In 1797, a province of Ecuador, about 100 miles south of Quito, was visited by what is described by Humboldt as 'one of the most fearful phenomena recorded in the physical history of our planet.' The shocks were vertical, and occurred as 'mine-like explosions.' The town of Riobamba was over the central area, and many of its inhabitants were thrown 100 feet into the air." (R1) Exaggeration?! (WRC)

X2. June 12, 1897. Assam, India. "One of the earliest dramatic accounts of upthrow of objects in earthquakes is by R.D. Oldham for the great Assam earthquake of June 12, 1897. He writes of loose stones being tossed in the air at Shillong, Gauhati, and elsewhere, 'like peas on a drum.' All the available reports indicate that the mechanism of this earthquake led to particularly violent shaking. People were thrown to the ground and even injured in this way by the shock. There were reports of boulders being thrown vertically upward, leaving cavities in the Earth in which they had lain with the sides of the cavities almost unbroken. D. Oldham writes, 'All accounts agree in showing that there was a very considerable vertical component in the shock.'" (R3)

X3. December 1908. Messina, Italy. Eyewitnesses declared that the ground appeared to throw out stones. (R2)

X4. December 26, 1949. Imaichi, Japan. "A number of publications dealing with Japanese earthquakes also allude to strong upward motion. In the two Imaichi earthquakes (Richter magnitude about 6) of December 26, 1949, some diverse pieces of evidence are mentioned. Near Ochiai village, which was near the center of the source area, a stone implement called an ishiusu, about 50 cm in diameter, was said by a woman observing it before her home to have been tossed upward about 20 cm a few times like a rebounding rubber ball." (R3)

References

R1. Lewis, Elias; "Earthquake Phenomena," Popular Science Monthly, 2:513, 1873. (X1)

R2. "The Italian Earthquake," Nature, 79: 287, 1909. (X3)

R3. Bolt, Bruce A., and Hansen, R.A.; "The Upthrow of Objects in Earthquakes," Seismological Society of America, Bulletin, 67:1415, 1977. (X2, X4)

GQH2 The Violent Expulsion of Solids from the Earth

Description. The energetic expulsion of solid materials from earthquake-produced fissures and craters. The phenomenon is usually accompanied by considerable noise, sulphurous air, and/or water (occasionally very hot).

Data Evaluation. Sand craters are occasionally reported after earthquakes, but the expulsion of other solids, especially carbonized wood and other burnt materials, is rare. Nevertheless, several good eyewitness accounts have been found. Rating: 2.

Anomaly Evaluation. The huge compressive forces generated by earthquakes certainly account for the energetic ejection of gases, liquids, and entrained granular solids. The only anomalous facet of this phenomenon is the appearance of carbonized wood and ashes, both of which could imply great subterranean heat and even electrical activity. Rating: 3.

Possible Explanations. Naturally buried charcoal (from ancient forest fires) is not uncommon in geology. However, some earthquakes generate considerable heat, as evidenced by the huge volumes of hot water engendered by the New Madrid quakes. Conceivably such heat could be generated piezoelectrically.

Similar and Related Phenomena. Ash falls attend volcanic eruptions, but the ashes are not derived from the combustion of wood. Rarely, the track of a tornado will be marked by burned and dried vegetation (GWT2).

Examples of the Violent Expulsion of Solids

X1. 1727. Newbury, Massachusetts. The earth opened, and a sulphurous blast threw up mounds of calcined dust. (R3)

X2. 1811-1812. New Madrid, Missouri. "The shocks here were vertical, proving, as we shall see hereafter, that the centre of energy was directly underneath. At other times, the shocks, which continued many months, were undulatory. The ground rose in huge waves, which burst, and volumes of water, sand, and pit-coal, were thrown high as the tops of trees." (R3, R7)

X3. January 6, 1812. New Madrid, Missouri. "During the earthquake which destroyed New Madrid on the 6th of January 1812, and which was felt two hundred miles around, Mr Bringier happened to be passing in its neighborhood, when the principal shock took place. The violence of the earthquake having disturbed the earthy strata impending over the subterraneous cavities existing probably in an extensive bed of wood, highly carbonized, occasioned the whole superior mass to settle. This mass pressing upon the water which had filled the lower cavities, forced it out, and blew up the earth with loud explosions. It rushed out in all directions, bringing with it an enormous quantity of carbonized wood, reduced mostly to dust, which was ejected to the height of from 10 to 15

Craters created when sand is blown out of the ground during earthquakes (X3) feet, and fell in a black shower, mixed with the sand which its rapid motion had forced along; at the same time, the roaring and whistling, produced by the impetuosity of the air escaping from its confinement, seemed to increase the horrible disorder of the trees, which everywhere encumbered each other, being blown up, cracking and splitting, and falling by thousands at a time. In the mean time, the surface was sinking, and a black liquid was rising up to the belly of Mr Bringier's horse, which stood motionless, struck with panic and terror. These occurrences occupied nearly two minutes. The trees kept falling here and there, and the whole surface of the country remained covered with holes, which, to compare small things with great, resembled so many craters of volcanoes, surrounded with a ring of carbonized wood and sand, which rose to the height of about seven feet. The depth of several of these holes, when measured some time after, did not exceed twenty feet, but the quicksand had washed into them. Mr Bringier noticed a tendency to carbonization in all the vegetable substances that had been soaking in the ponds, produced by the eruptions." (R1, R2, R5) The apparent burning of vegetation is similar to the effects produced by some tornados and ascribed to electrical action. (See GWT2.) (WRC)

X4. January 8, 1867. Fort Klamath, Oregon. After an earthquake shock, the sky was full of black smoke, the air seemed to have a sulphurous odor, and brownish ashes fell like snow. More shocks followed, during which the earth rolled like ocean waves. (R4) One might reasonably ask whether the ashes might have been from a distant volcano. (WRC)

X5. May 21, 1960. Concepcion, Chile. "A side effect of the earthquake of May 21, 1960, near Concepcion, Chile, was the eruption of water, sand, and clay from fissures and circular or elliptical vents in a cultivated field and in tidal mud flats near the mouth of the Bio Bio river. According to eye-witness acounts, muddy water continued to erupt for about 6 hours after the earthquake. Small ridges of sand along the fissures and cones of sand at the other vents were formed. Craterlike depressions in the center caused the cones to resemble volcanoes. Some of the miniature 'volcanoes' were double, others were breached on one side, still others had minute 'satellite' cones. 'Bombs' of clay and peat were ejected from the 'craters' and from fissures. Small cavities extended under the clayey topsoil. The accumulations of erupted sand ranged in width from 5 to 70 cm, and they attained a maximum height of about 10 cm above the adjacent soil surface. Some of the fissures attained lengths of several tens of meters. Clay 'bombs' as much as 20 cm across and 7-8 cm thick were found as far away as 1.2 m from the nearest fissure or 'crater'. The eruptive phenomena were restricted to sunken areas, as much as several hectares in extent, which had been displaced vertically at least 20-30 cm. The ejection of water and clastic material was apparently caused by settling and compaction of water-soaked sediments and rupture or perforation of the overlying topsoil." (R6)

References

R1. American Journal of Science, 3:20, 1821. (X3)

R2. "Eruption of Carbonised Wood at New Madrid," Edinburgh Philosophical Journal, 5:404, 1821. (X3)

R3. Lewis, Elias; "Earthquake Phenomena," Popular Science Monthly, 2:513, 1873. (X1, X2)

R4. Holden, Edward S.; "A Catalogue of Earthquakes on the Pacific Coast, 1769-1897," Smithsonian Miscellaneous Collections, vol. 37, 1898. (X4)

R5. Shepard, Edward M.; "New Madrid Earthquake," Journal of Geology, 13:45, 1905. (X3)

R6. Segerstrom, Kenneth; "Eruption of Water, Sand, and Clay Resulting from the Earthquake of May 21, 1960, near Concepcion, Chile," Geological Society of America, Bulletin, 71:1972, 1960. (X5)

R7. Flint, Mr.; "Notice of Earthquakes on the Mississippi," Edinburgh New Philosophical Journal, 7:262, 1829. (X2)

GQH3 The Supposed Appearance of Hairs after Earthquakes

Description. The purported appearance of whitish or silvery hairs protruding from the soil after earthquakes. The only reports found are from the Orient.

Background. It was a shock to find all of three items in the literature on this "droll phenomenon." Furthermore, one does find it instructive, as in X3.

Data Evaluation. The only careful investigation of the phenomenon declares it to be a case of mistaken identity. Rating: 4.

Anomaly Evaluation. If hairs or mineral whiskers do appear after earthquakes, it would not only be a delightful confirmation of Asiatic folklore but a perplexing geophysical puzzle, though certainly not one impossible of solution. Rating: 2.

Possible Explanations. Gaseous emanations from the earth might lead to the crystallization of mineral whiskers.

Similar and Related Phenomena. None.

Examples of the Supposed Appearance of Hairs after Earthquakes

X1. May 13, 1848. Chantibun, Siam (Thailand). Following a severe earthquake, long hairs were said to be found sticking out of the ground. They were thought to have been formed by the congealing of bituminous substances blown through the pores in the earth. (R1)

X2. June 12, 1878. Wusoh, China. After an earthquake, the inhabitants discovered long, white hairs sticking out of the ground. The author states that similar occurrences are to be found in the records of Chinese earthquakes. (R2)

X3. 1852. Shanghai, China. After an earthquake. "Groups of Chinese were seen in the gardens, roadsides, and fields, engaged in gathering hairs which are said to make their appearance on the surface of the ground after an earthquake takes place. This proceeding attracted a great deal of attention from some of the foreign residents in Shanghai, and the Chinese were closely examined on the subject. Most of them fully believed that these hairs made their appearance only after an earthquake had occurred, but could give no satisfactory explanation of the phenomenon, while some, more wise than their neighbors, did not hesitate to affirm that they belonged to some huge subterraneous animal whole slightest shake was sufficient to move the world. I must confess, at the risk of being laughed at, that I was one of those who took an interest in this curious subject, and that I joined several groups who were searching for these hairs. In the course of my travels I have ever found it unwise to laugh at what I conceived to be the prejudices of a people simply because I could not understand them. In this instance, however, I must confess the results were not worth the trouble I took. The hairs, such as I picked up, and such as were shown to me by the Chinese, had certainly been produced above the earth and not below it. In some instances they might readily be traced to horses, dogs, and cats, while in others they were evidently of vegetable origin. The northeastern part of China produces a very valuable tree known by the name of the hemp-palm, from the quantity of fibrous bracts it produces just under its blossoms. Many of these fibres were shown to me by the Chinese as a portion of the hairs in question; and when I poirted out the source from which such had come, and which it was impossible to dispute, my friends laughed, and, with true Chinese politeness, acknowledged I was right, and yet I have no doubt that they still held their former opinions concerning the origin of such hairs. The whole matter simply resolves itself into this; if the hairs pointed out to me were the true ones, then such things may be gathered not only after earthquakes, but at any other time. But if, after all, these were not the real things, and if some vegetable (I shall not say animal) production was formed, owing to the peculiar condition of the atmosphere and from other causes, I can only say that such production did not come under my observation." (R3)

References

R1. "A Droll Phenomena," Scientific Ameri-

can, 4:139, 1848. (X1)
R2. Macgowan, D. J.; "Note on Earthquakes in China," Nature, 34:17, 1886. (X2)
R3. Dyer, W.T. Thiselton; "Collection of Hairs after Earthquakes in China," Nature, 34:56, 1886. (X3)

GQH4 Gaseous Emissions prior to and during Earthquakes

Description. The expulsion of contained gases from the earth prior to and during earthquakes, as determined by the human nose and instruments. Typically, residents in the affected area detect a gassy or sulphurous odor.

Data Evaluation. The few data available are mainly testimonial, rather old, and of limited value. Modern instrumentation emplaced along active faults has, however, confirmed the emission of gases. Rating: 2.

Anomaly Evaluation. The application of stresses or their release could well expel gases contained in the soil and earth's upper crust. Subsurface decaying organic matter, common in many places, is a reasonable source for earthquake "smells." Thus, earthquake odors and gas releases are primarily curiosities, although perhaps of some predictive value. Rating: 3.

Possible Explanations. As discussed above, plus heating by piezoelectric currents.

Similar and Related Phenomena. The curious behavior of animals before quakes may be due to the release of gases or aerosols (GQB1). Tornados, lightning, brush discharge, and many other geophysical phenomena have been associated with sulphurous odors. (See the indexes of the appropriate volumes.) Prior to some earthquakes, increases in the radon content of wells are observed,

Examples of Gaseous Emissions Prior to and During Earthquakes

X1. July 10, 1756. Lisbon, Portugal. A cloud of smoke rose from the ground obscuring the sun. At the same time, the smell of sulphur pervaded the air. (R2)

X2. 1811-1812. New Madrid, Missouri. "Sulphurous or otherwise obnoxious odors and vapors were an attendant feature of the earthquake at many points, as stated by nearly every writer. Bryan speaks of the complete saturation of the atmosphere with sulphurous vapor a few minutes after the first shock, and of similar vapors after the shock of February 7. Hildreth speaks of the escape of sulphur gas through the cracks tainting the air and impregnating the water for a distance of 150 miles so it was unfit to use. Another observer, writing to Mitchill from New Madrid, states that although the air was clear at the time of the shock, within five minutes a vapor with a disagreeable smell and producing a difficulty of breathing impregnated the atmosphere. At Jeffersonville, Ind., warmth and smokiness were noted for several days after the shock, while at Columbia, S. C., the air during the shock felt impregnated with vapor which lasted for some time. The source of the odors in the New Madrid region seems to have been the buried organic matter which here, as elsewhere in the Mississippi embayment, occurs in the alluvium and underlying Tertiary deposits, the emanations coming mainly from the carbonaceous material extruded from below through the fissures and craterlets, which were numerous in the region. In the more remote localities the vapors probably represented normal atmospheric condensations which happened to be coincident with the earthquake disturbance." (R3)

X3. January 1975 up to February 4, 1975. Haicheng, China. "In January 1975, a surprising increase of the temperature was experienced along the large fault which had a basic role in the origin of the quake. The monthly mean temperature was higher than usual mean by 2°C. From January 21 to 31 the warm mass of air moved along the fault in question and the temperature was at least 3°C higher than the usual mean for the same period. A still more conspicuous increase in temperature was experienced prior to the occurrence of the shock: between January 29 and February 4, the temperature was higher by 5-6°C than the normal mean value for the same interval. On the day of the shock, the temperature was higher by 8°C than the usual average for that day (February 4)! This phenomenon was experienced primarily in the epicentral area. Far from this region, the increase in temperature was smaller. The quake occurred in the evening local time, but between 08 and 10 o'clock on the morning of February 4, a 12°C increase in the air-temperature was recorded in certain areas of Haicheng. In a town named Darien, the temperature increased only 2°C on the same day. This shows clearly that the increase of the air-temperature was related to the earthquake. (In all probability, slow movements along the main fault caused friction and thus heat production. This excess heat was added to the air, resulting in the increase of the temperature of the atmosphere near the soil. P. H.)

One month prior to the shock, a strange odor was detected in the region. According to the opinion of the local inhabitants this strong, strange odor was due to gases liberated from the soil. On January 8, the workers of the commune of Fung-hsing-hsien were forced to return to the farming building because the stink was insupportable on the field. The members of another commune detected the stink over an area 15 x 5 kilometers; and one man lost consciousness. In Fung-hsing-hsien, a worker saw gas bubbles bursting in a trench. Particularly strong gas-odor was experienced on December 24, 1974, January 14, 1975, January 15, 22, 27, and 30, as well as February 3, one day prior to the shock." (R6)

X4. General observations. In discussing South American earthquakes. "Though no certain indications of an approaching earthquake can be noted, yet I have heard persons in Arica and Tacna affirm that previous to heavy shocks, they were often sensible of a peculiar disagreeable smell or state of the atmosphere, which they assert may be considered a precursor of a coming shock. Between 1843-1848, the said odour was more rarely referred to in that quarter, which may have resulted from the greater paucity of of earthquakes there within that period. In 1826 and following years, prior to some severe shocks there, my olfactory organs were affected by the invisible agent above noted, which was something different from the effluvia emanating from decaying animal and vegetable matters. Native Peruvians call it 'Olor de tierra,' smell of the earth." (R1)

Analyses of soil samples along the Yamasaki fault, in Japan, show a clear correlation between hydrogen degassing of the earth and fault movement. (R5)

The relief of stress on coal formations may lead to the sudden release (outburst) of gas contained in the coal. (R4)

References

R1. Hamilton, Mathie; "Brief Notices of Earthquakes in South America in 1844, 1845, 1846, and 1847," Report of the British Association, 1850, part 2, p. 82. (X4)

R2. Mallet, Robert; "On the Facts of Earthquake Phenomena," Report of the British Association, 1853, p. 128. (X1)

R3. Fuller, Myron L.; "The New Madrid Earthquake," U.S. Geological Survey Bulletin 494, 1912. (X2)

R4. Ignatieff, A.; "Outbursts in Coal Mines," Geological Society of America, Bulletin, 64:1438, 1953. (X4)

R5. "Hydrogen May Flag Fault Movement," Science News, 118:280, 1980. (X4)

R6. Hedervari, Peter; "Strange Phenomena Prior to the Haicheng (China) Earthquake," Personal communication, 1983. (X3)

GQH5 Travelling Strain Events

Description. The progressive motion of crustal deformations across continental surfaces, as determined by gravity measurements, strain indicators, determinations of elevation, and so on. Although strain events may proceed only a few tens of miles per year, some scientists compare them to water waves moving out from some disturbance.

Data Evaluation. The data supporting the reality of this phenomenon come from recently installed networks of geophysical instruments in China, Japan, and southern California. The few papers published to date have led to much controversy concerning the accuracy of such measurements. The techniques are new and the data controversial. Rating: 3.

Anomaly Evaluation. The vision of slowly moving, ponderous crustal deformations inching across continental plates represents a significant departure from conventional concepts of geophysics. If real, this phenomenon represents a major paradigm shift and a new way of looking at the dynamics of the earth's crust. Furthermore, we can only conjecture on where these disturbances might originate. Rating: 2.

Possible Explanations. Upthrusting magma may induce moving crustal disturbances, as might transients at the edges of the crustal plates.

Similar and Related Phenomena. The moving "hot spots" that may lead to the formation of chains of volcanos. Solitary waves in water (GHW1) and the atmosphere (GWC12) may be analogous conceptually. The lunar tides in the crust propagate around the earth but are much faster.

Examples of Travelling Strain Events

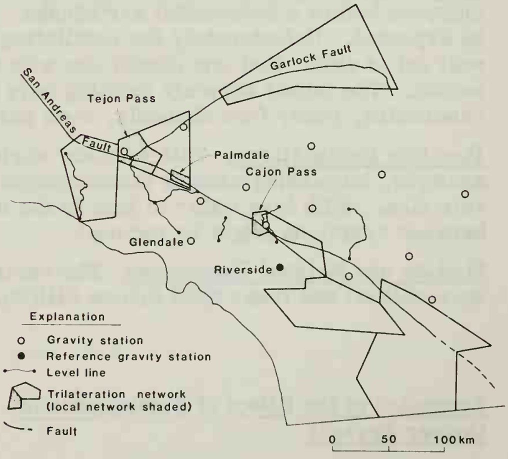
X1. 1966-1975. China. A pattern of earthquake shocks migrated out of the country's southwest toward the northeast, culminating in the February 1975 Haicheng quake. (R1)

X2. No date given. Japan. Five geophysical stations on the north end of Honshu island record a crustal strain that persisted at one station for four or five months before fading out and reappearing at the next station along the line. The strain event evidently travelled about 25 miles per year. (R1)

X3. 1973-1978. Southern California. From 1973 into 1978, geophysical instruments monitoring the San Andreas Fault indicated that north-south distances were contracting. The Pacific coast was moving north while the rest of North America was heading south. Then, in 1978, the strain eased in the far south of California only to reassert itself in a few weeks. This strain event seemed to propagate slowing across southern California, as seen by other instruments farther north. As the wave of relaxation moved ponderously along, much like a flexure of the earth's strata, microearthquakes almost disappeared while the flow of radon from the ground increased. When the strain reappeared, radon flow diminished and microearthquakes broke out once more. The strain wave took about one year to flow north from the Imperial Valley into the Los Angeles area. (R1)

"Two-color laser ranging measurements during a 15-month period over a geodetic network spanning the San Andreas fault near Palmdale, California, indicate that the crust expands and contracts aseismically in episodes as short as 2 weeks." (R2)

"Abstract. Measurements made once or twice a year from 1977 through 1982 show large correlated changes in gravity, elevation, and strain in several southern California networks. Precise gravity surveys indicate changes of as much as 25 microgals between surveys 6 months apart. Repeated surveys show that annual elevation changes



Locations of stations, baselines, and trilateration networks in southern California (X3)

as large as 100 millimeters occur along baselines 40 to 100 kilometers long. Laser-ranging surveys reveal coherent changes in areal strain of 1 to 2 parts per million occurred over much of southern California during 1978 and 1979. Although the precision of these measuring systems has been questioned, the rather good agreement among them suggests that the observed changes reflect true crustal deformation." (R5) A popularized summary of R5 appears in R3. R4 is an overview of R5, with a discussion of the many errors inherent in the surveys. Some scientists, for example, maintain that these moving crustal deformations may be much smaller or even nonexistent when all possible instrument errors are taken into account.

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R1. Alexander, George; "Quakewatch," Science 82, 3:38, September 1982. (X1-X3)

R2. Langbein, J. O., et al; "Observations of Strain Accumulation across the San Andreas Fault near Palmdale, California, with a Two-Color Geodimeter, Science, 218:1217, 1982. (X3)

R3. Simon, C.; "California's Ups and Downs," Science News, 123:164, 1983. (X3)

R4. Kerr, Richard A.; "Does California Bulge or Does It Jiggle?" Science, 219: 1205, 1983. (X3)

R5. Jachens, Robert C., et al; "Correlation of Changes in Gravity, Elevation, and Strain in Southern California," Science, 219:1215, 1983. (X3)

GQH6 The Effect of Earthquakes on Geyser Periods

Description. The decrease in the time between geyser eruptions before major local earthquakes, followed by a sharp increase after the quake relieves crustal strains.

Data Evaluation. Detailed data for only a single geyser have been found so far; but here the observations are sound and the phenomenon clearcut. The literature alludes to other geysers showing the same effect but no details are available. Rating: 3.

Anomaly Evaluation. Springs, wells, and geysers are often disturbed as crustal strains increase before a substantial earthquake. Some effect on geyser period, therefore, is to be expected. Unfortunately the oscillating system is so complex, with its major features well out of sight, that one cannot say with assurance which factors cause changes in geyser period. The minor anomaly existing here stems merely from our ignorance of the geyser reservoirs, water flow channels, rock porosity, size of heat source, etc. Rating: 3.

Possible Explanations. With so many variables, abundant scenarios are available. For example, increasing crustal strains might close channels and pores, thus reducing reservoir size. With less water to heat to the critical temperature for geyser action, the time between eruptions might be reduced.

Similar and Related Phenomena. The variations of geyser period with atmospheric pressure (GHG2) and lunar tidal forces (GHG3).

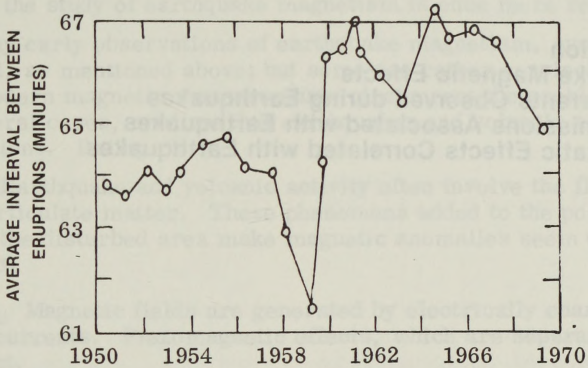
Examples of the Effect of Earthquakes on Geyser Periods

X1. August 17, 1959. Yellowstone Park, Wyoming. "Over the 100 years during which observations have been kept on Old Faithful, the geyser is seen to have responded to every major local earthquake, and the recent extensive records make it possible to examine in detail the response of Old Faithful to the Hebgen Lake earthquake. In 1956 the interval between eruptions began decreasing steadily and rapidly until the time of the quake three years later; then it started to increase. By the summer of 1960 it had reached 67 min, a much higher period than the previous 64-min average for 1950 and 1956. By 1969 it returned to a 65-min interval, where it remained steady until 1972, when it increased to 66.5 min. During the last half of 1972 and the first part of 1973 it went through a minimum of 63.5 min, which presaged 9 local earthquakes of 3.0-5.0 magnitude during March and April." (R1-R3)

References

R1. "The Stresses that Upset Three Old Geysers," New Scientist, 53:529, 1972.

(X1)
R2. Rinehart, J. S.; "Geysers," Eos, 55: 1052, 1974. (X1)
R3. Rinehart, John S.; "Fluctuations in Geyser Activity Caused by Variations in Earth Tidal Forces, Barometric Pressure, and Tectonic Stresses," Journal of Geophysical Research, 77:342, 1972. (X1)



Yearly averages of intervals between eruptions of Old Faithful, showing the effect of the 1959 Hebgen Lake earthquake (X1)

GQM ELECTRICAL AND MAGNETIC PHENOMENA ASSOCIATED WITH EARTHQUAKES

Key to Phenomena

GQM0 Introduction

Only a century or so ago, earthquakes, volcanos, and many other geophysical phenomena were believed with certainty to be caused by great currents of electricity in the earth and atmosphere. Now that we have learned more about the workings of the earth's crust and interior, electrical and magnetic phenomena have been demoted to mere byproducts of crustal stresses and ponderously moving internal fluids. Actually, the reality of some of the phenomena reported below is questioned. It is this attitude, of course, that makes them anomalous when held against the backdrop of prevailing geophysical theory.

There is no returning to the idea that electricity causes quakes and volcanic action, but evidence steadily accumulates confirming that earthquakes and volcanos do generate considerable electricity themselves. We detect this electricity visually (earthquake lights, GLD8), via radio emissions, through the magnetic fields generated, and by observing the earth currents themselves. All of these earthquake phenomena, however, are elusive and not generally accepted by scientists.

GQM1 Earthquake Magnetic Effects

Description. Changes in terrestrial magnetic field parameters prior to, during, and after earthquakes and volcanic eruptions. In recent years, the magnetic field changes have been measured with magnetometers, but the older observations concerned compass disturbances and the motion of suspended magnets. Magnetic anomalies accompanying earthquake activity may be local or planet-wide.

Background. Since earthquakes generate considerable shock and vibration, the disturbances of compasses and suspended magnets may well be caused by mechanical forces rather then magnetic variations. Indeed, early in this century, geophysicists thought that all magnetic observations made around the time of a quake should be rejected because of the strong likelihood of mechanical disturbances (X25). Better instrumentation, however, has overcome these objections, and the study of earthquake magnetism is once more respectable.

Data Evaluation. Many early observations of earthquake magnetism, such as compass disturbances,are suspect, as mentioned above; but some are rather convincing even in the face of the objections. Modern magnetic measurements circumvent the problem of mechanical vibration and, in several cases, confirm that earthquakes and volcanic activity do give rise to magnetic perturbations. Rating: 2.

Anomaly Evaluation. Earthquake and volcanic activity often involve the flow of electrically charged fluids and particulate matter. These phenomena added to the possibility of piezoelectricity flowing in the disturbed area make magnetic anomalies seem quite reasonable---even likely. Rating: 3.

Possible Explanations. Magnetic fields are generated by electrically charged flowing fluids and/or piezoelectric currents. Piezomagnetic effects, which are separate and distinct from the piezoelectric effect.

Similar and Related Phenomena. Earthquake lights (GLD8); the other electrical and magnetic phenomena described in this section (GQM).

Examples of Earthquake Magnetic Effects

X1. November 4, 1799. South America. Humboldt observed that during an earthquake the magnetic dip was reduced by 48', slowly recovering its normal value. Other magnetic parameters were unaffected. (R8) In all other quakes he experienced in the Andes, the magnetic field remained unaffected. (R22) But see X2 below.

X2. October 1802. Lima, Peru. Humboldt recorded that a compass needle made 219 swings in the 10 minutes before a quake, but only 213 after, inferring a decrease of 5%. The dip was permanently reduced by 28'. (R8)

X3. 1828. Mulheim, Germany. An engineer 410 feet deep in a coal mine found his compass impossible to use during an earthquake. (R8)

X4. April 18, 1842. Munich, Germany. A compass swung violently at the same time an earthquake occurred in Greece. (R1, R8) This type of effect might well be due to mechanical rather than magnetic forces. (WRC)

X5. January 19, 1845. No place given. On the steamer Thames, the compasses revolved rapidly during an earthquake in the West Indies. (R2)

X6. November 11, 1855. Tokyo, Japan. Two hours before a devastating quake, a large horseshoe magnet let go all iron clinging to it. (R21)

X7. December 26, 1861. No place given. All six compasses in a magnetic observatory were disturbed during a quake in Greece. (R1) Probably mechanically induced.

X8. October 29, 1867. St. Thomas, Virgin Islands. During a quake and hurricane, compasses were temporarily useless. (R2)

X9. February 23, 1887. The Riviera, France. This earthquake was recorded on most of the magnetographs in Europe. (R8)

X10. June 12, 1897. Bombay, India. "The investigations of Burbank and Reid show conclusively that the majority of the peculiar disturbances recorded by magnetographs at the time of an earthquake are produced mechanically. There is some evidence, however, that there may be a true magnetic disturbance occurring at the time of an earthquake, either resulting from the earthquake movement or from the same cause which produced the earthquake movement. Thus the earthquake of June 12, 1897, disturbed the declination magnet at Bombay, giving fourteen distinct waves in twenty-nine minutes, the natural period of the magnet being 5.33 seconds. Regarding this earthquake, Milne states that a strong disturbance was recorded at nearly every magnetic observatory in Europe which arrived at those stations some time in advance of the large seismic waves, or rather about the time of the preliminary tremors were recorded on the seismographs." (R8)

X11. November 16, 1901. Christchurch, New Zealand. "Probably the best record of long-period waves is one obtained by C. C. Farr at the magnetic observatory at Christchurch, New Zealand, in November, 1901. On the morning of November 16th, Christchurch was visited by a severe shock of earthquake. The magnetograph at the Christchurch Observatory, though in adjustment, was not recording at the time. On visiting the observatory shortly after the first shock it was found that the vertical-force instrument had been thrown out of adjustment, while the others remained undisturbed. As it seemed probable that there would be other earthquake shocks than the first, it was decided to attempt to record some of them by running the magnetograph at high speed. The was done from about noon on the 16th until 7:30 p.m. of the 17th, when the supply of paper ran out, and from 11 a.m. on the 18th until 6 p.m. on the 20th. When arranged for running at high speed, the drums of the magnetograph revolved at the rate of nearly four millimeters per minute. In this way four shocks were recorded, all of them perceptible to some of the residents of the Cheviot District. There were also on the sheets many small sudden irregularities which could scarcely be ascribed to ordinary magnetic phenomena. The records of the declination instrument are all of the same general character and show waves of practically the same period of 137 seconds. On the horizontal-force variometer waves having a period of between 41 and 42 seconds were present in each case. The natural period of the magnets was 10.34 seconds in the case of declination, and 13.07 seconds in the case of horizontal intensity. The Milne seismograph in Wellington showed a series of comparatively small tremors during most of the periods when the magnetograph was being driven at high speed. There was one small tremor corresponding to one of the four disturbances recorded on the magnetograph, but there were many tremors larger than this on the seismograph record which were not recorded at all by the magnetographs. It seems possible that this may have been a real magnetic effect of the earthquakes." (R8)

X12. May 8, 1902. Martinique. The eruption of Mont Pelee. "...in one very important respect, the electrical phenomena accompanying the explosion, Mont Pelee apparently surpassed Krakatoa; for the first time in the history of volcanic eruptions, so powerful electro-magnetic waves were shot out by a bursting volcano that magnetic needles 2,000 and 5,500 miles away were disturbed for many hours. Mr. O.H. Tittmann, Superintendent of the U.S. Coast and Geodetic Survey, reports that the magnetic needles at the Coast Survey magnetic observatories at Cheltenham, Maryland, at Baldwin, Kansas, and also in the Hawaiian Islands, were disturbed on the morning of May 8 at the time of the volcanic explosion at Pelee. The needles are very delicately suspended, and register automatically by photographic means the minutest variation in the direction and intensity of the earth's magnetic force. The magnetic disturbance began at the Cheltenham observatory at a time corresponding to 7.53, St. Pierre local mean time, and at the Baldwin observatory 7.55 St. Pierre time. Reports from St. Pierre state that the explosions of Mont Pelee occurred a few minutes before 8 o'clock in the morning. A clock in St. Pierre was stopped at 7.50 a.m. The magnetic disturbance was thus almost instantaneously recorded at the Survey observatories." (R3-R5)

X13. May 20, 1902. Martinique. The second eruption of Mont Pelee was also recorded on the U.S. Coast and Geodetic Survey magnetometers, as related in X12. (R4)

X14. September 8, 1905. Calabria, Italy. The majority of the magnetographs within 1900 kilometers of the epicenter were disturbed, but it was concluded after analysis that mechanical forces were the cause. (R8)

X15. April 18, 1906. San Francisco, California. Magnetographs throughout the U.S. recorded disturbances at the same times the long waves were registered by the seismographs. Conclusion: probably not a real magnetic effect. (R8)

X16. Late December 1908. Worldwide phenomenon. "An Examination of the magnetograms of the Coast and Geodetic Survey magnetic observatory at Cheltenham showed no disturbance either magnetic or mechanical at the time of the Messina earthquake (December 28, 1908). It called attention, however, to several magnetic disturbances of unusual character occurring during the three days following the earthquake. From an inspection of the magnetograms of the Baldwin and Porto Rico observatories, it was found that similar disturbances were recorded simultaneously at the three observatories. An examination of the Cheltenham magnetograms for the first six months of 1908 failed to discover any disturbances of similar character and the observer in charge of that observatory, Mr. Burbank, reports that none have been noticed by him during his 2 1/2 years duty there. The peculiar feature of these disturbances is that they were of short duration and occurred at times when the magnetic conditions were otherwise unusually calm. They might be compared to short thundershowers occurring on a bright summer day, were it not for the fact that they were evidently worldwide in extent rather than local.....It may be simply a coincidence that these peculiar disturbances occurred on the days immediately following the Messina earthquake, but there is at least a possibility that they were caused by some after effects of that convulsion of nature." Each disturbance lasted 20-30 minutes. (R5)

X17. August 3, 1926. Gulf of Tokyo, North Pacific Ocean. From the West Holbrook. "While the above-named vessel was entering the Gulf of Tokyo, 6:40 P.M. A.T.S. (apparent time of ship), on the above-named date, a slight tremor was felt, as if vessel was grounding. Vessel shivering and a noise was heard, as if touching a rocky ledge, but no reduction in speed could be noticed. Vessel heading at the time 328° P.S.C., 319° true. Deviation 3.°6 west on course. Bearings were immediately taken of Suno Saki Light bearing north 26° east true, and Merano Hana Light bearing north 93° east true; which placed vessel in latitude 34°55' north, longitude 139°43'30" east, and by chart in from 46 to 50 fathoms of water. From the above position to Yokohama, the ship's compasses were acting queerly, having on northerly courses a deviation of 0°.5 west; where before there had been 3° west. Upon arrival in Yokohama learned that an earthquake had taken place. The following morning, August 4, azimuths were taken for recording deviation. The compasses were still found to be out. On August 5 azimuths were again taken and the compasses were now found to be back to normal." (R9)

X18. April 22, 1928. Mediterranean Sea. "On April 22, 1928 at 18:20 G.M.T. in latitude 33°38' north, longitude 24°04' east, course 286° true---north 71° west (Standard)---a difference of 5° was noticed in comparison between gyro and magnetic-compass courses. As both standard and steering compasses were similarly affected, it was at first supposed that gyro compasses were at fault, but investigation showed both masters to be running normally, and they remained in agreement throughout---nor had any electrical changes taken place in the ship. It had therefore to be assumed that for some reason the north point of the magnetic compasses had been deflected to the westward. After 10 minutes the difference gyro and magnetic courses began to decrease, until at 19:10 G.M.T. the standard compass course became normal again ---to be followed shortly after by the steering compass. As both magnetic compasses were deflected similarly it is doubtful whether a vessel not fitted with gyro compasses would have been aware of the disturbance. Unfortunately no azimuths could be taken during the phenomenon. It is noteworthy that the time of the occurrence was practically coincident with the earthquake which destroyed the town of Corinth, and that the above position is on the same magnetic meridian as that place." (R9) Other magnetic transients of this type are cataloged in GM. (WRC)

X19. May 22, 1960. Port Moresby, Australia. "D.E. Winch, B.A. Bolt and L. Slancitajs, of the Department of Applied Mathematics of the University of Sydney, have made a frequency analysis of magnetic records obtained at the Port Moresby Observatory before and after the great Chilean earthquake of 22 May, 1960. After an earthquake of this magnitude (8.5 on the international scale), the Earth vibrates in a variety of different ways. Among others it has a torsional, or twisting, vibration in which one hemisphere oscillates in the opposite direction to the other. The three most important of these torsional 'modes' have periods of 43.6, 28.2 and 21.6 minutes. As a result of their analysis the Australian workers found that the vertical and horizontal components of the magnetic field had small harmonics with frequencies close to these values (namely 43.1, 29.0, and 22.4 minutes) which were clearly the result of the earthquake." (R10)

X20. March 27, 1964. Kodiak, Alaska. "Through a fortunate circumstance, a recording magnetometer was operating in the city of Kodiak, 30 km north-west of the surface trace of a fault zone along which movement occurred at the time when the earthquake occurred in Alaska on March 27, 1964. Fortunately, too, the instrument was on such high ground that it was not reached by the subsequent seismic sea wave, which virtually destroyed the city. The magnetometer recorded the fact that the largest of several magnetic disturbances briefly increased the intensity of the Earth's magnetic field by 100γ at Kodiak, 1 h 6 min before the earthquake..... One possibility is that the magnetic events which preceded the Alaska earthquake resulted from piezomagnetic effects of rocks undergoing a change in stress. Why such abrupt disturbances occurred in advance of the earthquake is unknown; but a causal relation is indicated by the fact that Breiner has recently reported similar positive magnetic disturbances prior to minor earthquakes in Nevada and California. These observations taken together, suggest that magnetic monitoring may provide a means of predicting a major earthquake in time to save lives and property." (R11)

Magnetometer records indicate that the Alaskan quake excited some of the torsional eigenmodes of the earth's magnetic field. (X12, X13)

X21. 1965-1966. California. An array of magnetometers recorded disturbances tens of hours before creep displacements and severe local earthquakes occurred. (R14)

X22. 1969. Mt. Ruapehu, New Zealand. Magnetic variations much larger than the usual fluctuations were detected before the eruption of this volcano. (R15)

X23. 1971. Hawaii. "Abstract. During the course of an electromagnetic survey about Kilauea Volcano in Hawaii, an unusual amount of low-frequency noise was observed at one recording location. Several weeks later an eruption occurred very close to this site. The high noise level appeared to be associated with the impending eruption." (R16) Additional magnetic surveys have been made around Kilauea, as discussed below.

Compiler's Summary. The investigators hoped to show that magnetic anomalies preceded volcanic eruptions and might be used to help forecast volcanic activity. Previous measurements in New Zealand (X22) had encouraged this hope. In this paper, magnetic measurements made around Kilauea Volcano, Hawaii, are reported. During 12 months of observations, only a weak correlation between magnetic anomalies and ground tilt were observed, leading to the conclusion that no large-scale pattern of stresses existed that might cause piezomagnetic effects. (R17, R18)

X24. November 28, 1974. Hollister, California. Abstract. "Simultaneous measurements of geomagnetic field with an array of seven proton precession magnetometers along the San Andreas fault shows that the most significant local changes during 1974 were recorded at a site 11 km from a magnitude 5.2 earthquake that occurred on November 28, 1974. A systematic increase in magnetic field of 0.9γ occurred at this site during the early part of 1974. A more dramatic increase of 1.5γ occurred about 7 weeks before the earthquake, lasting about 2 weeks. Four weeks prior to the earthquake the magnetic field returned to approximately its initial value and remained at this value through April 1975. These data cannot be explained by ionospheric disturbances or telluric currents. The most probable source is a piezomagnetic effect, which implies that the magnetic field changes represent changes in stress in the rocks nearby the anomalous station." (R19, R20)

X25. General observations. "There are so many ways by which oscillations can be produced mechanically that we are led to the conclusion that the broadening, blurring, or sudden interruption of the magnetic trace at the time of earthquakes is due to oscillations of the magnets caused by purely mechanical vibrations, and does not require us to assume the existence of real magnetic forces or electric currents; and, moreover, that the differences in the periods and other constants of the recording magnets in actual use account, probably sufficiently, for their various responses to earthquake disturbances." (R6, R7) As the more recent papers noted above imply, scientists are now much more receptive to the reality of seismomagnetic effects. (WRC)

X26. February 19, 1822. Paris, France. Changes in the dip and variation needles noted when a quake occurred in southern France. No shock felt at Paris. (R22)

X27. May 31, 1822. Paris, France. Same phenomenon as X26. (R22)

X28. 1869. South Atlantic Ocean. A supposed submarine earthquake. The sky became black. Distant detonations were heard. The sea became tossed and confused. The compass of the barque Euphrosyne vibratated violently and nearly lost its polarity. (R23) May not have been a quake. (WRC)

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R3. Bauer, L. A.; "Magnetic Disturbance at Time of Eruption of Mont Pelee," Science, 15:873, 1902. (X12)

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R5. Hazard, D. L.; "Peculiar Magnetic Disturbances in December, 1908," Terrestrial Magnetism and Atmospheric Electricity, 14:37, 1909. (X12, X16)

R6. Reid, Harry F.; "The Influence of Earthquake Disturbances on Suspended Magnets," Seismological Society of America, Bulletin, 4:204, 1914. (X25)

R7. Nature, 95:215, 1915. (X25)

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R9. Chapman, S.; "A Note on Two Apparent Large Temporary Local Magnetic Disturbances Possibly Connected with Earthquakes," Terrestrial Magnetism and Atmospheric Electricity, 35:81, 1930. (X17, X18)

R10. "Chilean Earthquake Disturbed Earth's Magnetism," New Scientist, 18:738, 1963. (X19)

R11. Moore, George W.; "Magnetic Disturbances Preceding the 1964 Alaska Earthquake," Nature, 203:508, 1964. (X20)

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R14. "Predicting Earthquakes by Changes in Rock Magnetism," New Scientist, 36:176, 1967. (X21)

R15. "Magnetic Variations before Eruption," Science News, 97:39, 1970. (X22)

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R19. Smith, B.E., and Johnston, M.J.S.; "A Tectonomagnetic Effect Observed before a Magnitude 5.2 Earthquake near Hollister, California," Journal of Geophysical Research, 81:3556, 1976. (X24)

R20. Johnston, Malcolm; "Tectonomagnetic Effects," Earthquake Information Bulletin, 10:82, 1978. (X24)

R21. Tributsch, Helmut; "A Seismic Sense," The Sciences, 22:24, December 1982. (X6)

R22. Mallet, Robert; "First Report on the Facts of Earthquake Phaenomena," Report of the British Association, 1850, p. 72. (X26, X27)

R23. "Submarine Earthquake in the Atlantic," Eclectic Magazine, 9:498, 1869. (X28)

GQM2 Earth Currents Observed during Earthquakes

Description. The observation of anomalous earth currents in the vicinities of earthquake epicenters. Earth current anomalies may be measured by special electrodes buried in the ground, but more often they are detected in long communication lines and pipelines carrying gas and oil.

Data Evaluation. Beyond one rather incredible account of metal fusion, only vague allusions to this phenomenon have been uncovered in the literature. Doubtless, more will be found in the journals covering communications and pipeline engineering. Rating: 3.

Anomaly Evaluation. The discovery of earth current anomalies near earthquake epicenters would not be considered especially remarkable in light of the many observations of earthquake lights (GLD8) and the known characteristics of the piezoelectric effect. Rating: 3.

Possible Explanations. Quake-induced stresses in rock formations in epicentral regions generate earth currents, which add to or subtract from the normal earth currents in the area.

Similar and Related Phenomena. Earthquake lights (GLD8), which may be electrical in origin; radio emission from fault regions (GQM3); electrostatic effects prior to quakes (GQM4); the electrical currents induced in long communication lines and pipelines by auroras (GLA20).

Examples of Earth Currents Occurring During Earthquakes

X1. March 30, 1828. Calloa Roads, Peru. "The morning clear, and a light breeze from the southward. At 7h, 28m, a black thin cloud passed over the ship, with very heavy distant thunder. At the same moment we felt the shock of a severe earthquake. I should think it continued seventy or eighty seconds. The ship trembled violently, and the only thing I can compare it to is, the ship being placed on trucks, and driven with rapidity over coarse paved ground. The ship was moored with two chain-cables, and on weighing the anchors a few days after, we found 56 links of the best bower cable much injured; the iron had the appearance of being melted, and nearly one-sixth of the link was destroyed. This piece was 30 fathoms from the anchor, and 20 fathoms from the ship. The bottom was soft mud, in which the cable was buried. During the earthquake the water alongside was full of little bubbles; the breaking of them sounded like red-hot iron put into water. The city of Lima suffered considerably, and a number of lives were lost." (R1) It is, of course, only conjecture that quake-generated earth currents melted the chain. (WRC)

X2. General observations. Telegraphic land lines and submarine cables have often been disturbed by earth currents at the times of earthquakes. (R2) No further details given.

X3. November 26, 1930. Idu region, Japan. "....on the occasion of the Idu Earthquake an unusual fluctuation of current was recorded by the recording system for the submarine cable of Guam Line, though it cannot be ascertained whether it was not due to a merely mechanical cause. Again, on the occasion of an earthquake in the neighborhood of Tokyo on 30th January of this year, a remarkable oscillation was revealed in the recording system of earth-current between Tokyo and Hoya while the similar system between Tokyo and Yokohama showed no trace of such fluctuation of current. The former circuit is perpendicular to the direction of the epicentre, while the latter is nearly parallel to it. Similar cases may be found frequently in the earlier literatures of earthquake phenomena, though regarded mostly as trivial and neglected by modern students of seismology." (R3)

X4. January 30, 1931. Tokyo, Japan. See details in X3. (R3)

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R3. Terada, Torahiko; "On Luminous Phenomena Accompanying Earthquakes," Earthquake Research Institute, Bulletin, 9:253, 1932. (X3, X4)

GQM3 Radio Emissions Associated with Earthquakes

Description. The correlation of episodes of strong radio noise with subsequent earthquakes. Such observations have been made in the range from 20 MHz to 1 kHz, but the total range of the emissions is unknown.

Data Evaluation. In addition to excellent data from Japanese receivers set up specifically to explore this phenomenon, radio precursors of the great Chilean quake of May 1960 were apparently picked up by cosmic radio noise monitors across the U. S. Rating: 2.

Anomaly Evaluation. Since the stressing and fracturing of rock are known to generate radio noise and electrical currents, radio-band earthquake precursors are not unexpected, although they have received little scientific attention to date. Rating: 3.

Possible Explanations. Radio noise is created by piezoelectric currents in the epicentral region of a quake, with the fault line possibly serving as a long antenna.

Similar and Related Phenomena. Earthquake lights (GLD8), earth currents correlated with quakes (GQM2), electrostatic effects associated with earthquakes (GQM4).

Examples of Radio Emissions Associated with Earthquakes

X1. May 1960. Apparent worldwide phenomenon. Radio emissions recorded at cosmic radio noise stations tuned to 18 MHz located at Lake Angelus, Michigan; Boulder, Colorado; Sacramento Peak, New Mexico; Makapuu Point, Hawaii. From the Summary: "We have tentatively identified radio emission that came about 6 days before the greatest earthquake of the past several decades and that was produced in the fault zone. While the direct evidence for this identification falls short of being absolutely compelling, nevertheless, the character of the radio event is of the same extraordinary nature as the earthquake itself. In particular, the lack of discrete direction of arrival of the radio waves over a region of continental dimensions implies a source comparable to the great fault itself. If the signal source is not the fault zone, it must be of similar angular dimensions as the fault and lie at least several thousands of kilometers from the radio observatories." (R2, R3) The earthquake referred to was doubtless that of May 21 in Chile. (WRC)

X2. 1976. Verscio, Switzerland. Just before a severe quake in northeast Italy, while listening at VHF frequencies. "I suddenly became aware of a high pitched, rustling noise in the speaker sounding like scrubbing a fine emery paper against glass. It occurred at longer and shorter intervals for a duration of about 1 to 3 seconds. I first thought my transmitter had gone wrong. Accordingly I checked the whole VHF line and found those scratching noises on the whole VHF range. But note: the much more interference-susceptible AM broadcast kept completely clear and clean over all that period. After I had checked everything (including the antenna connections) I went on listening, thinking that a thunderstorm was approaching, which of course was absolute nonsense. Lightning strong enough to be audible on such a strong FM field makes listening nearly impossible on AM..... Seconds later the tremor struck. It was strong enough to set the lamps moving and to produce a somewhat uncomfortable feeling." After the quake the radio noise disappeared. (R1)

X3. March 31, 1980. Tokyo, Japan. Abstract. "Recent observations in the USSR appear to suggest that wide-band electromagnetic radiation occurs just prior to earthquakes. To apply this phenomenon to earthquake prediction, measurements have been carried out at the Sugadaira Space Radiowave Observatory in Japan under the USSR-Japan Cooperation Program in 1980. The recorded noise level at 81 kHz is comparatively quiet throughout the day and night. However, about one half hour before the main shock of a magnitude 7 earthquake at 0733 UT on March 31, 1980, the instrument recorded an anomalous amplitude increase to 15 dB higher than the normal level. VLF data recorded synoptically at Sugadaira suggest that unusual impulsive radiation at frequencies below 1.5 kHz also occurred shortly before the earthquake. Similar 81-kHz emissions were observed prior to magnitude 5 and 6 earthquakes on September 25, 1980, and January 28, 1981." (R4)

X4. September 25, 1980. Tokyo, Japan. See details in X3. (R4)

X5. January 28, 1981. Tokyo, Japan. See details in X3. (R4)

References

R1. Markert, Mischa; "Earthquake," New Scientist, 70:488, 1976. (X2)

R2. Warwick, James W., et al; "Radio Emission Associated with Rock Fracture: Possible Application to the Great Chilean Earthquake of May 22, 1960," Journal of Geophysical Research, 87B:2851, 1982. (X1)

R3. "Radio Signals before Quakes?" Science News, 121:200, 1982. (X1)

R4. Gokhberg, M. B., et al; "Experimental Measurement of Electromagnetic Emissions Possibly Related to Earthquakes in Japan," Journal of Geophysical Research, 87B:7824, 1982. (X3-X5)

GQM4 Electrostatic Effects Correlated with Earthquakes

Description. Sparking, electrical shocks, the mutual attraction and/or repulsion of objects, and similar phenomena occurring around the time of earthquakes.

Data Evaluation. A single account of electrostatic repulsion. Rating: 3.

Anomaly Evaluation. Electrostatic effects are common in mountainous areas, particularly just before thunderstorms. Such phenomena would not be out-of-place in the neighborhood of an earthquake, providing quakes actually do generate considerable current flow. However, the mutual repulsion of light objects, described in X1, may indicate the emission of charged aerosol particles from the earth---a type of earthquake precursor that is not yet widely accepted. Rating: 2.

Possible Explanations. The piezoelectric effect might increase the atmospheric electric field strength in the epicentral area and, in addition, ionize gases and aerosols released from the earth. Reasonable as these phenomena sound, next to nothing is known about them.

Similar and Related Phenomena. Earthquake weather (GQW1), which may involve ions in the air; earth currents correlated with quakes (GQM2); the strange behavior of animals before earthquakes (GQB1), which may be the result of aerosol emissions.

Examples of Electrostatic Effects Correlated with Earthquakes

X1. May 6, 1976. Friuli, Italy. "...I spoke to a retired precision mechanic. As the time of the earthquake approached he was repairing a small wrist-watch. One operation consisted (of) placing a thin lamella of stainless steel---estimated to weigh a few tenths of a gram---on the clockwork. It would not stay there but jumped from its place. After several futile attempts the confused man went and looked at the weather outside; the sky was completely cloudless. After resuming his work he still found the strong electrostatic repulsion phenomenon; immediately afterwards the first shock occurred. Only charged aerosol particles could have caused such a strong charging of metal parts in the same polarity. It led me to hypothesise that before the earthquake an unknown geophysical phenomenon liberates electrostatic charges from underground." (R1) The author also believes that charged aerosols emitted from the ground before earthquakes are detected by animals. (GQB1)

References

R1. Tributsch, Helmut; "Do Aerosol Anomalies Precede Earthquakes?" Nature, 276: 606, 1978. (X1)

GQS EARTHQUAKE PERIODICITIES

Key to Phenomena

GQS0 Introduction

Earthquakes and volcanic eruptions do not occur randomly. This fact was apparent in the early 19th. century, when the first systematic catalogs of quakes and eruptions were put together from historical records. It was naturally assumed that seismic activity was triggered by some driving force that released pent-up crustal strains. And where could such periodic forces be found? In the gravitational influences of the sun and moon, of course. Based upon limited data and some imperfect statistical analysis, it seemed that earthquake frequency was high when: (1) Sunspots were abundant; (2) The moon was full and/or new; (3) It was winter; and (4) It was nighttime.

Today, these correlations seem simplistic, although there is some truth to them for some classes of earthquakes in some geographical areas. Earthquakes, it seems, have different periodicities according to their sizes and characters. Small aftershocks, for example, seem more easily triggered by lunar tidal forces than large quakes. The depth of the earthquake, too, is of importance, as is the location of the epicenter in relation to tectonic plate boundaries. The correlation of earthquakes and volcanic eruptions with astronomical phenomena is not as clearcut and certain as it was a few score years ago.

The cause-and-effect requirements of science insist that earthquakes be stimulated by some force. Periodic tidal forces exerted by the sun and moon are the most obvious, but inertial forces play a role, too. To illustrate, the earth undergoes frequent, very small changes in rotational velocity, possibly because of changes in wind-loading. Like a house creaking in a heavy wind, earthquakes may occur in the slightly bending crust. Even geomagnetism may produce slight glitches in the earth's rotation; and there are always tectonic forces caused by the motions of subcrustal magmas.

The scientific study of earthquake periodicity that began so confidently a century ago is now revealed to be an exceedingly complex situation---one that is remarkably similar to the analysis of sun-weather correlations (GWS). The two subjects, in fact, may be causally linked in several ways; viz., wind-loading affects quake frequency and volcanic activity, while volcanic dust in the air helps create weather and climate. No phenomenon is completely isolated.

GQS1 Earthquakes Correlated with Solar Activity

Description. The correlation of earthquake frequency with indices of solar activity, such as sunspot number, specific solar flares, or geomagnetic phenomena, which are in turn correlated with solar activity. Volcanic eruptions are sometimes included in the correlations.

Background. Over a century ago, some scientists suspected that earthquakes might be related to solar activity. But what seems to be a straightforward statistical task has turned out to be murky and contradictory. Down the years, the peaks of earthquake activity have been correlated with: (1) Sunspot maxima; (2) Sunspot minima; (3) Both sunspot maxima and minima; and (4) Specific solar flares. Furthermore, some data seem to indicate that solar and earthquake activities are not causally related at all. In reviewing the literature it is curious how firmly diametrically opposite conclusions are stated. The situation resembles the supposed relationship between solar activity and terrestrial weather (GWS5).

Data Evaluation. Excellent records of sunspot frequency exist for the last century and even farther back in time. Catalogs of major quakes are available, but the older ones do not include all geographical areas. Modern catalogs are more complete but still slight the more remote regions of the globe. Microearthquake records are very spotty. Rating: 2.

Anomaly Evaluation. A strong correlation between earthquake and solar activities would imply physical cause-and-effect acting across 93 million miles; or, as Ellsworth Huntington put it (X6), an unknown solar-system influence acting on both earth and sun. Scientists usually reject the latter possibility and search for physical links connecting sun and earth, such as the solar wind. No agreement exists on the nature of this link. Rating: 2.

Possible Explanations. Variations in solar activity modulate the solar wind, which interacts with the earth, causing small, abrupt changes in the earth's rate of rotation, which trigger earthquakes.

Similar and Related Phenomena. The correlation of earthquakes with the Chandler wobble (GQS10). The correlation of earthquake frequency with lunar position (GQS2) and solar position (GQS12).

Examples of Earthquakes Correlated with Solar Activity

X1. General observations. Earthquakes and volcanic eruptions tend to occur when sunspots are maximum and minimum. (R1)

X2. General observations. The major eruptions of Hawaiian volcanos tend to take place when the sunspot number is minimum. (R2)

X3. General observations. "The author of this paper mentions that the idea of the existence of such a connection was suggested to him by the fact that Vesuvius was in violent eruption in the years 1813, 1822, 1855, 1867, 1891, and 1900, all of which were minimum years. By means of a chart he shows that earthquakes and eruptions are most violent, numerous, and extensive when there is least sunspot activity. Though seismic disturbances do occur at all times, they seem for the last one hundred and twenty years to have been most severe around the minimum years---1811, 1822, 1833-4, 1844, 1855-6, 1867-8, 1878-9, 1888-9, and 1900-2, large groups of great earthquakes and eruptions having taken place in and about these years. On the other hand, the chart also shows that in years of maximum like 1893-8, 1884-5, 1869-71, 1858-65, and so on, these phenomena have been comparatively few and unimportant." (R3)

X4. Statistical analysis. There is little in any correlation between the frequency of volcanic eruptions and sunspot number. (R4)

X5. General observations. "Earthquakes of considerable or even tremendous magnitude have been remarkably numerous during these early years of the 20th. century, and have naturally given increased zest to the search for a scientific law---undiscovered, but certainly existent---which comprehends the operation of these formidable phenomena. Thus, Herr Novack, an Austrian savant, recently predicted that from Oct. 2 to 6 there would be a renewal of the seismic shocks which lately wrought such dreadful havoc in Southern Italy. This prediction was made in agreement with the theory that there is some connection between sunspots and earthquakes---an hypothesis which has had the attention of no less an authority on solar physics than Sir J.N. Lockyer, who, after an exhaustive examination of the available records, has found that the greatest earthquakes and volcanic eruptions have been coincident with the epochs of both maximum and minimum solar activity. As examples: the terrible Krakatoa eruption on August 27, 1883, took place at sunspot maximum, and the West Indies outbursts of May 1902, happened at a minimum period. The indictment against sunspots, or, more accurately, against the increased solar activity of which, after all, they are but the scenery, is a long and serious one, comprising as it does almost every human ill, from the incidence of German measles to the occurrence of an empire-shaking war. There is certainly not sufficient evidence, however, to convict them of causing, or even aiding and abetting in the perpetration of, earthquakes and eruptions; since if solar activity were an efficent or even subsidiary cause of these earthly tremors, one would reasonably expect to see increased solar and terrestrial activity existing coincidentally, whereas we find great seismic and volcanic disturbances occurring indifferently at maximum and minimum of the sunspots." (R5)

X6. General observations. "In regard to the relation of solar activity to earthquakes and volcanoes, there is at present no agreement among students. On the whole, the evidence has seemed to most investigators to indicate that there is no relation. This appears to be largely due to the use of individual cases instead of averages, and to an attempt to find a coincidence between telluric activity, manifested in earthquakes and volcanoes, and <u>maximum</u> epochs of solar spottedness. Jensen, however, who has taken up the subject in a comprehensive fashion in volume thirty-six of the "Proceedings of the Royal Society of New South Wales," has come to a different conclusion. He has compiled a list of notable earthquakes and volcanic eruptions from 1783 to 1902. Each occurrence has been assigned a value of one, two, three, or four, according to its severity, and all the earthquakes and eruptions for the whole series of years have been plotted as shown in Fig. 1. (Not reproduced) Having in this way obtained a graphic representation of the intensity of telluric activity in each year, Jensen added a curve showing the occurrence of sunspot maxima and minima. An inspection of the diagram thus obtained shows that earthquakes and volcanic eruptions are most frequent and most intense during the years shortly before and after sunspot minima." (Lengthy analysis of graphs omitted.) "The resemblance between the mean sun-spot and mean seismo-volcanic curves is extraordinary. The maximum of the one occurs at the same time as the minimum of the other, and in both cases there is a steady progress from maximum to minimum and back. If our terrestrial data of earthquakes and volcanoes were as complete as our solar data of sun-spots, it is probable that the resemblance between the two curves would be still closer. It may be that the occurrence of earthquakes and eruptions lags somewhat behind the change in the number of sun-spots, but the lag is so slight that it does not appear where the unit of measurement is a year, although it might if the unit were a month. It seems to be impossible to avoid the conclusion that the marked coincidence between telluric and solar activity indicates a relation of some sort between the internal phenomena of the earth and the sun. As to what that relation may be we have as yet no clue. The best that we can do is speculate. It may be, perchance, that there is some cosmic source of energy as yet unknown, which pulsates through the universe causing both the earth and the sun to respond, each according to its kind. Possibly changes in the amount or in the nature of the energy emitted by the sun engender corresponding changes in the earth in some manner as yet beyond our ken." (R6)

X7. General observations. A review of earthquakes and volcanic activity for the decade 1900-1909, noting that in this and the two preceding decades, the two phenomena have followed the sunspot cycle (R7)

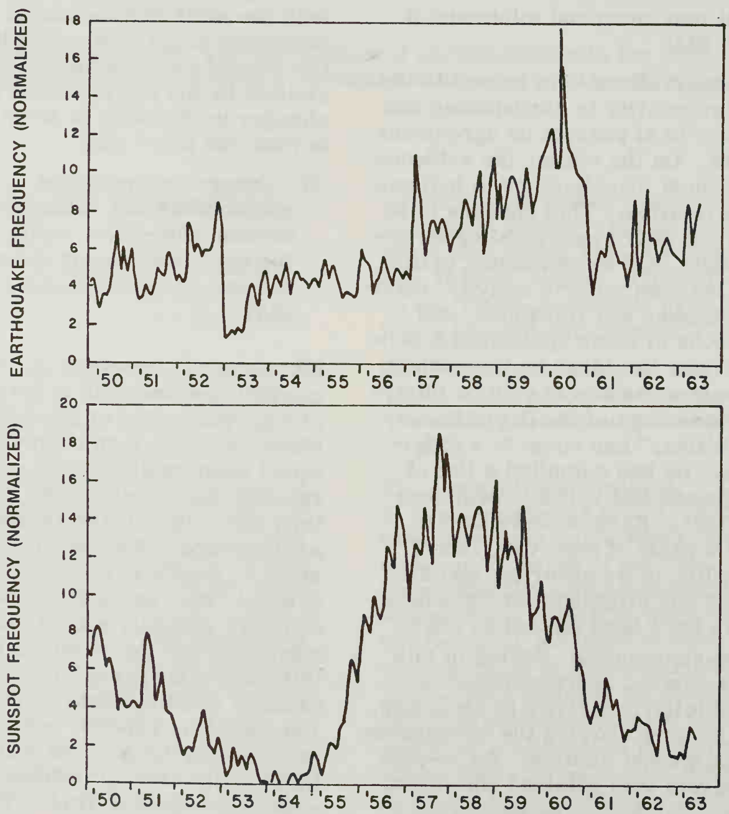
X8. General observations. "I have noticed a marked synchronization between the position of a certain group of Sun-spots and earth-shocks of more than ordinary intensity. It would seem that when the group of spots reached the extreme edge of the Sun's eastern limb (after being carried across the averted face of the Sun, and therefore just about to reappear to our sight), then, at that critical date, an earth-shock of more than ordinary intensity was recorded. Time after time did this occur in connection with this particular group of spots, until several of these synchronizations having been noted, I ventured to 'predict' earthquake shocks on or about the dates of the sun-spot group attaining this critical position on the extreme edge of the eastern limb. These 'predictions' were in due course verified, but whether the matter was a series of remarkable coincidences or not, I cannot, in my present position, venture to say." (R8) This item differs by connecting earthquake activity with a specific group of spots. The following paper considers the distribution of spots on the sun's hemispheres. (WRC)

X9. General observations. "An interesting paper by Prof. T. Terada has recently been received which bears the title 'On Some Remarkable Relations Between the Yearly Variations of Terrestrial Phenomena and Solar Activities.' The association of earthquakes with spot frequencies in the north and south hemispheres of the sun, called N and S is examined, and Terada finds that for some places in Japan and Jamaica, minima of earthquake frequency occur in years when N - S is small, while for others, maxima occur under these conditions; some places show neither feature.....The idea that important geophysical phenomena depend on the difference of the sun's activities in the northern and southern hemispheres is so important that Prof. Terada's future papers will be awaited with much interest." (R9)

X10. Statistical analysis. The frequency of destructive earthquakes peaks just before the minimum in sunspot frequency. (R10)

X11. Statistical analysis. Abstract. "Solar activity, as indicated by sunspots, radio noise and geomagnetic indices, plays a significant but by no means exclusive role in the triggering of earthquakes. Maximum quake frequency occurs at times of moderately high and fluctuating solar activity. Terrestrial solar flare effects which are the actual coupling mechanisms which trigger quakes appear to be either abrupt accelerations in the earth's angular velocity or surges of telluric currents in the earth's crust. The graphs presented in this paper permit probabalistic forecasting of earthquakes, and when used in conjunction with local indicators may provide a significant tool for specific earthquake prediction." (R11, R12)

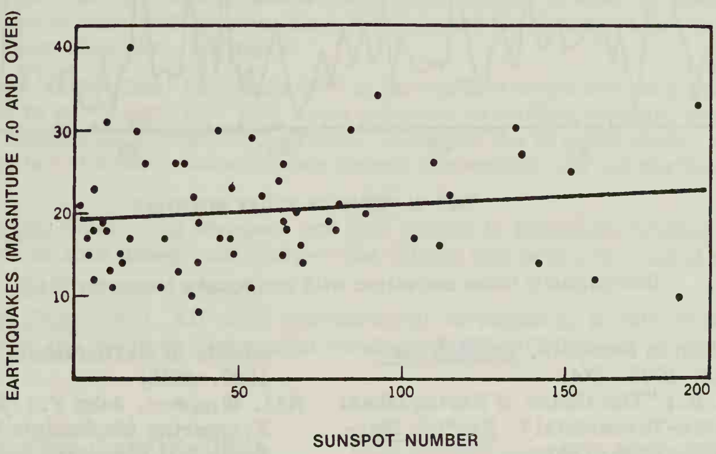
X12. General observations. Author asserts that solar activity may be linked to sudden changes in the earth's rate of rotation,



Comparison of earthquake frequency with sunspot frequency (X11) and that the latter may initiate earthquakes. (R13)

X13. Statistical analysis. "...observation shows that there is no relation between the solar activity and the number of big earthquakes. For example, there were 31 earthquakes of magnitude 7.0 or greater in 1944, the year of a sunspot minimum (mean sunspot number N = 9.6), while there were only 25 in 1947, a year of high sunspot maximum (N = 151.6). The figure shows the number E of earthquakes of magnitude 7.0 and greater, and the annual mean of the Zurich sunspot numbers N, for each year from 1905 to 1964. The numbers of earthquakes have been taken from the list of S. J. Duda. There is clearly no relation between solar activity and the number of earthquakes." (R14)

minor peak of microearthquakes at March 17 to March 31, 1966, also corresponds to a relatively less prominent peak in A_p at March 17 to March 31, 1966. However, a very prominent peak of microearthquakes at May 11 to May 25, 1967, precedes a prominent peak in A_p at May 26 to June 9, 1967, erroneously suggesting that microearthquakes produced the increased solar activity. This apparent contradiction can be explained when we examine the daily values of microearthquakes and A_p, instead of 15 days averaged values. For this interval, there is an increase of A_p on May 3 to 90 and on May 26, 1967, to 145. Whereas the daily background is about 15. For the same interval the only increase in microearthquake activity is on May 13, 1967, being 28 compared to a daily background of about 2.



The number of large earthquakes does not correlate well with sunspot number (X13)

X14. Statistical analysis. After noting that the great solar storm of August 1972 coincided with a large surge of microearthquake activity. "...it was decided that microearthquakes for a longer period of time be used to check whether such a relation still exists. Though there is a continuous monitoring of microearthquakes at this place (Socorro region, New Mexico), data of only 5 years from 1963 to 1968 were available, at the time of this study, in the processed and accesible form on computer cards. These microearthquakes are shown in Figure 2, along with the geomagnetic index A_p. A clear rise in the number of microearthquakes can be seen corresponding to A_p peaks on September 14 to September 28, 1963, October 29 to November 12, 1963, and August 29 to September 12, 1966. A

Thus, even for this peak, microearthquake increase follows a peak in A_p. There exist some minor peaks, like the one at December 7 to December 21, 1964, with no corresponding increases in A_p. It seems, therefore, that the solar activity is by no means an exclusive factor in the timing of microearthquakes." (R15)

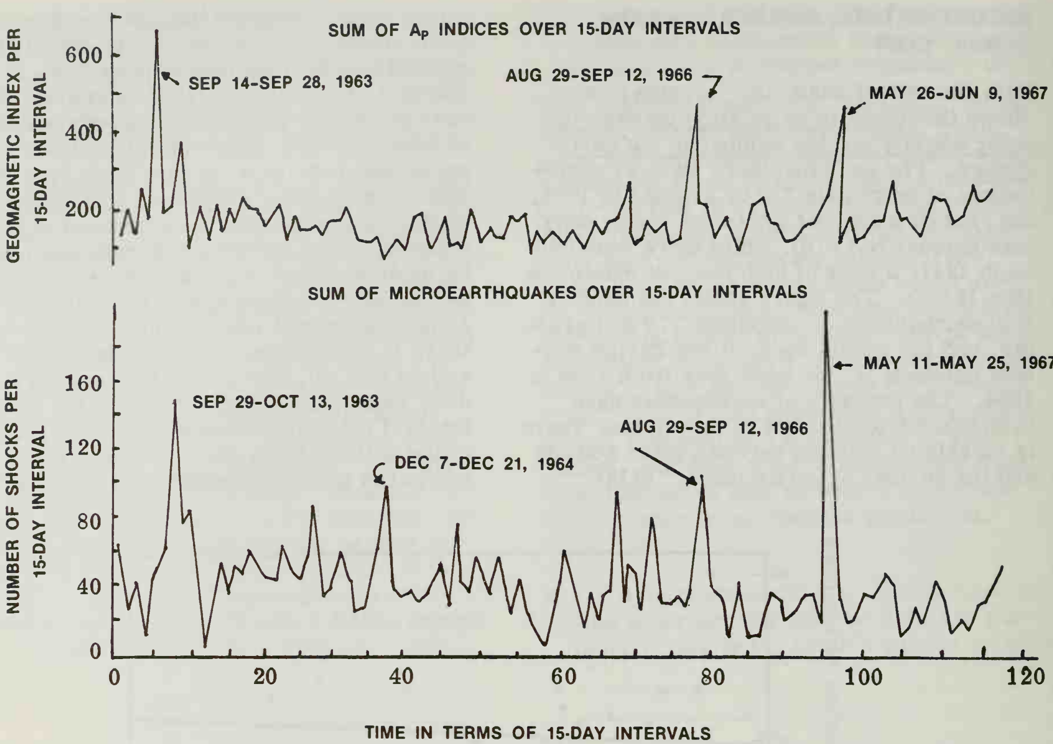
References

R1. Swinton, A. H.; "Sun-Spottery," Journal of Science, 20:77, 1883. (X1)

R2. Lyons, Curtis J.; "Sun Spots and Hawaiian Eruptions," Monthly Weather Review, 27:144, 1899. (X2)

R3. "Volcanic Eruption and Sunspot Phenomena," English Mechanic, 75:498, 1902. (X3)

R4. Espin, T. E.; "Volcanic Eruptions, and



Geomagnetic index correlated with earthquake frequency (X14)

Their Relation to Sunspots, English Mechanic, 76:13, 1902. (X4)

R5. Wallis, J. B.; "The Cause of Earthquakes: Is It All Extra-Terrestrial?" English Mechanic, 82:277, 1905. (X5)

R6. Huntington, Ellsworth; "Coincident Activity of the Earth and the Sun," Popular Science, 72:492, 1908. (X6)

R7. Soley, John C.; "The Messina Earthquake and the Events Preceding It," Scientific American Supplement, 68:90, 1909. (X7)

R8. Hawks, Ellison; "The Sun and Earthquakes," British Astronomical Association, Journal, 20:38, 1909. (X8)

R9. "Sunspot Frequencies and Terrestrial Phenomena," Nature, 119:293, 1927. (X9)

R10. Davison, Charles; "Clustering and Periodicity of Earthquakes," Nature, 120:587, 1927. (X10)

R11. Simpson, John F.; "Solar Activity as a Triggering Mechanism for Earthquakes," Earth and Planetary Science Letters, 3:417, 1967. (X11)

R12. "Earthquakes May Be Triggered by the Sun," New Scientist, 38:357, 1968. (X11)

R13. Gribbin, John; "Relation of Sunspot and Earthquake Activity," Science, 173:558, 1971. (X12)

R14. Meeus, Jean; "Sunspots and Earthquakes," Physics Today, 29:11, August 1976. (X13)

R15. Singh, Surendra; "Geomagnetic Activity and Microearthquakes," Seismological Society of America, Bulletin, 68:1533, 1978. (X14)

GQS2 Earthquakes Correlated with the Moon's Position

Description. The increase of seismic and volcanic activity with increasing lunar tidal action. The major cycles involved are the lunar semidiurnal and monthly tides, particularly the apparent clustering of volcanic and earthquake activity near the new and full moons.

Background. Several tens of thousands of earthquakes and thousands of episodes of volcanic activity have been recorded over the past 2000+ years. Scientists never seem to tire of trying to relate these events to the position of the moon. Some extensive studies have reached opposite conclusions with regard to major quakes and volcanic eruptions; that is, some conclude that no lunar tidal effect exists while others are certain it does. More recently, however, a consensus seems to be developing supporting the thesis that lunar tidal forces definitely trigger microearthquakes and aftershocks.

Data Evaluation. The times and places of many thousands of earthquakes and volcanic eruptions are well known as, of course, is the moon's position at all times. Nevertheless, the correlations of seismic and volcanic activity with the moon's cycles are not all clearly positive; some in fact are negative. Major quakes and eruptions seem to show less correlation with lunar tidal forces than microearthquakes and small tremors around volcanos. Further, the correlations seem to vary with geographical location and the depths of the earthquakes. The picture is far from clearcut. Rating: 2.

Anomaly Evaluation. Lunar tidal forces applied to the earth's crust are very small, but if they are considered to be "triggers," they seem adequate to initiate seismic and volcanic action through the release of accumulated strains. Although the precise nature of the supposed trigger effect is not known, its existence seems reasonable and not particularly anomalous. Rating: 3.

Possible Explanations. Small tidal stresses are just enough to stimulate crustal sections already under strain to shift along fault lines---the "straw that broke the camel's back" concept.

Similar and Related Phenomena. All other astronomical correlations in this section (GQS); the possible effects of the moon on terrestrial weather (GWS1, GWS2).

Examples of Earthquakes Correlated with the Moon's Position

X1. General observations. Earthquakes and great atmospheric changes are in many instances occasioned by the action of the moon. (X1)

X2. Statistical analysis. The analysis of about 35,000 earthquakes in the 1843-1872 period showed that a large preponderance of them occured around the syzygies. (R2)

X3. Statistical analysis. Capt. de Montessus collected information on about 60,000 quakes and concluded that the moon had no effect on their time of occurrence. (R3)

X4. Statistical analysis. Prof. Eugenio Semmola analyzed the activity of Vesuvius from July 1895 to July 1897 and showed that the moon had no influence on eruptions. (R4)

X5. General observations. "Kindly permit me to call your attention to some remarkable coincidences between certain positions of the moon, relative to the earth and sun, and the recent earthquakes and volcanic disturbances. Do not the following comparisons of facts go to prove that such disturbances are most likely to take place when the moon is directly in line with the earth and sun (conjunction, opposition, eclipse), when the moon is nearest the earth (perigee), and when it crosses the earth's equator? The moon crossed the earth's equator on April 19; the terrible earthquakes in Guatemala began on the evening before and continued until the 21st. The moon was full and at eclipse node on April 22; the volcanoes in the West Indies first showed signs of activity on the day following. The moon crossed the equator again on May 3---the day that Mont Pelee, on the island of Martinique, first began eruption. The moon was new and at eclipse node on May 7 and in perigee on the 8th; La Souffriere volcano, on the island of St. Vincent, began violent eruption on May

7, and Mont Pelee destroyed the city of St. Pierre on the 8th. Then, as the moon receded from perigee, getting farther away from earth, the volcanoes gradually quieted down until the activity ceased on May 15. The moon crossed the equator again on Friday evening, May 16, and on Friday Mont Pelee again began eruption, which became violent next day." (R5) "The moon's equatorial passage has certainly no gravitational influence, and yet it must be something more than mere coincidence that severe volcanic and seismic disturbances have accompanied this planetary position every time during the past four months, with but one exception: None were reported for June 27; but the abnormally severe storms on and about that date proved the electrical effect. The moon's last equatorial passage, on August 21, caused terrific earthquakes in Mindanao, Philippine Islands, and a violent eruption of Mont Pelee on that date, more shocks at Los Alamos, Cal., on August 20, 21, and 22, earth tremors for two hours in Austria and violent tremors near St. Petersburg on the 22nd, and an eruption of Mount Allomonte, Italy, beginning the same day. All these were two to four days after full moon and half-way between apogee and perigee. Within twenty-four hours of the direct opposition of Saturn on July 17, there were terrific tremors on St. Vincent Island, cloudbursts in Illinois, a tornado in Ontario, and a typhoon at Hongkong---all electrical disturbances." (R6) In a way, these two articles (R5 and R6) are period pieces, for they reflect a common opnion of the times that many natural phenomena were controlled by electricity. Also, they portray a common tendency to examine only occurrences that prove the point at hand. Abnormal weather, quakes, volcanic eruptions, and other upheavals of nature occur every day somewhere on the globe. Some phenomena can be selected to prove almost any point. (WRC)

X6. Statistical analysis. "Circular No. 49 of the Wolsingham Observations contains a summary, by the Rev. T.E. Espin, of the results obtained by arranging and charting the data which he has collected in regard to the times of volcanic eruptions and earthquakes. The results point to a period of between eight and nine years in the phenomena of which Mr. Espin has received the records. This period agrees with the period of revolution of the moon's perigee, and further investigation indicates that the greatest volcanic activity takes place when the perigee occurs at its maximum northerly declination." (R7)

X7. General observations. Conclusions based on Milne's data: Quakes are more frequent at full moon than at half-moon, and when the moon is near the earth than when it is far away. (R8)

X8. 1811-1812. New Madrid, Missouri. In connection with the many aftershocks of the New Madrid convulsion: With one marked exception, the groups of aftershocks occurred either at the time of new or full moon. There appeared to be little difference of activity at the two maximum periods.

X9. General observations. Magnetic, electric, and seismic phenomena tend to synchronize with the position of the moon near standard lunar longitudes of 53°, 143°, 233°, and 323°. ((R10)

X10. Statistical analysis. Count de Ballore divided the lunar day into eight parts and found that the 45,000 earthquakes in his catalog were distributed almost equally among them. (R11)

X11. General observations. A review of recent analyses showed that the effect of the moon on earthquake frequency was negligible.

X12. General observations. "During the year 1927 the seismographs at the Hawaiian Volcano Observatory recorded 1149 local earthquakes. Among them, the regular recurrence of times of increased seismic activity was too noticeable to be set aside as accidental. These epochs of greater activity occur at intervals of about two weeks and near the times of the first and last quarter phases of the moon. According to Perrey's first law, similar epochs coincide nearly with the times of new and full moon, but it should be remembered that Perrey's law relates to ordinary earthquakes, while most of the Hawaiian tremors are of volcanic origin." (R13)

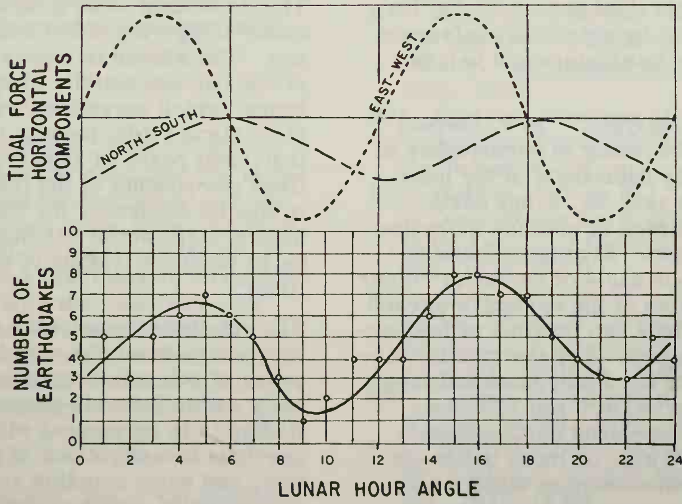
X13. Statistical analysis. "The relation between tidal phases and the frequency of earthquakes is discussed in a recent paper by S. Yamaguti. In earlier investigations on the subject, the origins of the earthquakes considered were unknown. Mr. Yamaguti confines his study to the after-shocks of the Kwanto earthquake of 1923, the Tango earthquake of 1927, etc., in which the epicentres were distributed within well-defined areas. In all of these, he finds that the frequency is greatest at, or a little before, the time of low-water at a neighboring station; while a secondary maximum appears before high water on the Kwanto curve and a little after high water on the other curves. There is, however, an interesting difference between the Tango after-shocks that originated beneath the sea-bed and on land on the northern side of the Yamada fault. The former have two maxima, 1 1/2 hours before and after high water; the latter a principal maximum about low water and a secondary maximum about high water." (R14) Apparently, the lunar effect, if it exists at all, depends upon the severity of the shocks, geographical location, and perhaps other variables. (WRC)

X14. General observations. With respect to destructive earthquakes of the 20th. century, the moon's phase seems to have no bearing at all. (R15)

X15. Statistical analysis. Recent earthquakes in southeastern California. "These earthquake shocks are not caused by the moon, said Dr. (Maxwell W.) Allen, and they would have occurred anyway without its assistance. But in far more cases than chance would allow, the earthquake occurs when the moon is in a certain part of the sky. The critical time seems to be about five hours after the moon has reached its highest point in the sky and again some twelve hours later. Earthquakes do occur at other times but less frequently." (R16)

X16. General observations. The aftershocks of many major quakes tend to occur at 14.8-day intervals at the new and full moons. (R17, R18)

X17. Statistical analysis. "One hundred and twenty-two well-determined deep-focus earthquakes, taken from a list furnished me by Dr. J. A. Sharpe, of the Massachusetts Institute of Technology, have furnished the material for the results summarized in Table I (not reproduced). This selected list includes only those earthquakes whose depth of focus exceeds one hundred kilometers and for which an ample number of reliable observations have been secured. In Table I is listed the number of occurrences of these deep-focus quakes for twenty-four equal intervals corresponding to hourly values in the changing hour angle of the moon referred to the epicenter at the time of the occurrence of each deep-focus earthquake. The full line curve printed herewith is drawn through points representing the running means of the numbers of earthquakes for hourly intervals. The broken line curve represents the north and south component, and the dotted line curve the east and west component of the horizontal lunar tidal force for the corresponding hour angles and declinations of the moon. It will be observed that the curve of earthquake frequencies shows a much closer correspondence to the curve representing the east and west component of the lunar tidal force than to the curve representing the north and south component. A curve representing the resultant of the north-south and east-west curves would resemble the earthquake frequency curve with striking similarity." (R19)



Tidal force compared to number of earthquakes (X17)

X18. Statistical analysis. "To summarize: 1216 shocks from inland faults of California, grouped as they occurred, show an epoch of the second harmonic ranging in the different fault groups from 36 to 60 degrees, an extreme variation of only 24 degrees where a possibility by chance of a variation of 180 degrees exists. This is the only harmonic which does show systematic agreement in epoch in different groupings of the data. Schuster's criterion for the reality of the suspected periodicity mounts constantly with respect to the second harmonic as the body of data grows, whereas with respect to the other harmonics it remains at a low value, indicative of chance variation. Finally, with reference to the southeastern California shocks, which alone comprise a body of data large enough to justify an attempt to subdivide and study by different energy classifications, there is a suggestion that in the period of a month or two preceding the stronger shocks the earth stresses are increasing at an accelerated rate, and that during the hours before a strong shock the rate of accumulation of that part of the increment which is applicable to producing rupture is slowed up, presumably not because the actual forces are growing at a lessened rate, but because a part of the increment is used up in some other manner in the hours before final rupture, possibly in plastic deformation. It appears also that the lunar control is more nearly complete for the stronger than for the minor earthquakes. This seems to be shown both by a later epoch in the flow of tidal energy twice daily and by the greater response of the bigger earthquakes to the smaller changes in tidal energy during lunation, manifested by a decided preference for the days after quadrature and before syzygy." (R20)

X19. Statistical analysis. "H. T. Stetson has studied the frequency of earthquakes in connexion with the hour angle of the moon. During the years 1918-29, 2,569 earthquakes were recorded at stations more than 80^{o} from the origin. Arranging these according to the hour angle of the moon referred to the meridian of the epicentre of each earthquake, he finds two maxima of frequency, at 7 and 18 hours. For the smaller district consisting of the Philippines and Japan. the maxima occurred at 6 and 21 hours. Again, for 113 deep-focus earthquakes, with depths of 100 km. or more below the surface, the maxima were at about 5 and 16 hours, and the curve representing the means of the numbers of earthquakes for lunar-hourly intervals corresponds closely with the curve of the east and west component of the lunar tidal force." (R21)

X20. Statistical analysis. Approximately 80% of the great earthquakes show preference for times of new and full moon. (R22)

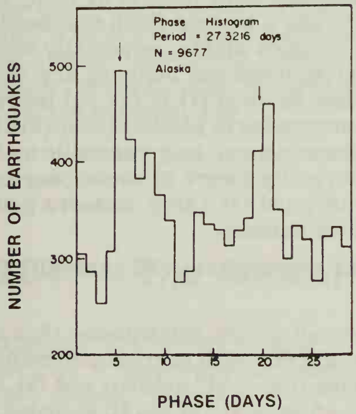
X21. Statistical analysis. Montserrat, West Indies. For this small volcanic island, earthquakes and abnormal gas eruptions were most likely to occur near lunar opposition and conjunction with the sun (full and new moons). (R23)

X22. Statistical analysis. A significant correlation was found between earth tides and earthquakes with a magnitude greater than 6, but when aftershocks were eliminated from the data, the correlation fell below the 75% confidence level, implying that the initial quakes are not triggered by tidal stress. (R24)

X23. Statistical analysis. Alaska. "Abstract. Microearthquake activity at St. Augustine volcano, located at the mouth of Cook Inlet in the Aleutian Islands, has been monitored since August 1970. Both before and after minor eruptive activity on 7 October 1971, numerous shallow-foci microearthquake swarms were recorded. Plots of the hourly frequency of microearthquakes often show a diurnal peaking of activity. A cross correlation of this activity with the calculated magnitudes of tidal acceleration exhibited two prominent phase relationships. The first, and slightly more predominant, phase condition is a phase delay in the microearthquake activity of approximately 1 hour from the time of maximum tidal acceleration. This is thought to be a direct microearthquake-triggering effect caused by tidal stresses. The second is a phase delay in the microearthquake activity of approximately 5 hours, which correlates well with the time of maximum tidal loading. Correlation of the individual peaks of swarm activity with defined components of the tides suggests that it may be necessary for tidal stressing to have a preferential orientation in order to be an effective trigger of microearthquakes." (R25)

X24. Statistical analysis. Abstract. "The frequency, intensity, and latitude of occurrence of volcanic eruptions vary systematically within the well-known tide cycles. This finding is in agreement with the results of previous investigations of earthquake activity, and some eruption activity, like seismic activity, may be related to changes in the length of the day. Eruptions are favored in months wherein tidal amplitude is large at the latitude of the volcano. The eruptions of two volcanoes, Pelee and Soufriere (St. Vincent), have occurred in this century only within a very narrow range of values of phase angle between the anomalistic and tropical lunar tides." (R26) This is a long, very detailed paper that considers periods ranging from semidiurnal in length to 19 years.

X25. Statistical analysis. Alaska and Central America. Abstract. "The Earthquake Data File Summary catalog for the years 1949-1974 was used for time analysis. Periodic changes in the number of quakes in Alaska and Central America are reported and statistically evaluated. The suspected period is 13.65 days, which is half the lunar sidereal period. Periodicities in other locations are examined and evaluated." (R27)



Phase histogram for Alaska. Arrows indicate the days when the moon crosses zero declination. (X25)

X26. Statistical analysis. Ebro, Spain. "Father Luis Rodes has examined the influence of the moon on the frequency of 2,242 earthquakes recorded at the Observatory of the Ebro (Tortosa) during the years 1914-1932. He concludes that there is no definite period connected with the lunar day, but that the distance of the moon has a very marked effect, the number of shocks being 15 per cent higher about the time of perigee than about that of apogee." (R28)

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GQS3 The Appearance of Meteors During Earthquakes

Description. The appearance of confirmed meteors prior to and during earthquakes with a frequency greater than coincidence allows.

Background. Over a century ago, both earthquakes and meteors were thought by many to be electrical in nature. It was therefore not unexpected to see a meteor flash overhead when the ground shook below. Since meteors are rather common sights, especially during the major annual showers, some coincidences between earthquakes and meteors are expected statistically. The situation is complicated by four other factors: (1) In the old literature the word "meteor" was employed to mean just about any atmospheric phenomenon; (2) Earthquake lights (GLD8), a more respectable quake-related phenomenon, may resemble meteors; (3) Persons experiencing an earthquake often become abnormally aware of accompanying phenomena and in their excitement exaggerate what they see; and (4) Large meteors generate considerable sound and vibration which may resemble an earthquake.

Data Evaluation. Those reports that seem to describe bona fide meteors are generally very old and frequently second-hand. Rating: 3.

Anomaly Evaluation. If more bona fide meteors are observed during earthquakes than coincidemce allows, two inference are possible---both wildly at odds with current scientific thinking: (1) Earthquakes and meteors have a common cause (the "old" notion); and (2) Meteors cause earthquakes! If either of these is true we have an anomaly of the first order. Rating: 1.

Possible Explanations. A statistical study of the situation may reveal that meteors are no more common during quakes than meteor statistics require; in other words, coincidence is an adequate explanation. Many meteor-earthquake reports are simply observations of earthquake lights.

Similar and Related Phenomena. Earthquake lights (GLD8); the correlation of planetary positions with earthquakes (GQS7), another situation where no known physical influence seems possible.

Examples of Earthquakes Correlated with the Appearance of Meteors

X1. February 5, 1663. St. Lawrence River, Canada. Various meteor-like luminous objects seen in the air before the earthquake. (R7)
X2. November 4, 1704. Zurich, Switzerland. The earthquake was preceded by a brilliant meteor. (R3)
X3. November 13, 1761. Geneva, Switzerland. At the time of the quake, a meteor in the form of an immense globe appeared, changing afterwards into a train of light and disappearing in an explosion. (R4)
X4. February 2, 1766. Rhode Island and Massachusetts. A remarkable meteor attended the quake. (R4)
X5. October 13, 1766. Cumana, Peru. An extraordinary meteor shower was seen over a wide area prior to this disasterous quake. (R6, R8)
X6. February 4, 1790. Riobamba, Ecuador.

Another extraordinary meteor display before a major quake. (R6) Date given as February 4, 1797. (R8)

X7. November 13, 1799. Cumana, Peru. A large meteor display during the shocks. Meteors supposedly moving in the same direction as the shocks. (R1, R6) Date given as November 11, 1799. (R8)

X8. August 13, 1816. Dunkeld, Scotland. At the time of the shock a meteor passed from east to west, contrary to the direction of the shock. (R1, R2)

X9. February 20, 1818. Inverness, Scotland. A meteor about the size of a cannonball with a streamer behind it. (R2)

X10. November 20, 1822. Chile. Meteors were seen moving in the same direction as the shocks. (R1)

X11. 1869. South Atlantic Ocean. A submarine disturbance of great violence was observed from the barque Euphrosyne. The sea became tossed and confused and a noise resembling cannonading was heard. Several large meteors shot out from the heavens. (R5)

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GQS4 The Annual Variation of Earthquake Frequency

Description. The annual peaking of earthquake frequency. The phenomenon seems rather complex for it apparently depends upon the size of the quakes being considered and where they are located relative to plate boundaries. The depth of the quake may also be important. A semiannual peaking is noticed frequently.

Background. As with the supposed influence of solar activity upon earthquake frequency (GQS1), the annual effect is not clearcut, although most students of the subject seem to agree that yearly peaks do exist. The results so far are confusing and sometimes contradictory.

Data Evaluation. This is no shortage of excellent earthquake data, with adequate recording of magnitude, time, location, and in many cases depth, too. However, the correlations of these data on an annual basis leave much to be desired in consistency and common ground rules. Rating: 2.

Anomaly Evaluation. If the annual variation of earthquake frequency depends only upon barometric pressure and other seasonal meteorological factors, the anomaly is weak. But, if a variable gravitational constant is the initiator of the phenomenon, we have a major anomaly. Composite rating: 2.

Possible Explanations. Annual and semiannual tidal stresses could enhance earthquake activity. Seasonal meteorological factors (pressure, wind loading, temperature) are also possible ingredients. Anomalous changes in the gravitational constant with solar distance (X9).

Similar and Related Phenomena. All the entries in this section (GQS). Astronomical modifications of terrestrial weather (GWS).

Examples of Annual Variations in Earthquake Frequency

X1. General observations. "In the equinoctial regions earthquakes have been thought to occur more frequently during the rainy season than at any other time of year. Sometimes they have been supposed to be peculiar rather to the period of the equinoxes, sometimes to the winter months; with many other similar opinions. Indeed examples are not wanting which appear to favour such views; as for instance, the observation, that of all the earthquakes which occurred in Sicily from 1792 to 1831, double as many took place in March as in any of the other months. Still however an almost profound obscurity hangs over the question, whether earthquakes and volcanic eruptions are more peculiar to one time of the year or day than to any other, than over the consideration of the other connections of these phaenomena with those of the atmosphere. This subject has also been treated of in an elaborate manner in another paper on the causes of earthquakes by Herr Kries, who has brought forward instances in no small number, which prove that earthquakes, even of the most violent kind, have occurred at every time of day and in every season of the year. I myself (says Von Hoff) have in another place, made the experiment of collecting and arranging all the instances of earthquakes which occurred during ten years, in order to find whether any one time of the day or year presented a greater number of these phaenomena than the others. The result of these researches however seems to be, that with respect to this relation of earthquakes also, no law can be laid down. We must consider it as an established fact, that both earthquakes and volcanic eruptions <u>may</u> occur at any time of the day or year, since experience has shown this with respect to almost every time. The only question which remains on the subject is, whether we can ascribe to any one or other season or time, a greater tendency to produce or favour the production of such phaenomena. A mere collection of facts, even though embracing a long period of time, would of itself hardly supply an answer to this question; since, in order to draw tolerably accurate conclusions from such a collection, many other circumstances would have to be taken into consideration. We ought not to content ourselves with collecting and arranging a mere successive list of these phaenomena, but on the contrary, we should compare with one another only the most considerable, and those which occurred in the same climate, with other precautions of the same nature." (R1) Eight years after the first of his several reports and the serial publication of his massive catalog, Mallet again addressed the question of seasonal variation in earthquake frequency. He summarizes thus: "... we find in the northern hemisphere the annual paroxysmal minimum in July, in the southern it appears to be in March. The duration of this minimum in the northern extends, with no very considerable fluctuation, over nearly two months, and suddenly rises in July; in the southern the minimum is more suddenly arrived at, and as suddenly abandoned, and it extends over less than one month. If we take May and June as one minimum in the northern, we have a second but very much lower one in September, and the corresponding second minimum for the southern hemisphere in August. The annual paroxysmal maximum for the northern hemisphere is distinctly in January, and for the southern in November. January and March are secondary maxima in the southern, as August and October are in the northern. Whatever be the irregularities month by month however, the preponderance of seismic paroxysm for the whole twelve months lies amongst those that form the winter of our northern hemisphere." (R12)

X2. General observations. The research of M. Perrey, of Dijon, indicates that earthquakes are usually more frequent in winter and autumn than in spring and summer. But this law varies considerably in different localities. (R2) From this one would conclude that the seasonal effect is not clearcut. (WRC)

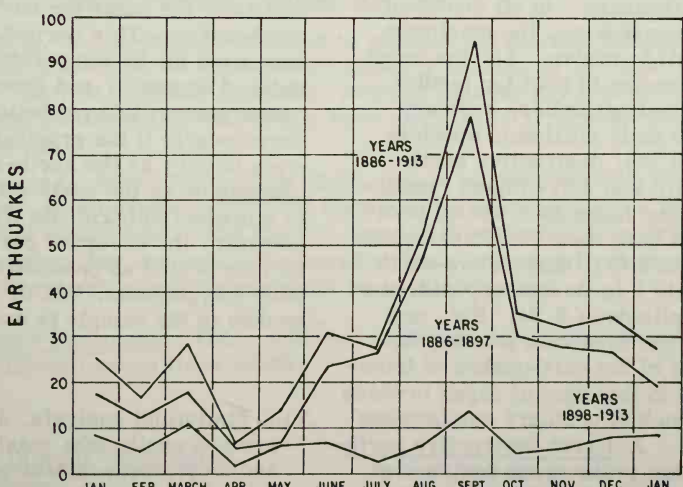
X3. Statistical analysis. 62 long records of quakes from different stations in various parts of the globe. "In every district, and in all but five records (which are obviously incomplete), there is a fairly well-marked annual period. As a rule, different records for the same district agree in giving the same, or nearly the same, maximum epoch. Excluding, however, those which disagree in this respect, we have left 34 records for the northern hemisphere, 9 for the southern, and 2 for equatorial countries. In the northern hemisphere, 4 records give the maximum in November, 16 in December, and 6 in January; in the southern hemisphere, 2 in April, 2 in May, 3 in July, and 2 in August; the end of the month being supposed in each case. As a rule then, the maximum epoch occurs in winter in both hemispheres." A semiannual period also appears in the records. (R3)

X4. General observations. Earthquakes are more frequent in winter than in summer in the proportion of 3 1/2 to 1. (R4) No authority given for this statement.

X5. Statistical analysis. Charleston, South Carolina. "In order to determine whether there is any annual, semi-annual, or quarter-yearly periodicity in the earthquake frequency of this region the following table was compiled (not reproduced, see graph), and since the records are more nearly complete for the years 1898-1913 than for the years 1886-1897, the data are listed separately for each interval as well as for the entire period. In summing up the number of earthquakes, two or more separate shocks occurring within an interval of fifteen minutes are counted only once. The number of days on which earthquakes have occurred is also given, as in this way it is possible to reduce the influence of aftershocks that are really parts of a single disturbance. Another reason for believing that the number of earthquake days rather than the number of shocks may possibly furnish a more accurate index to the relative seismicity of the different months, is that during the earlier years slight tremors often went unrecorded, especially when they occurred on the same day as disturbances of greater intensity.....The similarity of all these curves and especially of the three showing the number of earthquake days for each month is very striking, and indicates that they are probably for this district fairly accurate representations of the relative seismicity of the different months of the year. In every instance the maximum frequency falls in September with the minimum in April, and there is a well-marked secondary maximum in March." (R5) Only the graphs showing earthquake frequency for each month are reproduced; these have the same shapes as those for earthquake days. Note that the pronounced peaking in September contradicts some of the preceding analyses. (WRC)

X6. Statistical analysis. Spurred by the Charleston study (X5), the author reviews English, Japanese, U.S. West Coast, and Charleston data, concluding that earthquakes generally peak at the equinoxes and are least at the solstices. (R6)

X7. General observations. Kilauea Volcano, Hawaii. "The molten surfaces nearly always visible in Halemauman at Kilauea, on Hawaii, rise and fall through a considerable vertical range, standing high near times of solstices and low near equinoxes. Also, from fortnight to fortnight a similar movement of smaller range is noticed frequently, and a movement, probably of greater vertical range, appears to go on over an interval of several years. To explain such cyclical behavior a crude hypothesis is offered; a refined development of it would be very difficult. An effect of the varying declination of the sun is a nutation of the earth's axis produced by fields of gravitational attraction acting obliquely to the earth's equatorial protuberance, and its rotation. This action conflicts with the earth's gyrostatic tendency. Hence, very minute earth-strain, or earth-distortion, is considered to accompany it.



Shocks in the Charleston area peak in September (X5)

This effect ranges from a maximum at solstice and after (lag) to nothing at equinox. A similar effect, but with period of only a fortnight, is produced by changing declination of the moon. Further, a minute change in the configuration of the earth is believed to accompany variation of latitude. These minute changes in earth configuration are considered to produce minute changes in the shape and volume of the deep magma reservoir, which are integrated into visible, or pronounced, changes in the relatively small passages which lead up into the crater-pit where the free surfaces rise and fall. These tendencies sometimes reinforce and sometimes oppose each other, and many other complications enter." (R7) Such thinking may also be applicable to the tidal effects on water geysers (GHG3).

X8. Statistical analysis. "Conclusions. 1. Ordinary earthquakes. ---Throughout the vast continental areas of both hemispheres, the maximum epoch of the annual period in ordinary earthquakes falls during the mid-winter months. These great areas are, however, fringed by certain insular or peninsular regions in parts of which the maximum epoch is reversed. There is some reason for connecting such annual variation in seismic frequency with the annual variation in atmospheric pressure. The reversed epoch in insular districts is probably due, as Omori suggested, to the annual variation in the total pressure on the ocean bed. 2. Slightly destructive earthquakes. ---Slightly destructive earthquakes, those of intensity 1 (Milne scale), are closely akin to ordinary earthquakes. They are, indeed, the limiting degree of such earthquakes. In all continental areas of either hemisphere, the maximum epochs of both fall in winter. And the same correspondence seems to hold for insular areas also. In the East Indies, ordinary earthquakes have their maximum epoch in May (amplitude 0.21), destructive earthquakes of intensity 1 in July-August (amplitude 0.24). Taking Japan as a whole, ordinary earthquakes have their maximum epoch in May (amplitude 0.08), destructive earthquakes of intensity 1 in December, with the rather large amplitude of 0.24. But, and this is a case of the exception proving the rule, 99 per cent of the earthquakes of intensity 1 originated in that part of Japan in which the maximum epoch of ordinary earthquakes occurs in winter. 3. Great destructive earthquakes. ---Turning to the great destructive earthquakes, those of intensities 3 and 2 (Milne scale), the most striking fact is that their annual periodicity, in either hemisphere, is independent of geographical conditions. The maximum epoch occurs in the summer months, whether the regions are continental, peninsular, or insular. So clearly marked is this occurrence that it holds for such closely adjoining regions as the North and South Tropical Zones. In Japan, it falls throughout the summer months; in the southwestern portion, in which the epoch for ordinary earthquakes falls in winter, the maximum is in July, with the rather high amplitude of 0.25; in the northeastern portion, it is probably in May or June (amplitude 0.38), but the number of earthquakes is too small to define the epoch with accuracy. It would seem, then, that destructive earthquakes of great intensity differ entirely in their origin from those of less strength and from ordinary earthquakes. And, in this connection, it is worthy of notice that many destructive earthquakes of the first magnitude originate at depths that may be perceptible fractions of the earth's radius, and the relation that Milne detected between the occurrence of great earthquakes and the displacements of the pole holds, as Omori has shown, for a strong, but not for slight, earthquakes in Japan." (R8, R9) See GQS10 for more on the relation between earthquakes and the earth's wobble.

X9. Statistical analysis. "Abstract. Times of occurrence for a total of 1933 earthquakes are analyzed for periodicities. The results show no definite evidence for effects due to earth tides. Small indications of a solar-date periodicity are assumed to be thermal in origin. A strong, statistically significant annual period is found, and the phase is substantially the same for northern and southern earthquakes. This periodicity is not wholly accounted for by temperature effects, wind-induced stresses, and observer bias. The occurrence of this periodicity would be understandable if the gravitational constant were to vary as the earth-sun distance changes or as the earth's velocity relative to a preferred cordinate frame changes; however, the observed periodicity cannot be interpreted as conclusive support for such a hypothesis." (R10) The number of quakes in the sample is small here. (WRC)

X10. Statistical analysis. Jamaica. There are two earthquake maxima (February and July), both months of minimum rainfall. The corresponding quake minima are in May and October, both months of maximum rainfall. (R11)

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GQS5 The Diurnal Variation of Earthquake Frequency

Description. The peaking of earthquake frequency at a specific time of day. Usually earthquakes are more frequent at night, but many exceptions exist. Not only are semidiurnal cycles common but the time of maximum frequency seems to depend upon the magnitude and depth of the quake.

Data Evaluation. Earthquake data are abundant, but this phenomenon is clouded by two factors: (1) Instrument-detected quakes are masked by daytime noise; and (2) Quakes sensed directly by human observers, especially the smaller ones, are more likely to be reported during daytime hours when people are awake. Even when these factors are considered, true diurnal peaks occur in many records. Rating: 2.

Anomaly Evaluation. No agreement exists as to whether the diurnal variation is due to meteorological (pressure changes) or tidal (solar-induced) forces, or perhaps some unappreciated mechanism. As with the other externally induced changes in earthquake incidence introduced here, no one has shown precisely how very small crustal stress changes can trigger earthquakes. Rating: 3.

Possible Explanations. Solar tidal action might explain peaks occurring near noon and midnight, although one would expect solar tidal effects to be overwhelmed by lunar tidal forces, as they are in most ocean tides. The diurnal changes in atmospheric pressure are also suspect here, because they are small compared to those barometric changes associated with storms. Diurnal temperature changes cannot be excluded either.

Similar and Related Phenomena. Other astronomical correlations in this section (GQS). The diurnal and semidiurnal ocean tides (GHS).

Examples of the Diurnal Variation of Earthquake Frequency

X1. Statistical analysis. "Summary of Results. 11. The following conclusions may, I think, be drawn from the results of the above analysis. (1) The reality of the diurnal variation of earthquake-frequency seems to be proved by the approximate agreement in epoch (mean local time) of the first four components for the whole year at Tokio and Manila, and for the winter and summer halves of the year at Tokio. (2) In ordinary earthquakes there is in nearly every case a marked diurnal period, the maximum generally occurring between 10 A.M. and noon. The semi-diurnal period, though less prominent, is also clearly marked, the maximum occurring, as a rule, between 9 A.M. and noon and between 9 P.M. and midnight. Other minor harmonic components are also occasionally important---the first maximum of the eight-hour component probably occurring about 6.30 A.M. and that of the six-hour component about 3 or 4 A.M.; but in these two epochs the results are not always concordant. (3) Though the materials are insufficient for any general conclusion, a comparison of the results for Tokio and Rocca di Papa seems to show that the slighter disturbances at the latter place are subject to a more marked diurnal periodicity. (4) In the after-shocks of great earthquakes the diurnal periodicity, as a rule, is strongly pronounced. The maximum of the diurnal period occurs within a few hours after midnight, but the epochs of the other components are subject to wide variation. A special feature of after-shocks is the prominence of the eight-hour and four-hour components. After a year or two there is some return to ordinary conditions; but even when the average hourly number of shocks is reduced to one-hundredth of that during the first few days, the characteristics of after-shocks are still perceptible." (R1)

X2. General observations. Assam, India. Seismograph records, 1897-1901. "On examining these it is clearly seen that there was a real and a very large variation in the diurnal distribution of shocks in Assam during 1897-1901, their greatest frequencies occurring at 10-11 p.m. and 6-7 a.m., and superimposed on this regular but unexplained variation there was a smaller one, which appears to have been due to the tidal stresses set up by the attraction of the sun." (R2)

X3. Statistical analysis. From the 1811-1812 series of shocks around New Madrid, Missouri. "For the purpose of determining the relation of distribution to time of day, about 178 shocks, the hours of which were more or less specifically stated, were selected from the list of Brooks and grouped in the table given on page 36 (not reproduced), which shows the number of shocks of five grades of intensity occurring in each hour of the day. It will be noted that of the minor shocks very few are recorded in the night, doubtless because they were not of sufficient strength to awaken the sleepers. Beginning at 6 a.m. there is, according to the tables, a gradual increase of activity to a time between 9 and 11, after which it falls of until 1 o'clock, at which hour almost no shocks are recorded. A second but lesser period of intensity develops about 3, with a falling off from 4 to 7, after which the intensity increases again from 8 to 11. Between 11 and 12 only 1 shock is recorded, but considerable activity is manifest between 12 and 1 in the night." (R3) It is curious to note that early records attribute low nighttime frequencies to people being asleep while modern reports, which employ instruments, seem to indicate high nighttime frequencies due to lower noise levels. (WRC)

X4. Statistical analysis. Considering deep-focus earthquakes from 1919-1928, little diurnal variation is apparent. (R4)

X5. Statistical analysis. "Abstract. Though non-instrumental records of earthquakes give an apparent nocturnal maximum, it is shown that, for several regions in which earthquakes are weak or moderately strong, there is a real diurnal period, with its maximum about midnight. The instrumental records obtained in Japan and Italy and at various seismological observatories are examined, and it is shown that the maximum epoch of the diurnal period usually falls about noon or midnight, and that the noon maximum of the diurnal period is associated, as a rule, with a summer maximum of the annual period, and the midnight maximum of the former with a winter maximum of the latter. It is suggested that the noon and summer maxima occur in earthquakes caused by an elevation of the crust, and the midnight and winter maxima in those caused by a depression of the crust. It is noticed that the midnight and winter maxima prevail in regions in which the earthquakes are of slight or moderate intensity, and the noon and summer maxima in those visited by the most destructive shocks. In the aftershocks of great earthquakes, the maxima epoch are suddenly reversed, usually from near noon to near midnight, and the duration of the reversal varies from about a week to a year or more." (R5)

X6. Statistical analysis. 5922 Italian earthquakes, 1891-1910. Considering only the 1503 quakes that were so strong that they could not escape notice at any time of day, 865 occurred during the night, 638 during the day. Conclusion: the diurnal effect is real and not just due to the quiet of night hours. (R6)

X7. Statistical analysis. "Summary. Analysis of the 15 325 events reported for 1968-1970 by the United States National Oceanic and Atmospheric Administration showed that there is a significantly higher seismic activity during night-time than during other hours of the day. It is conjectured that the position of the sun is the cause of this phenomenon." (R7) Several critics maintain that higher earthquake frequency is illusory because high daytime noise masks daytime quakes. (R8)

References

R1. Davison, Charles; "On the Diurnal Periodicity of Earthquakes," Philosophical Magazine, 5:42:463, 1896. (X1)

R2. "Periodicities of the Tidal Forces and Earthquakes," Nature, 68:111, 1903. (X2)

R3. Fuller, Myron L.; "The New Madrid Earthquake," U.S. Geological Survey Bulletin 494, 1912, p. 35. (X3)

R4. "Periodicity of Earthquakes," Nature, 134:631, 1934. (X4)

R5. Davison, Charles; "The Diurnal Periodicity of Earthquakes," Journal of Geology, 42:449, 1934. (X5)

R6. Nature, 99:392, 1917. (X6)

R7. Shimshoni, Michael; "Evidence for Higher Seismic Activity During the Night," Geophysical Journal, 24:97, 1971. (X7)

R8. "Noctural Earthquakes," Nature, 239:131, 1972. (X7)

GQS6 A 42-Minute Period in Earthquakes

Description. The enhancement of earthquake aftershocks 42 minutes after the primary shock. Earthquake surface waves travel to the antipodes and back in about 42 minutes.

Background. This phenomenon is analogous to the earth "ringing" like a bell, with a period of about 42 minutes. The situation is more curious than anomalous and is included in the Catalog because of its association with the more controversial topic of antipodal earthquakes. (GQG1)

Data Evaluation. This may be a well-established phenomenon, but only two brief mentions of it have been found---both by the same author. Rating: 3.

Anomaly Evaluation. It is reasonable to expect that earthquake waves travelling around the globe and converging on the original source point might initiate aftershocks. The anomaly rating is thus low. Rating: 3.

Possible Explanation. Surface earthquake waves trigger aftershocks when they return and focus on the original source area.

Similar and Related Phenomena. Antipodal earthquakes (GQG1).

Examples of a 42-Minute Period in Quakes

X1. General observations. "Though it is confined to the after-shocks of earthquakes, the evidence of the 42 minute period is less uncertain, for there can be little doubt that the period is due to the throbbing of the earth after the great initial displacement. The time taken by an earthquake-wave to travel from a focus near the surface to the antipodes and back is almost exactly 42 minutes. As the crust within and near the focus remains for a long time in a sensitive condition, the return pulsations should, and do, affect the frequency of the after-shocks."(R1, (R1) No specific data are presented.

References

R1. Davison, Charles; "The Origin of Earthquakes as Illustrated by Their Periodicity," Geological Magazine, 71:493, 1934. (X1)

R2. Davison, Charles; "Periodic Variations in the Mean Focal Depth of Japanese Earthquakes," Nature, 135:76, 1935. (X1)

GQS7 Earthquake Activity Correlated with Planetary Positions

Description. The periodic peaking of earthquake activity when certain planetary configurations recur. Such configurations may be: (1) The passage of a single planet through a specific longitude or other celestial mark; (2) The conjunction and opposition of pairs and large groups of planets (including in some cases earth and/or moon); and (3) The celebrated alignment of planets in a narrow sector of the solar system every 179 years.

Background. Scientists in general have always been wary of accepting any correlation of terrestrial phenomena with planetary positions because of the astrological overtones. The current dogma states that the planets are so small and so far away that they exert so significant forces on the earth. The same reasoning applies to the sun and the long-debated connection between the sunspot cycle and planetary positions (AS).

Data Evaluation. Both earthquake and planetary position data are of high quality, except for quakes prior to about 1500 A.D. Two kinds of correlations of these data have been made: (1) Single earthquakes, usually violent ones, have been related to a specific planetary event, such as the meridian passage of Uranus (X3); and (2) Cycles of earthquake activity encompassing many events have been correlated with specific planetary configurations (X4). In the first type of relationship, so many "noteworthy" planetary events occur that one can almost always find some sort of relationship. Generally, neither type of correlation has proven especially convincing to those who have studied them dispassionately. Rating: 3.

Anomaly Evaluation. The planets exert no known forces capable of triggering terrestrial quakes; neither can they influence solar activity, which in turn might affect terrestrial earthquake frequency. A convincing demonstration of a strong correlation between planetary position and earthquakes would infer either an unrecognized force exists or causal relationships have broken down and the coincidences are due to some unappreciated property of the cosmos. Either of these situations would require considerable scientific rethinking. Rating: 1.

Possible Explanations. As above, an unrecognized physical force is exerted by the planets upon the earth, or acausal factors are involved.

Similar and Related Phenomena. The oft-claimed correlation between planetary positions and solar activity (AS); the correlation of planetary positions with radio propagation (GES) and terrestrial weather (GWS8).

Examples of Correlations of Earthquakes with Planetary Positions

X1. Statistical analysis. "Mr. J. Delauney has presented to the Paris Academy of Sciences some new results obtained from a study of Perrey's tables of earthquakes from 1750 to 1842. He finds two groups of maxima, commencing in 1759 and 1756 respectively, each with a period of about twelve years; and two other groups, commencing in 1756 and 1773 respectively, with a period of about twenty-eight years. He remarks that those of the first two groups coincide with the times when Jupiter reaches the mean longitude of 265° and 135°; while those of the last two coincide with the times when Saturn reaches the same longitudes; whence he infers that terrestrial earthquakes have a maximum when these planets are in the mean longitudes mentioned." (R1)

X2. General observations. In three letters, the author gives several specific instances when terrestrial quakes coincided with sundry oppositions and conjunctions of the planets. (R2-R4) Since oppositions, conjunctions, equinoxes, and other notable planetary configurations occur frequently, coincidence doubtless plays a major role here. (WRC)

X3. Statistical analyses. "Thanks to the excellent collection of uniform data of earthquakes given by Gutenberg and Richter, it is now easily possible to study statistically the influence of different factors on earthquakes. In the course of a study of tidal effects on earth-quakes, the astronomical positions of the planets have also been taken into account and a remarkable correlation between the positions of Uranus and the moment of great earthquakes has been established for a certain period. Gutenberg and Richter's data of all earthquakes equal or greater than magnitude 7 3/4 have been used. The investigations will be published in detail later, but here attention is directed to the results concerning the position of Uranus. A total of 134 earthquakes has been investigated. In this a fairly significant amount of cases has been found, where Uranus was very near its upper or lower transit of the meridian of the epicentre in the time of great earthquakes. Closer investigation showed that this occurred especially during the years 1904, where Gutenberg-Richter's data start, and also 1905 and 1906. ..... The correlation cannot be explained by a tidal effect, since the statistical investigation for all the great earthquakes (M = 7 3/4) during 1904-1950 in regard to the absolute and relative position of the Sun and the Moon give no indication of a significant deviation from chance distribution. The tidal forces of the planets are extremely small compared with those of the Sun and the Moon. That the accumulated stresses within the Earth's crust are released at times which, at least for a period of several years, are strongly correlated with certain positions of Uranus may, therefore, not be a relationship of cause and effect in the usual mechanical sense." (R8)

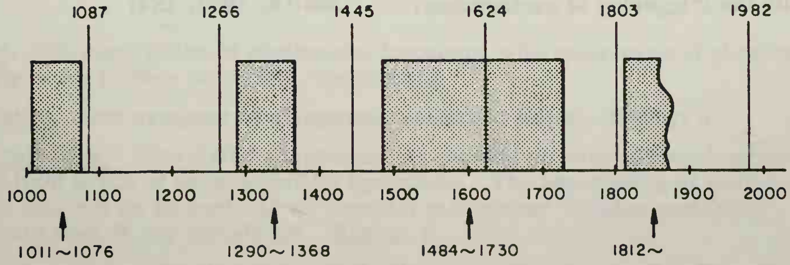
Analysis of the preceding statistical analysis. The correlation of the position of Uranus with great earthquakes is most likely just coincidence, although the correlation may be significant at the 1% level. "This means that we must choose between two conclusions: either the null hypothesis is to be rejected in favour of the alternative hypothesis of a temporary association between the occurrence of great earthquakes and the positions of Uranus; or we retain the null hypothesis and say that an unlikely coincidence has occurred---a coincidence which would occur on the average more often than once in 1,000 investigations, but perhaps less often than once in 100. In the absence of any theory to account for the supposed association, and in view of the remarks contained in the opening paragraph above, the second conclusion seems preferable." (R9)

In essence, this critique states that one should not bother persuing curious coincidences if they are not particularly strong and theory cannot explain them. (WRC)

X4. Statistical analysis. "From an examination of the records of Chinese earthquakes, H.H. Turner has recently deduced a period of 240 years (Monthly Notices, May, 1919). It shows a similar periodicity to the Nile Floods, with a change of phase. Turner makes the suggestion that a variation of the Earth's radius could account for the earthquakes and possibly at the same time for the fluctuations of the moon's longitude by changing the speed of rotation of the earth. The measurements of the tree-growths in California from The Climatic Factor, by Ellsworth Huntington, reveal a striking similarity to the curve of the Chinese earthquakes.... It seems reasonable to suggest that the meteorological variations produced simultaneous changes in the tree-growth and in the Chinese earthquakes." (R5, R6) This is an early reference to the long periods evident in the Chinese records, which in more recent years have been correlated with planetary positions. The paper is also precocious in mentioning the possible link between earthquake cycles, the earth's wobble (as measured by changes in the moon's longitude) (GQS10), and the changes in the earth's rate of rotation. (WRC)

Statistical analysis. A review of Chinese earthquake records shows a 300-year period. (R7)

Statistical analysis. "Recently, there have been renewed debates on whether the so-



Distribution of quiet and seismically disturbed periods in northern China since 1,000 A.D. The disturbed periods (shaded) correlate with the 179-year cycle of planetary alignment. (X4) called Jupiter Effect, a name coined for the heliocentric alignment of all the planets on the same side of the Sun, can cause abnormal solar activity and trigger earthquakes. The planetary theory of sunspots has been studied in detail by Okal and Anderson. From their calculations, these authors conclude that such heliocentric planetary alignment has no significant effects on the tides, and also that the peaks of the planetary tidal effect do not correlate with the peaks of the sunspot activity. This seems to be a strong argument against the theory of the Jupiter effect by Gribbin and Plagemann. But it would be even better still, so far as evaluation of the planetary theory is concerned, if we can compare the data of seismic activity with the occurrence of heliocentric planetary alignment. This problem has been investigated, going through the Chinese records of earthquakes in the past. A popular account has been given by Shen in Chinese. Since no reference has been made to these materials it seems useful to give a brief summary of Shen's article to the reader here. It is hoped that this will help us in settling the controversy of Jupiter Effect. In Fig. 1 we present the time intervals defined as disturbed periods of seismic activities in the northern region of China since A.D. 1000. The years of heliocentric alignment of all the planets separated by intervals of ~ 179 yr are also marked. It is observed that only the alignment in 1624 took place within a disturbed period. To be more specific, since 780 B.C. there have been 15 to 16 total heliocentric planetary alignments; of the 125 recorded earthquakes with intensities corresponding to 6 on the Richter scale, only the one that occurred in 1624 coincided with a heliocentric planetary alignment. Also, beginning from A.D. 1000 there were 11 earthquakes with intensities corresponding to 8; none of them coincided with any heliocentric planetary alignments. All these data lead to the conclusion that heliocentric planetary alignments have nothing to do with the triggering of earthquakes, at least in Northern China." (R10, R11)

Note that earlier investigators of the Chinese earthquake data found periods of 240 and 300 years, whereas the Jupiter Effect requires a 179-year cycle. (WRC)

References

R1. "Earthquakes and the Planets," American Journal of Science, 3:19:162, 1880. (X1)

R2. Still, Elmer G.; "Volcanoes and the Sun and Moon," Scientific American, 87:54, 1902. (X2)

R3. Still, Elmer G.; "Gravitation as a Cause of Volcanic Action," Scientific American, 87:203, 1902. (X2)

R4. Still, Elmer G.; "Sun-Spots and Earthquakes," Scientific American, 95:283, 1906. (X2)

R5. Turner, H.H.; "Note on the 240-Year Period in Chinese Earthquakes....," Royal Astronomical Society, Monthly Notices, 80:617, 1920. (X4)

R6. DeLury, Ralph E.; "Apparent Relation between Chinese Earthquakes and California Tree Growths, 0-1680 A.D.," Popular Astronomy, 27:560, 1919. (X4)

R7. Clough, H.W.; "The 11-Year Sun-Spot Period, Secular Periods of Solar Activity, and Synchronous Variations in Terrestrial Phenomena," Monthly Weather Review, 60:99, 1933. (X4)

R8. Tomaschek, R.; "Great Earthquakes and the Astronomical Positions of Uranus," Nature, 184:177, 1959. (X3)

R9. Burr, E.J.; "Earthquakes and Uranus: Misuse of a Statistical Test of Significance," Nature, 186:336, 1960. (X3) A reply by Tomaschek follows this article.

R10. Ip, W.-H.; "Chinese Records on the Correlation of Heliocentric Planetary Alignments and Earthquake Activities," Icarus, 29:435, 1976. (X4)

R11. Hughes, David W.; "Planetary Alignments Don't Cause Earthquakes," Nature, 265:13, 1977. (X4)

GQS8 Seismic Activity Correlated with Pulsar Radiation

Description. Seismic activity with the same periods as pulsars or other probable sources of gravitational waves.

Data Evaluation. Two studies; one pro, one con. Rating: 3.

Anomaly Evaluation. This phenomenon, if real, depends upon the earth acting as a giant detector of gravitational radiation from cosmic sources. Since gravitational waves themselves have not been conclusively demonstrated, verifiable seismic activity tuned to cosmic sources would constitute an important body of supporting data for the concept. However, gravitational waves are already anticipated by current theories and can be at most only weak anomalies. Rating: 3.

Possible Explanations. The earth expands and contracts at the frequencies of impinging gravitational waves.

Similar and Related Phenomena. Human-constructed gravity wave detectors have been built on a much smaller scale but have not conclusively intercepted gravitational radiation.

Examples of Seismic Activity Correlated with Pulsar Radiation

X1. Statistical analysis. Records from a vertical seismograph installed in Israel. Computer analysis of the seismograph records showed a strong peak at a period 0.53-0.60 seconds. The amplitude of this peak varied semidiurnally. The authors correlated the data with pulsar CP1133, which has a radio-frequency period of 1.1879 seconds. According to theory, the gravitational waves emitted by the pulsar should possess a period one half that of the radio-wave period; a semidiurnal period would be superimposed by the earth's rotation, as the entire earth acted as a gravitational-wave detector. (R1) A second study of this possible phenomenon failed to find any seismic signals correlated with CP1133. (R2)

References

R1. Sadeh, Dror, and Meidav, Meir; "Periodicities in Seismic Response Caused by Pulsar CP1133," Nature, 240:136, 1972. (X1)

R2. Mast, Terry S., et al; "Search for Seismic Signals from Gravitational Radiation of Pulsar CP1133," Nature, 240:140, 1972. (X1)

GQS9 Earthquakes Correlated with Other Periodic Natural Phenomena

Description. The correlation of earthquake frequency with other natural phenomena which superficially seem to have no causal relationship.

Data Evaluation. One synopsis of a Japanese scientific paper. Rating: 3.

Anomaly Evaluation. Correlated phenomena possessing no demonstrated causal connections usually highlight areas of deep scientific ignorance. The association of earthquakes and fish catches may not be as esoteric as quantum mechanics' "hidden variables", but it does signify a blank area in our knowledge. Rating: 2.

Possible Explanations. Earthquakes might stir up ocean waters and sediments, increasing biological productivity, and attracting fish.

Similar and Related Phenomena. None.

Examples of Earthquakes Correlated with Other Periodic Natural Phenomena

X1. General observations. "Prof. T. Terada has shown that there exists a curious relation between the numbers of earthquakes in the Idu peninsula and the numbers of fishes caught near the northern end of Sagami Bay (Proc. Imp. Acad. Tokyo, vol. 8, pp. 83-86; 1932). During the spring of 1930,swarms of earthquakes occurred in the neighborhood of Ito on the east coast of the peninsula. It was found that the epochs of abundant catches of horse mackerel (Caranx) at the Sigedera fishing ground coincided very nearly with those of the earthquakes. This result led Prof. Terada to compare the numbers of fishes caught in the six years 1924-1929 with the numbers of felt and unfelt earthquakes in and near the Idu peninsula. For the year 1928, the parallelism of the two curves was very close, though in other years it was less conspicuous. During 1928, the curve representing the numbers of immature tunny (Thynnus) caught shows a remarkable similarity with the horse mackerel and earthquake curves. In another paper (Bull. Earthq. Res. Inst., vol. 10, pp. 29-35; 1932) Prof. Terada points out that, though the daily numbers fluctuate, the time-distribution curve of the Ito earthquakes resembles on the whole the probability curve, and he shows that the daily number of falls of camelia flowers follows a similar statistical distribution." (R1)

References

R1. "Earthquakes, Fisheries, and Flower Fall," Nature, 130:28, 1932. (X1)

GQS10 Earthquakes Correlated with the Polar Wobble

Description. The correlation of earthquake frequency, magnitude, and direction of strike with the earth's wobble, as measured by sudden and secular changes in the position of the pole of rotation. The dominant wobble is the 14-month Chandler wobble, which is detected astronomically in terms of minute latitude variations.

Background. The linking of the Chandler wobble to earthquakes is a century-old idea. Of late, however, it has become apparent that other variables, such as wind loading and solar activity, are also part of the picture.

Data Evaluation. Although the times, epicenters, and magnitudes of the larger quakes are well known for most of this century, it is difficult to estimate the size of the mechanical impulse exerted on the earth as a whole. In addition, the path of the pole depends upon latitude measurements which as yet do not have the precision to give us a clear insight into this phenomenon. Rating: 2.

Anomaly Evaluation. The anomaly here is the lack of a clear-cut cause-and-effect chain. Do earthquakes cause part of all of the Chandler wobble? Does the Chandler wobble actually stimulate quakes instead of vice versa? Do both phenomena have a common, unidentified cause? How do terrestrial winds, solar radiation, and geomagnetism fit in? Rating: 2.

Possible Explanations. The Chandler wobble may be the combined effect of earthquake impulses, surface wind loads, and geomagnetic forces. Conceivably, the wobble may excite earthquakes. There may be types of mass displacements far below the crust that have not been taken into account and are inaccessible except through wobble observations.

Similar and Related Phenomena. The correlation of earthquake frequency with solar activity (GQS1), the moon's position (GQS2), and the seasons (GQS3).

Examples of Earthquakes Correlated with the Polar Wobble

X1. Historical observations. "Some twenty years ago Professor Milne called attention to the relationship that appeared to exist between the frequency of earthquakes and irregular movements of the poles. He has given much attention to the examination of these phenomena, and, as the result of a very careful and exhaustive investigation, has arrived at the conclusion that the years of greatest pole movements are also years of maximum earthquake frequency, and conversely, that great seismic activity seems to be followed by more marked pole displacements. Sir G.H. Darwin suggested that earthquakes tend to adjust the figure of the earth to one of equilibrium about its instantaneous axis. This result is not surprising, for the amount of material suddenly put into motion during a 'world-shaking' earthquake is often very great." (R1)

X2. Statistical analysis. "The Rev. H.V. Gill has sent us a reprint of his paper read at the last meeting of the British Association on the distribution of large earthquakes in time and space. Mr. Gill's theory is that a great mass displacement of the crust, such as occurs during a violent earthquake, gives rise to a 'wobble' or unevenness in the rotation of the earth, which is neutralized by other mass displacements occurring either in a distant region or regions symmetrically placed along the great circle through the origin, or of displacements in the opposite direction in the neighborhood of the origin. To test this view he has examined the distribution of the 889 world-shaking earthquakes recorded by the seismological committee of the British Association. He finds that 674 (or three out of every four) great earthquakes occurred in groups, successive members of which were separated by a week or less, while the remaining 215 were isolated disturbances. Of the former, 163 (or 18.6 per cent. of the whole) belonged to groups of two or more earthquakes occurring at different places symmetrically situated with reference to the origin of the first earthquake of the group; 511 (or 57.1 per cent.) were members of groups occurring at or near the same place. No attempt, however is made to show that the displacements of individual groups of the latter class occurred in opposite directions." (R2)

X3. General observations. Dr. E.E. Free hypothesizes that earthquakes occur when the earth's speed of rotation changes slightly. Such changes may result from very small expansions and contractions of the earth's crust. (R3) No explanation given as to why the earth's crust should behave this way.

X4. General observations. Great earthquakes change the path traced by the earth's pole sharply both in direction of travel and speed. (R4)

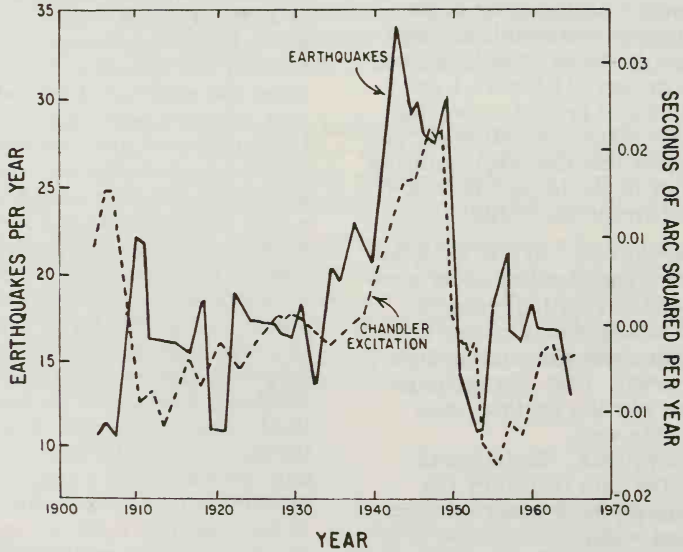
X5. Statistical analysis. "It has been known for over 80 years that the earth's axis of rotation moves with respect to an observatory coordinate system. To earthbound observers this represents a variation of the astronomically determined latitude. Viewed from space, it represents a wobble of the earth about its rotation axis. The observed motion is most conveniently displayed as the path of the instantaneous north pole of rotation. In 1891, S.C. Chandler isolated a component of a 14-month period from the latitude observations. Rigid-body dynamics gives a 10-month period for the earth's natural wobble, but the longer observed period can be reconciled with theory if allowance is made for rotational deformation. The motion is now called the Chandler wobble. The accompanying rotational deformation implies that the Chandler wobble must be subject to damping, and therefore a more or less continuous excitation is required to maintain it. Identifying the source of the excitation has remained one of the principal problems in studies of the earth's rotation. We now report evidence in support of theoretical calculations which led to the hypothesis that large earthquakes provide the hitherto unidentified excitation...... Changes in the BIH (Bureau International de l'Heure) path (of the pole) have been found to correlate closely with the occurrence of 15 out of a total of 22 earthquakes with magnitude M greater than 7.5 that occurred in the period examined, 1957.0 to 1968.0. Evidence of a systematic deviation of the pole path, not revealed by breaks in the least-squares-fitted arcs, can be found for each of the remaining seven earthquakes. Breaks which do not correlated with large earthquakes may arise from the presence of systematic errors, smaller earthquakes, and gradual strain release not associated with shocks. No significant relation between changes in the ILS-IPMS pole path and earthquakes is found. There are promonitory indications of changes in the BIH pole path 5 to 10 days before a high proportion of the large recorded quakes. If these fluctuations are confirmed with an increased number of observations, a change in the pole path might be a valuable signal that a very large scale strain release is about to occur. In combination with instrumentation in active fault zones, such indications would provide information on the likely size of an impending quake. Finally, the observational evidence found in the BIH pole path strongly supports the theoretical prediction that the excitation of the Chandler wobble and the observed secular polar shift are due to large earthquakes." (R5) Any premonitory movement of the pole path would seem to require a large-scale motion of mass before the actual quake. (WRC)

X6. Theoretical calculations. The cause of the Chandler wobble is still a mystery. Computations by Ben-Menahem and Israel (Geophysical Journal, 19:367, 1970) show that even under the most favorable conditions, using optimistic assumptions, earthquakes could account for only 30% of the Chandler wobble. (R6)

X7. Statistical analysis. The results of Mansinha and Smylie (X5) are reviewed first, noting that their theory was not supported by the more extensive pole-position data of the ILS-IPMS (International Latitude Service-International Polar Motion Service). Next, a new suggestion by Robert Myerson is discussed. "Myerson has compared yearly mean values in the amplitude of the wobble, computed from the ILS-IPMS figures, with annual earthquake counts. He treats the problem as a two-dimensional 'drunkard's walk' in which the pole position shifts in random fashion. The step's here are the 'mean square break size' and he shows that the rate at which this factor varies with time should be roughly proportional to the earthquake rate if there is a relationship between the two. The diagram summarises his results for earthquakes of magnitude 7.0 or bigger. The (dotted) line and the right-hand ordinate represent the Chandler wobble; the black curve and left-hand ordinate the earthquakes. While Myerson says that the earthquake data prior to 1918 are not highly reliable, there is still a remarkable similarity between the two graphs which is borne out by more detailed statistical tests. On breaking down the earthquake data into subsets based upon earthquake magnitude, type and location, he finds that the correlation continues to hold, except for very large earthquakes greater than magnitude 7.5. This discovery argues against Mansinha and Smylie's conclusion. The correlation with smaller deep and intermediate earthquakes is better and implies that the relationship is not a simple one of cause and effect. If both some earthquakes and the wobble are excited by a still deeper mechanism, what is it? Perturbations, either mechanical or electrical, in the Earth's fluid conducting core could provide one answer." (R7)

X8. General observations. A review of the debate over the cause of the Chandler wobble. One problem is that the various sources that measure the wobble show discrepancies as much as 0.1 arcsecond. Some scientists propose that the wobble causes quakes rather than vice versa. (R8)

X9. Theoretical analysis. Abstract. "Earthquakes may be triggered by changes in the elastic energy which are neither too fast (~days) not too slow (~10^6 yr). Such a point of view provides a qualitative understanding



Earthquake frequency compared with Chandler Wobble excitation (X7) of suggested correlations between polar motion and the annual seismic energy release. The Chandler wobble and earthquakes may have a common excitation source---the release of elastic energy stored in the earth---and we show that a resonant coupling between seismic activity and polar motion has the right sign and strength to explain the pumping of the Chandler wobble as a consequence of in-phase release of elastic energy." (R9) Possible common sources of quakes and wobble are offered in the next item.

X10. General observations. "Abstract. A correlation exists between long-term variations in the length of the day, Chandler wobble amplitudes, and global seismic activity. These variations may be partially due to climatic changes and ultimately to explosive volcanic activity." The changes in the length of the day seem to be related to variations in zonal wind patterns, which, in turn, are affected by solar radiation and the amount of volcanic dust in the atmosphere. (R10) The next paper brings the earth's magnetic field into the picture.

X11 General observations. Abstract. "A pattern recognition algorithm can be applied to the seismicity of major earthquake belts, to the amplitudes of Chandler Wobble, to changes in the rotational velocity of the Earth, and to the drift of the eccentric geomagnetic dipole for the years 1901-1964. The patterns which emerged suggest that all of these diverse phenomena are related." (R11)

X12. Theoretical analysis. Abstract. "Superposition of the polar shifts computed for 234 large earthquakes ($M_S \geqslant 7.8$) that occurred between the years 1901 and 1970 yields a synthetic curve that closely resembles the observed pattern of variations of the Chandler wobble during the same period. We conclude that earthquakes represent the major factor in the wobble excitation." Instead of employing the usual statistical correlations and associations of quakes with specific breaks in the curve of polar motion, the authors used the geometries of great earthquakes predicted by plate tectonics and computed the cumulative effects of the quakes on polar motion. Although the direct effect of earthquakes still seems much too small account for the Chandler wobble, they suggest that quakes may accompany large aseismic deformations which cannot be detected by existing seismological instruments. Furthermore, atmospheric excitation of the wobble may be sufficient to make up the difference. (R12, R13)

References

R1. Gill, H. V.; "Some Recent Earthquake Theories," Nineteenth Century, 63:144, 1908. (X1)

R2. Nature, 93:276, 1914. (X2)

R3. "Earth's Speed Changed by Its Palpitations," Literary Digest, 100:32, February 9, 1929. (X3)

R4. Nagaoka, H.; "Variations of Latitude and Great Earthquakes," Nature, 130:541, 1932. (X4)

R5. Mansinha, L., and Smylie, D.E.; "Earthquakes and the Earth's Wobble," Science, 161:1127, 1968. (X5)

R6. "Why Chandler Wobble?" Nature, 227: 889, 1970. (X6)

R7. "Earthquakes May Parallel, Not Cause, Polar Wobble," New Scientist, 49:105, 1971. (X7)

R8. "The Wobbling Earth," Science News, 100:108, 1971. (X8)

R9. Pines, David, and Shaham, Jacob; "Seismic Activity, Polar Tides and the Chandler Wobble," Nature, 245:77, 1973. (X9)

R10. Anderson, Don L.; "Earthquakes and the Rotation of the Earth," Science, 186: 49, 1974. (X10)

R11. Press, Frank, and Briggs, Peter; "Chandler Wobble, Earthquakes, Rotation, and Geomagnetic Changes," Nature, 256: 270, 1975. (X11)

R12. Kanamori, Hiroo; "Are Earthquakes a Major Cause of the Chandler Wobble?" Nature, 262:254, 1976. (X12)

R13. O'Connell, Richard J., and Dziewonski, Adam M.; "Excitation of the Chandler Wobble by Large Earthquakes," Nature, 262:259, 1976. (X12)

GQV UNUSUAL VIBRATIONS

Key to Phenomena

GQV0 Introduction

Earthquake vibrations and tremors, which are natural stirrings of the earth's solid crust, may be emulated by vibrations induced by flowing water, violent thunder, crashing waves, and artificial detonations, especially underground nuclear tests. As a matter of fact, very sensitive seismometers always record a faint background of noise (microseisms) from such diverse, non-tectonic sources. Some of the more interesting of these non-quake vibrations are recorded below.

Perhaps more intriguing than miscellaneous crustal noise are icequakes and vibrations. Because of their inaccessibility, the sounds and vibrations of the polar ice sheets have attracted little scientific attention. Polar explorers have been duly impressed by the massive surges, the heaving up of pressure ridges, and travelling disturbances, which could be heard long before they arrived. (R3) We may be sure that this section of the Catalog will grow rapidly when the voluminous literature of polar exploration is assimilated.

GQV1 Unidentified Vibrations

Description. Vibrations without an obvious source. Usually, these low frequency impulses are transmitted through the ground; but air, wires, water, and other media may be involved.

Data Evaluation. The few reports at hand seem to be of good quality, although all one-of-a-kind. Rating: 2.

Anomaly Evaluation. Since the sources of these vibrations are totally unknown, estimation of the anomalousness of the phenomenon is difficult. Generally, though, such vibrations have prosaic origins when finally tracked down. Rating: 3.

Possible Explanations. Power lines (X1) often vibrate in the wind; and ground motion from machinery and other sources can be communicated through the poles. Electromagnetic coupling forces cannot be estimated from the data given. One would anticipate, however, that all three lines in X1 would vibrate regardless of the explanation. Periodic ground vibrations (X2) might be due to some capricious subterranean flow of gases and/or liquids, as in geysers and periodic springs.

Similar and Related Phenomena. Vibrations associated with waterfalls and dams (GQV2); geysers and periodic springs (GHG).

Examples of Unidentified Vibrations

X1. January 8, 1959. Shropshire, England. "Can any of your readers explain the periodic vibration on a power line loaded with snow observed here on 8 January? The periods were as thus:

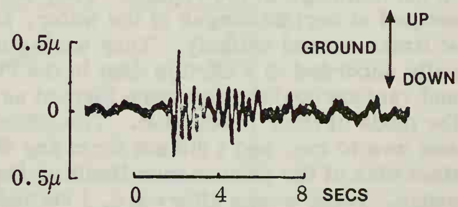
Could they be caused by a harmonic of the 50 cycle grid? Only one wire of the three phases was performing in this way. It went on for several hours." (R1)

X2. September 1959. Dominica, West Indies. "Tremors the origin of which has not been identified were recorded by our seismograph station at Roseau in the volcanic island of Dominica during September 1959, and have been recorded at irregular intervals ever since. Each tremor consists of an approximately sinusoidal ground motion of 0.3-sec. period. The first swing is always down, the first and eighth swings are maxima and there are about twelve swings in all. The ground amplitude of these maxima varies from about 0.1μ, which is the point at which the tremors become masked by the microseismic background, to 1.0μ, They are quite unlike the tremors produced by near earthquakes or by explosions on land or at sea. Factories, quarries and other possible artificial sources for the tremors in Dominica have been investigated and eliminated. The tremors tend to occur in bursts, numbering from two or three to several hundred tremors, which may start at any hour of the day or night and continue for periods up to twelve hours. The average period between bursts has been seven days, but there is no evidence of periodicity. We have operated three additional Willmore-Watts seismographs in Dominica for six weeks in January and February 1960 and have found that the tremors can be recorded only within a few kilometres of the town of Roseau. Because of long quiet periods between bursts of activity, useful recordings were obtained only of a burst of five tremors at one station 1 km. from the Roseau Station and at the Roseau Station itself. There is a possible correlation between the differences in arrival times and the ratios of the maximum amplitudes of tremors at the two stations, which is consistent with each tremor having originated at a point source and having obeyed an inverse square law of attenuation. Assuming such an attenuation law the amplitudes at the two stations indicate that the sources lie close to a circle of about 5 km. diameter, the northern part of which passes through the town of Roseau..... The island contains several active thermal areas and ancient centres of eruption, but none is near the apparent sources of the tremors. We can find no evidence that these are related in any way to the volcanic activity of the island; but we cannot put forward an alternative explanation for their origin." (R2)

References

R1. Motley, L.; "Vibration on a Power Line," New Scientist, 5:198, 1959. (X1)

R2. Robson, G.R., and Barr, K.G.; "Unidentified Earth Tremors in Dominica, West Indies," Nature, 188:306, 1960. (X2)



Unidentified earth tremor on Dominica, 1959 (X2)

GQV2 Vibrations Induced by Falling Water

Description. Low-frequency vibrations emanating from waterfalls and overflowing dams. Typically, the vibrations are under 30 Hz and are felt or heard or both, being communicated both through the ground and air.

Data Evaluation. These phenomena are apparently well-known but little-explored. (The literature of hydraulic engineering has not been investigated; and dam vibrations may be thoroughly treated there.) The reports uncovered so far are of good quality. Rating: 1.

Anomaly Evaluation. In all instances the flow of water causes either a dam or rock at the base of a waterfall to vibrate. Although the precise mechanism(s) coupling the energy is not known, one would expect it to be well within the capability of fluid mechanics and hydraulics to explain. In other words, the problem seems to be a simple one. Rating: 3.

Possible Explanations. Wooden dams (X1) might be forced to vibrate at low frequency by rushing water (analogous to the reed in a wind instrument), but masonry dams (X4) would not. The water columns in both waterfalls and overflowing dams might vibrate longitudinally (analogous to standing waves in organ pipes).

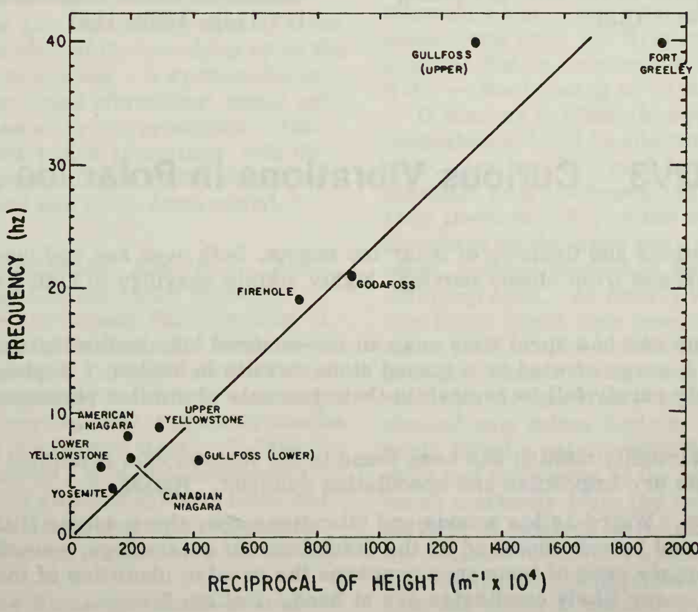
Similar and Related Phenomena. Flashes of light at the bases of waterfalls (GLD14); the Yellowstone Whispers, "desert sounds," and other curious sounds of uncertain origin (GSH).

Examples of Vibrations Induced by Falling Water.

X1. Permanent feature. Cuyahoga Falls, Ohio. "Sometime in the winter of 1841-2, my opinion was asked respecting a remarkable phenomenon noticed at Cuyahoga Falls, a village on the Cuyahoga River about eight miles from Hudson. The phenomenon consisted in the vibrations of the doors and windows, and other movable objects belonging to the buildings in the village. They were noticed at certain stages of the water, and at times ceased entirely. They were generally accorded to a certain dam in the river and various conjectures were formed as to the mode of their production. The subject was new to me, and I did not form any distinct idea of the phenomenon itself or its cause. Some weeks afterward, I visited the locality, and although the water was at too low a stage to exhibit the phenomenon in question, I succeeded in obtaining a pretty good description of the facts and formed my opinion as to its cause. I published a notice of it in the Ohio Observer which led to some discussion, and brought to light several similar cases elsewhere. As I have not succeeded in finding any notice of this subject in such books as I have had the opportunity of consulting, I have thought it desirable that the facts should be placed on record. I propose therefore to communicate such information as I have been able to collect, and shall conclude with some speculations as to the cause of the phenomena. Dam at Cuyahoga Falls, Ohio. This dam is a portion of an arc of a circle, the convexity of course being turned upstream. It is formed of hewn oak timbers one foot square, piled upon each other in tiers, all morticed firmly together, so as to form as it were one huge plank two feet thick; twelve and one half feet in breadth, and ninety feet in length, measured not between the banks, but between the points of support. Its curvature is described with a radius of a hundred and twenty feet; that is, the arc is about one eighth of the circumference of a circle. There is an embankment of earth upon the upper side, which until recently was left in an unfinished state. The bank did not rise to the top of the dam, and sloped off very abruptly. This dam was erected in the summer of 1840. During the winter of 1840-1 there was noticed considerable rattling of the windows of the neighboring houses; a phenomenon different from what had ever been noticed before; but during the winter of 1841-2, which was a very open and wet winter, the vibrations were more remarkable and became a matter of general complaint. The doors and windows of most of the houses in the village would shake for days together violenty as with the ague, and to such a degree as seriously to disturb sleep. This phenomenon was apparently somewhat capricious. After continuing for a time; perhaps an hour or a day or longer, the vibrations would suddenly cease, and after some interruption might be as suddenly resumed. The rattling of vibrating objects would frequently cease, while the vibrations could still be felt. A window, when apparently at rest, if put in motion by the hand, would continue to rattle. The buildings themselves (stone as well as wood) would vibrate with the doors and windows. This might be felt and also seen; as for example, a slender branch of a grape vine trained up against the side of a stone building, was seen to vibrate in exact time with the doors and windows. The vibrations ceased entirely when water ceased to pour over the dam; they were also inconsiderable when the depth of the water was eighteen or twenty four inches. A depth of five or six inches produced the greatest effect. The number of vibrations per second was thought to be about constant, but no accurate experiments on this point were ever made. From the best estimate I could obtain, they amounted to twelve or fifteen per second. A heavy log resting against the dam materially impaired the effect. The vibrations were seldom noticed in the summer, as the water rarely ran six inches over the dam; I however formed a plan during the summer of 1842, for a series of experiments during the ensuing winter and spring, to determine particularly the number of vibrations per second." Before the experiments could be performed, the dam was backed completely by earth, which stopped the vibrations completely. (R1) Several other vibrating dams are also described in the article.

X2. June 1903. Africa. "In June, 1903, I was trekking toward the Victoria Falls. On the night before arrival we 'outspanned' some twelve miles to the south, and on retiring to rest on the bare ground I became aware of a curious rhythmic sound, quite distinct when my ear was pressed against the soil. I told my two brothers, who found they could also hear the pulsation, and one of them suggested that it must be due to the booming of the distant cataract. To me the most interesting point is not that the sound was transmitted by the earth, but that it was transformed into rhythmic vibration---very different from the constant roar one hears when close to the Falls. Some process of interference would seem to occur and give rise to this result." (R2) See also musical echos (GSE2).

X3. General observations. "Typically, a waterfall produces continuous earth vibration with one frequency predominating; this frequency is inversely proportional to the height of the waterfall. Frequency data for nine waterfalls in Iceland, Alaska, and continental United States, ranging in height from 5 to 93 m, were obtained with an HS-10 geophone, whose position, whether at the brink or the base of the fall was immaterial. Waterfalls in which the flow is thoroughly broken up by ramps and ledges, such as a 'horsetail' fall, have high background noise with no characteristic predominant frequency. While wide



Waterfall vibration frequency depends upon waterfall height (X3) waterfalls---such as the Canadian and American Niagras, also have high background noise ---their predominant frequencies are discernable. Generally the data are not as consistent for low waterfalls as they are for high ones. A multiple-level fall, such as Gullfoss, a wide two-stage Icelandic waterfall, has as many characteristic frequencies as it has levels. Fourier analysis of the vibration frequencies of Gullfoss shows the two frequencies of 6 and 40 hz, which correspond, respectively, to drops of 7.5 and 27 m. While vibration set up in the earth must result from the water impinging against the base of the fall, details of the transfer of momentum are obscure. It is noteworthy that the slope of the solid line in Fig. 1 is 250 m/sec, about one-fourth the velocity of sound in water, suggesting that the entire water column may be resonating in the quarter wavelength mode. The impedance match at the base of the fall is good whereas that of the top is poor; this would place the node at the brink of the fall. Water breaks up into discrete turbulent eddies as it falls, with the length of each eddy increasing with distance of fall. Such separation, which would give intermittent impacts and lower frequency with greater height, is clearly evident in most regular waterfalls. A small individual turbulent eddy usually does not maintain its identity the full length of fall. It grows in length and then melds with others to form large and longer eddies, each of which strikes the base of the fall, producing strong earth motion." (R3)

X4. Permanent feature. Ringwood, New Jersey. "At Ringwood, New Jersey, the Ringwood Creek passes over a vertical masonry dam, approximately 20 m long by 5 m high, producing a strong beat at flood time (about 10 hz) enough to rattle buildings nearby, and often to be heard plainly a half mile downstream. According to Rinehart (R3) we ought to expect another frequency around 50 hz. Such a note, if present, must however be of low amplitude, too small to be heard above the general din without instrumentation. Apparently a separate explanation is needed for the above-mentioned low-frequency pulses which we plainly see as well as hear." (R4) Rinehart replies that waterfalls are structurally quite different from dams, and that the 10 hz vibration might be associated with the length of the dam rather than the height.

References

R1. Loomis, Elias; "On Vibrating Dams," American Journal of Science, 1:45:363, 1843. (X1)

R2. Durrant, Reginald G.; "Sound Transmitted through Earth," Nature, 107:140, 1921. (X2)

R3. Rinehart, John S.; "Waterfall-Generated Earth Vibrations," Science, 164:1513, 1969. (X3)

R4. Blade, Ellis, and Blade, Mary; "Water Generated Earth Vibrations," Science, 165:1148, 1969. (X4)

GQV3 Curious Vibrations in Polar Ice

Description. Vibrations and flexures of polar ice sheets, both over sea and land. The frequency spectrum ranges from slowly moving, highly visible heavings to high frequency sounds.

Background. Anyone who has spent time near an ice-covered lake knows that ice sheets are extremely noisy. A surge of wind or a tossed stone results in bedlam. Explorers of the Arctic and Antarctic rarely fail to remark in their journals of similar phenomena on much grander scales.

Data Evaluation. Virtually nothing has been found in the mainstream scientific journals reviewed so far. Data are imprecise and speculation rampant. Rating: 3.

Anomaly Evaluation. Weird as ice sounds and vibrations are, there seems little anomalous about them that cannot be encompassed by the disciplines of seismology, acoustics, and rheology. The primary area of ignorance concerns the precise identities of the vibration sources; however, many likely candidates are at hand. Rating: 3.

Possible Explanations. Some possible sources of ice disturbance: the wind, tidal action, temperature changes, earthquakes, volcanic action, iceberg calving.

Similar and Related Phenomena. Earthquake noises and vibrations are often just as strange as those experienced on the polar ice sheets. Sounds heard from the Greenland interior (GSM2-X2)

Examples of Curious Vibrations in Polar Ice

X1. 1933-1934. Chukchi Sea, Arctic Ocean. "In the course of the Polar expedition on the S.S. Cheluskin in the Chukchi Sea, 1933-34, I noted a very interesting phenomenon, concerning which I have been unable to find any descriptions in the literature available to me. The solid ice-cap of the sea, which represents, as it were, an immense elastic plate on a liquid foundation, is in a state of perpetual vibration. Though I had no special seismic apparatus at my disposal, I was nevertheless able, by means of very primitive hand-made instruments, to detect and roughly to measure these vibrations. They proved for the most part to be caused by the wind, and the direction of the greatest amplitudes tallied with the direction of the prevailing wind. A few cases of considerable vibrations running in a determined direction were observed on a windless day. Some hours later (up to eight hours) the wind blew in that same direction; evidently it did not keep pace with the sound oscillations it had caused in the ice. We call these vibrations 'wind vibrations', but we admit that they may consist in a periodic warping of the ice-plate. Besides these strictly directed 'wind vibrations' there may be observed 'disturbance vibrations' in the ice, spreading equally from the centre---the spot of the breaking up of the ice in different directions. A systematic investigation of the 'wind vibrations' would evidently greatly assist arctic synoptics. The study of the 'disturbance vibrations' will obviously permit periodicities in the dynamics of the ice-covered sea to be determined." (R1)

X2. Frequent occurrence. Antarctic. "Antarctica, disregarding the small volcanic earthquakes that accompany the eruptions of volcanos, is actually an aseismic land, as far as tectonic shocks are concerned. It is, however, surrounded by an almost continuous ring of tectonic earthquakes; but these shocks do not belong to Antarctica itself. Taking this fact into account, it is understandable that when the first reports arrived from Antarctica about a curious kind of earthquake, the news caused great surprise, even among geoscientists.

In 1957, at the Komsomolskaya station---a Soviet Antarctic base---seismic measurements were carried out to determine the structure of the ice layers. A great quantity of dynamite was exploded, and the artificial seismic waves in the ice were studied. These waves reached the base of the ice at a depth of some 2,500-3,000 meters beneath the surface.

At the time of the first seismic explorations, an unknown phenomenon was observed. After the explosion, a curious murmur was observed within a circle of radius 4 kilometers around the center where the explosion had taken place. The murmur became stronger and stronger; and its character was quite different from those murmurs that can be observed at the time of normal earthquakes or volcanic eruptions. This sound finally became similar to the rumble of thousands of airplanes! Its effect was frightful. The Soviet scientists who worked there had the opinion that the murmur was caused by the explosion, which had caused an earthquake-like event in the thick ice and snow layer. However, on the surface no no other abnormal phenomena were observed.

In 1960 the same phenomenon was observed at the American Byrd station. Comparing the events at the Soviet and American stations, it was stated that the foci of these icequakes were very near the surface. These phenomena were the first two artificial icequakes; that is, consequences of human activity---the blowing up of the ice.

It became evident, however, that natural icequakes existed in addition to the artificial ones. During the Third International Geophysical Year, between 1957 June 1 and 1958 December 31, at the Scott base, near the shore of the Ross Sea, more than 300 weak, natural icequakes were observed by seismographs. At first it was believed that these might have been volcanic shocks, since the distance between the Scott station and the volcano Erebus was only 30 kilometers. At this time, though, Erebus showed only minor activity. But the experts found a relationship between the energy and frequency of the shocks that differed markedly from the relation characteristic of volcanic shocks. Therefore, the volcano idea was rejected. In the course of the investigations that were carried out later, it became evident that the frequency of the shocks follows the variations of the seasons---which would be impossible in the case of volcanic shocks. Thus, the Antarctic icequakes were correlated with weather changes.

In addition, it was possible to fix the epicenters of the icequakes more exactly than before. It was certain that the majority of the shocks originated not at Erebus but on the mighty ice shelf extending out over the sea. Further, it was established that the icequakes were caused by the movements that take place on the ice-walls existing on this shelf. More precisely, the quakes were the consequence of the breaking up or 'calving' of the edge of the ice sheet into icebergs. Calving depends strongly on the weather and thus on the seasons. The events are particularly frequent on the Drigalsky ice tongue and along its extension, the David glacier." (R2)

X3. General observations. By Nansen, while his ship, the Fram, was being carried along by the Arctic ice pack. "Such an ice conflict is undeniably a stupendous spectacle. One feels one's self to be in the presence of Titanic forces, and it is easy to understand how timid souls may be overawed and feel as if nothing could stand before it. For when the packing begins in earnest, it seems as though there could be no spot on the earth's surface left unshaken. First you hear a sound like the thundering rumble of an earthquake far away on the great waste; then you hear it in several places, always coming nearer and nearer. The silent ice-world re-echoes and thunders; nature's giants are awakening to the battle. The ice cracks on every side of you, and begins to pile itself up; all of a sudden you too find yourself in the midst of the struggle. There are howlings and thunderings round you; you feel the ice trembling, and hear it rumbling under your feet; there is no peace anywhere. In the semi-darkness you can see it piling and tossing itself up into high ridges nearer and nearer you---floes 10, 12, 15 feet thick, broken, and flung on the top of each other as if they were featherweights.....All round there is thundering and roaring, as if of some enormous waterfall, with explosions like cannon salvoes. Still nearer you it comes. The floe you are standing on gets smaller and smaller; water pours over it; there can be no escape except by scrambling over the rolling ice blocks to get to the other side of the pack. But now the disturbance begins to calm down. The noise passes on, and is lost by degrees in the distance." (R3)

References

R1. Fakidov, Ibrahim; "Vibrations of the Ice-Cap of the Polar Seas," Nature, 134: 537, 1934. (X1)

R2. Hedervari, Peter; "Ice Phenomena," in The Strange Phenomena of the Earth, Budapest, 1977. (Translated and submitted by Peter Hedervari.) (X2)

R3. Nansen, Fridtjof; "The Winter Night," in Farthest North, London, 1897, p.166, vol. I. (X3)

GQW EARTHQUAKE WEATHER

Key to Phenomena

GQW0 Introduction

The term "earthquake weather" is generally taken to mean the hot, stagnant, oppressive state of the atmosphere that is supposed to prevail just before an earthquake. The study of earthquake data provides little to support this popular notion---earthquakes, it seems, happen in all weather conditions.

Several other possible sorts of weather have been associated with earthquakes. These have not been well-examined by scientists; rather they have been dismissed as improbable. Wind gusts, sudden storms, and ground-hugging fogs are reported with surprising frequency in conjunction with quakes. Are they causally connected or just coincidences? No one really knows. Since reasonable cause-and-effect mechanisms are available, further research seems in order.

GQW1 Earthquake Weather

Description. Hot, still, oppressive weather preceding earthquakes. One is tempted to add the adjectives forboding and ominous, but they are even less objective, although they are definitely part of the popular concept of "earthquake weather."

Data Evaluation. No quantitative surveys of earthquake records seem to have been made, but even cursory examinations of earthquake catalogs reveal that quakes occur in all kinds of weather. No studies have been found supporting the notion of "earthquake weather." The situation is complicated because hot, oppressive weather is very common and usually not attended by earthquakes. Rating: 4.

Anomaly Evaluation. Earthquakes may, in principle, be triggered by changes in barometric pressure, which in turn usher in weather changes. Thus, some connection between weather and earthquakes is possible and not a significant anomaly. Rating: 3.

Possible Explanations. Changes in barometric pressure applied over large areas are immense and could conceivably initiate quakes.

Similar and Related Phenomena. Tornado weather and the oppressive, calm conditions before thunderstorms closely resemble earthquake weather.

Examples of Earthquake Weather

X1. General observations. "In the south of Europe a general belief prevailed that calms, oppressive heats and a misty atmosphere, were the usual preludes of earthquake. Hamilton says he found it a general observation in Calabria, 'that before a shock the clouds seemed to be fixed and motionless, and that immediately after a heavy shower of rain (during the earthquake), a shock quickly followed.' And in the Philippine Islands, De Guignes informs us that 'a calm, the sky gray and cloudy, the atmosphere heated and heavy, occasional gusts of wind, and at intervals gentle showers of rain, are the prognostics by which earthquakes are anticipated there,' After recording a number of vague opinions held by the South Americans, as to the weather prognostics of earthquakes, Humboldt says, 'These are however very incertain, and when the whole of the meteorological variations at the times when the globe has been most agitated are called to mind, it is found that violent shocks take place equally in dry and in wet weather, when the coolest winds blow, or during a dead and suffocating calm.' Again, the veteran philosopher says that 'even in Italy this belief is dying away;' and expresses his own conviction, strengthened by that of those who have lived long in the great shaken countries of South America, that earthquakes are independent of the weather or appearance of the heavens immediately before the shock. He says he has felt earthquakes when the air was clear and a fresh east wind blowing, and also when there was rain and thunder-storms; and this has been very recently confirmed by the continuous observations made at New Zealand during the earthquake of 1848, which began in a gale of wind." (R1)

"Anybody who has ever lived for any length of time at a stretch in a region where earthquakes are common objects of the country and the seaside, known perfectly well what earthquake weather in the colloquial sense is really like. You are sitting on the piazza, about afternoon tea-time let us say, and talking about nothing in particular with the usual sickly, tropical languor, when gradually a sort of faintness comes over the air, the sky begins to assume a lurid look, the street dogs leave off howling hideously in concert for half a minute, and even the grim vultures perched upon the housetops forget their obtrusive personal differences in a common sense of general uneasiness. There is an ominous hush in the air, with a corresponding lull in the conversation for a few seconds, and then somebody says with a yawn, 'It feels to me very much like earthquake weather.' Next minute you notice the piazza gently raised from its underpropping woodwork by some unseen power, observe the teapot quietly deposited in the hostess's lap, and are conscious of a rapid but graceful oscillating movement, as though the ship of state were pitching bodily and quickly in a long Atlantic swell. Almost before you have had time to feel surprised at the suddenness of the interruption (for the earth never stops to apologize) it is all over; and you pick up the teapot with a smile, continuing the conversation with the greatest attainable politeness, as if nothing at all unusual had happened meanwhile. With earthquakes, as with most other things and persons, familiarity breeds contempt." (R2) Proctor, the author of this delightful piece, was an early popularizer of science. (WRC)

"He (Prof. G.E. Goodspeed) explained that 'earthquake weather' which often occurs in California comes when a low pressure area moves in, lowering the barometric pressure. This makes a difference of thousands of pounds of pressure per square foot. It might be 'the straw that breaks the camel's back' in setting off a quake, he suggested." (R3)

References

R1. Mallet, Robert; "On the Facts of Earthquake Phaenomena," Report of the British Association, 1850, p. 67. (X1)
R2. Proctor, Richard A.; "Earthquake Weather," Living Age, 160:306, 1884. (X1)
R3. "'Earthquake Weather' and Moon May Set Off Tremors," Science News Letter, 55:278, 1949. (X1)

GQW2 Earthquakes Associated with Sudden Storms

Description. The nearly simultaneous occurrence of earthquakes and sudden, localized storms. General rains and stormy weather associated with widespread low-pressure areas are excluded here.

Background. The intent of this Catalog entry is to highlight sudden weather changes in an epicenter region that might have been stimulated by earthquake precursors, such as the release of gases and particulate matter.

Data Evaluation. Many old earthquake records mention "violent tempests," although most do not. Indeed, many quakes hit in the finest weather. Although no statistical studies are at hand, the earthquake catalogs seem to list many instances of sudden storms that sometimes end as abruptly as the quake itself. (So far, the major earthquake catalogs have only been sampled; there are many more examples.) Rating: 3.

Anomaly Evaluation. As mentioned above, prequake release of gases, aerosols, and particulate matter may induce storms. So, a causal mechanism does exist, even though its efficacy is unevaluated. The question again is whether coincidence reigns or earthquake precursors are storm-makers. Rating: 3.

Possible Explanations. Earthquake precursors may induce storms, as explained above.

Similar and Related Phenomena. Earthquakes correlated with precipitation (GQW3); the earthquake fogs (GQW5); pressure waves created by earthquakes (GSW2).

Examples of Earthquakes Associated with Violent, Sudden Storms

X1. February 18, 1756. Silesia, Europe. Earthquake occurred during a terrible tempest. (R2)

X2. May 30, 1756. Lisbon, Portugal. Earthquake followed three days of tempest. (R2)

X3. August 17, 1756. Padua, Italy. Quake preceded by a terrible tempest. (R2)

X4. August 29, 1757. Barbados, West Indies. The quake was followed by a terrible storm. (R2)

X5. December 6, 1758. Russia. The earthquake, which lasted anywhere from ½ to 3 hours depending upon the witness, was accompanied by a terrible tempest that ceased when the quake ended. (R2)

X6. August 17, 1760. Salonika, Greece. Violent thunder, wind, and rain immediately succeeded the shock. (R2)

X7. January 25, 1761. Hermosand, Sweden. A terrible storm preceded the quake. (R2)

X8. January 11, 1762. Montfort l'Amaury, France. Quake preceded by a severe storm. (R2)

X9. December 26, 1764. Lisbon, Portugal. Bad weather with wind, thunder, and rain prevailed during the quake, but for a moment after the shock a sudden calm descended. (R2)

X10. July 23, 1765. West Bothnis, Sweden. The earthquake began during a terrible storm of thunder, lightning, and rain. (R2)

X11. August 13, 1766. Martinique, West Indies. Quake accompanied by a terrible hurricane. (R2)

X12. February 27, 1786. Hungary. A violent storm followed the shock. (R3)

X13. June 14, 1790. Ancona, Italy. In the Calabrias, the shock was followed by terrible storms with thunder. (R3)

X14. August 29, 1791. Pressburg, Hungary. A violent storm occurred with the quake. (R3)

X15. November 29, 1793. Lisbon, Portugal. The earthquake was followed by abundant rain. (R3)

X16. February 21, 1799. Frankfort, Germany. A terrible storm with lightning accompanied the shock. (R3)

X17. November 4, 1799. Cumana, Venezuela. Before the shocks, thunder and lightning were observed. Large, electrified drops of rain followed. Compass needles were disturbed. (R3)

X18. October 10, 1839. Comrie, Scotland. On the day of the shock, rain fell in torrents, and a very violent wind blew from the southwest. (R1)

X19. October 9, 1885. Sorunda, Sweden. A great thunderstorm passed overhead and heavy rain fell during the quake. (R4)

X20. September 25, 1899. Darjeeling, India. The earthquake was associated with a remarkable fall of rain---over 20 inches in 24 hours. (R5)

X21. May 28, 1902. Capetown, South Africa. "As certain peculiar meteorological phenomena seem to have been closely associated with the earthquake felt in the Cape Peninsula on May 28, the following particulars of this occurrence seem to deserve notice. After being practically calm all day, a loud sound resembling a clap of thunder or the rumbling of approaching heavy waggons was heard about 11.45 p.m. (Cape mean time of $22\frac{1}{2}^{\circ}$ east), followed in Cape Town and Green Point by a heavy downpour of rain, and in the suburbs by a severe squall of wind and rain; practically simultaneous with the sound there occurred a shaking and rattling of windows and doors; some state they felt also a distinct shock, others that their beds rocked, while information was received of the cracking of the walls of at least two dwelling houses. The wind squall was strong enough to uproot or blow down trees in some of the eastern suburbs. One gentlemen, whose written account is in our possession, states that 'it fairly shook the room and its contents which I occupy at Rosebank; shortly afterwards a similar sound (tremor ?) was felt; it lasted only a few seconds and died away.' Dogs were apparently conscious of the occurrence, one which was never known to be affected by thunder and lightning moving about and whining in a peculiar manner, while a parrot indicated by its screeching that it was sensible of something unusual happening.... No record of any seismic disturbance was, however, shown on the seismometer at the Royal Observatory." (R7) This may not have been an earthquake at all. (WRC)

X22. General observations. "In considering whether there is any possibility of a connection between the phenomena here considered we must remember that observations showing that rain and cloud have followed closely on the heels of certain earthquakes appear to be confined to tropical and semi-tropical countries; and it is in these countries where sudden showers, indicating the collapse of critical atmospheric conditions, are frequent. Given, therefore, such conditions at no great distance above the surface of the earth, which was probably the conditions in the highlands of Assam, and then admit that beneath the gaseous covering consisting of layers of air of different temperatures and with different degrees of saturation, 10,000 square miles of mountainous country was moved, or that a much larger area was thrown into violent wave-like movement, we recognize that the relationship of earthquakes and atmospheric precipitation may not be so improbable as is generally supposed. As the ground rose upwards, the air immediately above it would suffer compression, and as the ground fell there would be rarefaction, whilst layers of air differing in their physical state might be mixed, and a vigorous seismic activity might in this way result in precipitation." (R6)

References

R1. Milne, David; "Notices of Earthquake Shocks Felt in Great Britain,....," Edinburgh New Philosophical Journal, 32:111, 1842. (X18)

R2. Mallet, Robert; "On the Facts of Earthquake Phaenomena," Report of the British Association, 1853, p. 125-156.(X1-X11)

R3. Mallet, Robert; "On the Facts of Earthquake Phaenomena," Report of the British Association, 1854, p. 11-43. (X12-X17)

R4. Nature, 33:18, 1885. (X19)

R5. Nature, 60:535, 1899. (X20)

R6. Judd, J.W., et al; "On Seismological Investigation," Report of the British Association, 1900, p. 106. (X22)

R7. Stewart, Charles; "Earthquake of May 28 at the Cape, and Coincident Meteorological Effects," Nature, 66:369, 1902. (X21)

GQW3 General Rainfall Correlated with Earthquake Frequency

Description. The correlation of earthquake frequency with the quantity of precipitation.

Background. This phenomenon is distinct from the sudden, localized storms sometimes associated with quakes (GQW2) by the fact it is time-averaged; that is, specific earthquakes and not correlated with specific storms.

Data Evaluation. Several rather old statistical studies are available, but not all support the existence of this phenomenon. Rating: 3.

Anomaly Evaluation. A great earthquake can inject considerable dust and, perhaps, gases and aerosols into the atmosphere. These can serve as precipitation nuclei and encourage precipitation. Furthermore, earthquake frequency often correlates positively with volcano activity; and volcanos are well-accepted as weather modifiers. Statistically, therefore, a positive correlation of earthquake frequency with precipitation is not particularly surprising. Rating: 3.

Possible Explanations. As discussed above. Also, earthquakes and terrestrial weather may have a common driving force; viz., solar activity; and actually be independent of each other and yet positively correlated.

Similar and Related Phenomena. Sudden storms associated with quakes (GQW2), earthquake fogs (GQW5), astronomical influences on earthquakes (GQS) and weather (GWS).

Examples of General Rainfall Correlated with Earthquake Frequency

X1. General observations. "With reference to the remarkable letter of "A.B.M.," which appeared in your number of this week (May 19), p. 31, as to the recurrence of cold and wet periods at about thirty five years' interval (Measuring from the centre of one such period to that of the next), I beg leave to call attention to the fact that thirty five years represents a marked period of recurrence of maximum frequency of earthquakes, as I showed in a paper which was submitted to the Royal Irish Academy in 1887, but not published. That a relation should exist between earthquakes, volcanic disturbances, and the atmospheric conditions which determine wet and dry periods, seems to me more reasonable to accept a priori, than to assume that these phenomena are quite independent of each other. From Mallet's Catalogue of Earthquakes I have compiled a list between the dates 365 and 1842, showing the intimate relations between the shocks and immediate and violent atmospheric perturbations on those occasions (about 500 in all); this list could be very much extended for more recent times from Perry's and Falb's lists, and would be a valuable contribution on the subject. But discussing simply the figures presented by your correspondent from this point of view, very interesting results can be shown. I begin by assuming (a) an intimate though undefined relation between most great earthquakes and intense volcanic action; (b) intense volcanic action in one or other of the great volcanic centres or lines of action during certain periods, giving rise to the emission of vast quantities of gases which rise into the upper atmosphere, and disturb or influence the upper currents; and (c) that the upper currents of the atmosphere are more and more looked on as dominating meteorological phenomena. Hence a dependency in the meteorological conditions which determine maxima of drought or wet, on maxima of volcanic action, but not concordance as to date or period. These lag upon the former." Several specific earthquakes and volcanic eruptions are then discussed in connection with specific storms. (R1)

X2. Statistical analysis. A rough correlation between U.S. rainfall in 1904 and earthquake frequency. (R2)

X3. Statistical analysis. "Although Ferdinand de Montessus de Ballore after a study of the rainfall conditions preceding 4,136 earthquakes, was unable to find any connection, Professor Omori has found an apparent relationship between the annual frequency of earthquakes at Tokyo and the amount of rainfall in northwestern Japan. The periods when earthquakes were infrequent but severe correspond in a striking manner with those when rainfall was deficient at Niigata and Akita on the Japan seacoast, while in the years of maximum earthquake frequency at Tokyo, the amount of rain and snow falling in the north was much above the average." (R3, R4)

X4. Statistical analysis. Jamaica, West Indies. For this region, earthquake frequency peaks in February and July, both months of minimum rainfall. The earthquake curve shows minima in May and October, which are the months of maximum rainfall. (R5). In this study, the quakes and rainfall are 180° out of phase, contradicting other correlations. (WRC)

References

R1. O'Reilly, J.P.; "Rainfall and Earthquake Periods," Nature, 58:103, 1898. (X1)
R2. Sayles, R.W.; "Earthquakes and Rainfall," Seismological Society of America, Bulletin, 3:51, 1913. (X2)
R3. Nature, 91:65, 1913. (X3)
R4. "Earthquakes and Rainfall," Science, 38:629, 1913. (X3)
R5. "Earthquakes and Rainfall," Nature, 136:958, 1935. (X4)

GQW4 Wind Gusts Associated with Earthquakes

Description. Sudden gusts of wind striking simultaneously or just before the shock of an earthquake.

Data Evaluation. The early earthquake catalogs, such as those of Milne and Mallet, occasionally remark on sudden gusts of wind that seem in sympathy with the shocks. It is possible that this phenomenon may sometimes be confused with earthquake sounds that frequently resemble wind. Also, observers inside buildings might identify shocks as wind gusts hitting the structure. Despite these possibilities for error, the catalogs contain enough of these events to make it worthwhile collecting them. Rating: 3.

Anomaly Evaluation. Although the great earthquakes are known to distort the ionosphere over the epicenters (GET), there seems to be no obvious mechanism by which a quake can accelerate air horizontally. Rating: 2.

Possible Explanations. The magnetohydrodynamic acceleration of air---made conducting by the emission of ions from the crust---should be considered.

Similar and Related Phenomena. Gusts of hot air associated with lightning strikes (GLL12). Atmospheric pressure waves created by earthquakes (GSW), rushing sounds accompanying earthquakes (GSH1).

Examples of Earthquakes Associated with the Sudden Onset of High Winds

X1. August 30, 1757. Florence, Italy. The earthquake was preceded by a very high wind which ceased immediately after the shock. (R1)

X2. January 16, 1759. Aix-la-Chapelle, France. Great blasts of wind accompanied the quake. They increased and decreased with the shocks. (R1)

X3. November 6, 1764. Oxford, England. The wind was calm before the quake but became tempestuous afterward. (R1)

References

R1. Mallet, Robert; "On the Facts of Earthquake Phaenomena," Report of the British Association, 1853, p. 132-150. (X1-X3)

GQW5 Fogs Associated with Earthquakes

Description. The appearance of ground fog before, during, or after an earthquake. On occasion, the so-called earthquake fog will be observed in localities where fog is a rarity.

Data Evaluation. A suprising number of earthquakes have been accompanied by fogs and mists, and many more will be added to the Catalog as examination of various earthquake catalogs continues. What is not certain is whether these fogs prevailing at the times of earthquakes represent anything more than coincidence. Most quakes, in fact, are not associated with fogs. Rating: 3.

Anomaly Evaluation. If some earthquakes and some fogs are truly related causally, several possible mechanisms for generating the fogs exist (see next paragraph). None of these mechanisms requires any modification of current theories, although fogs are not now considered among the recognized attributes of earthquakes. Rating: 3.

Possible Explanations. Heat generated along earthquake faults could generate steam or vapor from ground water, which then condenses in the air. Gases and aerosols expelled from the crust, if not directly visible, might serve as condensation nuclei. Electrical fields created piezoelectrically might produce luminous phenomena with fog-like characteristics, much like auroral fogs and mists. (GLA4, GLA21)

Similar and Related Phenomena. Dry fogs (GWD4), low-level auroras (GLA4), auroral fogs and mists (GLA21).

Examples of Fogs Associated with Earthquakes

X1. 1638. Sicily, Italy. Fog enveloped earthquake area. (R5)

X2. 1693. Millitello, Italy. Fog and quake. (R5)

X3. March 16, 1761. Boston, Massachusetts. The sky was clear, but the entire horizon was obscured by a whitish fog that seemed to have a light behind it. (R2)

X4. December 11, 1799. Silesia, Europe. The earthquake occurred when there was a thick fog with a sulphurous odor. Thunder and lightning seemed to come out of a thick mist. (R4)

X5. June 6, 1807. Lisbon, Portugal. A thick fog preceded the quake. (R1)

X6. February 1, 1816. Lisbon, Portugal. Thick fog before the earthquake. (R1)

X7. August 13, 1816. Aberdeen, Scotland. After the second shock, a thin white vapour settled on the mountains though the air was otherwise clear. (R1)

X8. November 13, 1833. Dorsetshire, England. A thick fog accompanied the earthquake. (R3) The fog rose from the soil as if the ground had been heated. (R1)

X9. June 12, 1897. Assam, India. The afternoon had been lovely without a cloud in the sky. Five minutes after the earthquake residents were surrounded by cloud and mist. Rain followed. (R6)

X10. January 24, 1899. Mexico. Three hours after the quake, a heavy mist settled over the head of a canyon at 8,700 feet. (R6) Date set at 1898. (R7, R8)

X11. February 4, 1975. Haicheng, China. "Some hours before the quake, a strange mist was seen in many places. This fog covered the soil up to a height of 2 to 3 meters. It was extraordinarily dense; some places is was white, but elsewhere it was black. Its distribution was uneven; it had a layered structure. Its odor was extremely strong. This fog appeared 1 or 2 hours prior to the shock. Objects under or behind this fog were almost completely invisible. After the shock, the fog disappeared quickly. Its distribution followed exactly the strike of the fault that created the shock." (R9)

X12. November 12, 1839. Comrie, Scotland. A dense, dark, indescribable species of mist enveloped the mountains. (R10)

References

R1. Clarke, W.B.; "On Certain Recent Meteoric Phenomena,....., Magazine of Natural History, 7:289, 1834. (X5-X8)

R2. Mallet, Robert; "On the Facts of Earthquake Phaenomena," Report of the British Association, 1853, p. 139. (X3)

R3. Milne, David; "Notices of Earthquake Shocks Felt in Great Britain.....," Edinburgh New Philosophical Journal, 31:92, 1841. (X8)

R4. Mallet, Robert; "On the Facts of Earth-

quake Phaenomena," Report of the British Association, 1854, p. 43. (X4)
R5. Lake, John J.; "Earthquakes and Their Causes," English Mechanic, 21:51, 1875. (X1, X2)
R6. Judd, J.W., et al; "On Seismological Investigation," Report of the British Association, 1900, p. 106. (X9, X10)
R7. "Earthquake Weather," Royal Meteorological Society, Quarterly Journal, 35: 30, 1909. (X10)
R8. "Recent Earthquakes," Nature, 79:368, 1909. (X10)
R9. Hedervari, Peter; "Strange Phenomena Prior to the Haicheng (China) Earthquake," Personal communication, 1983. (X11)
R10. Milne, David; "Notices of Earthquake-Shocks Felt in Great Britain,....," Edinburgh New Philosophical Journal, 32:111, 1842. (X12)

UNUSUAL SOUNDS IN NATURE

When the research work for this Catalog began, the number and variety of mysterious natural sounds was not foreseen. Strange lights, mirages, weather oddities, and the like were believed to constitute the great majority of strange geophysical phenomena. The famous Barisal Guns were recognized, of course, due to the publicity given them by Sir George Darwin. Additional curious sounds have been discovered in the foray through the literature at a modest but surprising rate. Even now, after years of search, this Catalog section cannot be considered near completion, for how many individuals take the time to write to scientific journals about ephemeral, elusive sounds? For that matter, who, in these noisy latter days, can separate natural and man-made sounds? Almost all strange sounds reported here have been heard either in remote spots of the globe, where almost all sounds are natural, or in earlier and quieter days.

The most noticeable and startling of the anomalous natural sounds are the detonations---sudden bursts of acoustical energy---which accompany many violent natural events. Natural explosive sounds are clearly linked genetically to atmospheric pressure waves, which are rarely perceived by humans because of their very long wavelengths. Very sensitive barometers may record them, but they wash over humans unnoticed. Pressure waves are also the consequence of energetic geophysical events.

Faint, elusive hums and hisses tend to emanate from more subdued natural processes, such as auroras, blowing sands, meteor trails, and some as-yet-undiscovered sources. This category of sounds harbors members which, according to acoustical theory, cannot exist because of unacceptably long travel times from their apparent sources. Other members of this class, on the other hand, are simply curiosities and threaten no physical laws.

Perhaps the most delightful types of unusual acoustical phenomena are those that are also pleasing to the ear; that is, musical. Most mysterious sources of natural music either convert wind energy into music via vibration (natural reed instruments) or resonating air columns (organs). Other types of natural music probably come from elusive animals, particularly in the case of underwater music, such as that heard near the mouth of the Pascagoula River in Mississippi. Less mysterious but no less pleasing are nature's musical echos heard when rocks, trees, and other sound reflectors convert noise into haunting tones.

Modern technology for all of its masking of natural sounds has also led us to the understanding of infrasound; that is, sound with frequencies below those detectable by the ear. Much infrasound seems to originate with the auroras, with weather systems, with volcanos and seismic activity---just those phenomena that contribute so many curious observations via our other sensory channels.

GSD EXTRAORDINARY DETONATIONS

Key to Phenomena

GSD0 Introduction

In these days of sonic booms and frequent blasting, detonations heard afar are usually written off as manmade with good reason. A century ago, the world was much quieter, and people tried to track down the sources of strange detonations. For example, E. Van den Broeck was able to compile almost 200 pages of testimony on the "mistpouffers" in the Belgian scientific journal Ciel et Terre (Sky and Earth) in 1895 and 1896. Mistpouffers are dull, distant explosive sounds heard around the coasts of northern Europe all the way to Iceland. It turns out that similar sounds break the silence of warm, summer days around the Mediterranean shores and along the North American and Asian coasts. Every country has its own name for them. Despite their universality, science takes little interest in them.

Probably the most famous natural detonations are the Barisal Guns heard in the Ganges delta. These "guns" and the mistpouffers, the Italian "marina", and all similar explosive sounds observed along the seacoasts form a class called "waterguns." The name is apt, because the booms seem to emanate from the sea itself. Waterguns, though, are not confined to salt water. Some of New York's finger lakes have their own private waterguns; so do lakes in Europe. Doubtless many waterguns have never been mentioned in scientific journals and are thus excluded from the collection. We must assume that they are as common along fresh-water shores as salt.

"Land guns" are also ubiquitous. Residents of dozens of inland localities hear strange detonations year after year, some seeming to originate beneath their feet and others from the sky overhead. Most of these regions are known to be seismically active; that is, subterranean forces are slowly cracking and grinding rocks. Curiously, though, many of the land guns cannot be correlated with shocks or tremors, although others can. It seems likely that the land guns and waterguns are closely related---they do sound pretty much the same---and that we are only hearing the restless earth.

GSD1 Explosive Sounds Heard along Seacoasts and near Large Bodies of Water

Description. Natural explosive sounds, distant and muffled, resembling far-off artillery, but coming from directions difficult to specify precisely. The detonations are episodic, sometimes heard several times per day and then not for months or years. Triplets of booms a few seconds apart are a rare feature. Records comes from all seasons and all times of the day, although warm, calm, misty summer days seem to be favored. The detonations assigned to this category prevail along seashores and around large lakes, and thus deserve the name "waterguns." The booms are generally picked up by sensitive barometers, but seismographs frequently fail to record them. The literature focusses on the Ganges Delta (the Barisal Guns), the coasts of northern Europe (the mistpouffers), Italian shores (marina), and several other localities; but waterguns may well be a global phenomenon.

Background. The history of the "waterguns" is long and well-documented. Nevertheless, little scientific research has been expended upon them. The attention of scientists has been caught only twice; once, when George Darwin asked for data in Nature in 1895, and in the period 1977-1978, when powerful booms rocked the east coast of North America. Today, the phenomenon doubtless persists, but it is masked by supersonic aircraft and many other artificial detonations.

Data Evaluation. The data are abundant and good. The validity of the phenomenon cannot be doubted. The use of newspaper accounts, if all were admitted here, would expand this section manyfold. Rating: 1.

Anomaly Evaluation. Several likely explanations of natural detonations are at hand. It is simply a question of deciding which explanation suits which episode of booms. In fact, more than one explanation may apply, as in the 1977-1978 series of booms along the east coast of North America. None of the proposed explanations seriously tries geophysical theory. There are, however, facets of the phenomenon that remain somewhat enigmatic: the occasional triplet structure, the tendency to occur on warm, calm, foggy days, and the rare association with flashes of light. Rating: 2.

Possible Explanations. (1) Most likely of all is the seismic theory, for the mystery booms are essentially identical to the cannonading frequently heard prior to and during earthquakes; (2) Supersonic aircraft probably account for most booms heard today; (3) The eruption and possible natural detonation of natural gases from underwater deposits; (4) Rare atmospheric electrical phenomena, such as lightning from a clear sky (GLL6); (5) The breaking of long ocean rollers; (6) Unseen detonating meteors; (7) Fish sounds (GSM).

Similar and Related Phenomena. Detonations heard in known seismic regions (GSD2). See suggested explanations above.

Examples of Explosive Sounds Heard along Seacoasts and near Large Bodies of Water

X1. Frequent occurrence. The Ganges Delta, India. Selected accounts of the Barisal Guns follow in chronological order.

"On a distant island in the Bay of Bengal (we learn from Naturforschen) there is a phenomenon known under the name of the Barisal guns, which, according to the accounts given by natives, is often heard at the beginning of rain, and is like the sound of firing of cannon. It seems to have no connection with the season, and sometimes comes from the north, sometimes from the south or southwest. Mr. Beveridge, who has collected some data on the subject, comes to the conclusion that these sounds are atmospheric, and connected in some way with electricity." (R1)

"The 'Barisal Guns' are sounds resembling the firing of heavy cannon at a distance. They are heard at various points in the Delta of the Ganges and Brahmaputra, and in the hills to the north of it; their origin has never been satisfactorily explained, though many theories have been advanced to account for it. Of these the principal are:---(i.) The breaking of surf rollers during the Southwest Monsoon on the shores at the head of the Bay of Bengal; (ii.) The falling in of high banks along the courses of the rivers in the Delta; (iii.) The firing of bombs by the natives at their marriage festivities; (iv.) Atmospheric electricity; and (v.) Subterranean or subaqueous volcanic or seismic agencies. It is shown that none of these theories is entirely satisfactory, except perhaps, the last; and that a cause of the sounds may possibly be found in slight movements of the layers of silt, composing the Delta, over each other, as they settle down; movements whicb may be augmented by the strains set up by the increase and decrease of pressure on the surface, due to the inflow and outflow of the tides along the river channels. " (R2)

After a brief review of the status of knowledge on the Barisal Guns and mistpouffers (X2), G. H. Darwin appealed to the scientific community for more data on the subject. (R3) It was in fact this request, made in 1895, that led to the publication of many of the accounts that follow. (WRC)

H. S. Olcott, who had heard the Barisal guns personally, noted that they were sharp and gun-like rather than dull and distant, as mistpouffers were reported to be. (R5)

E. Van den Broeck, in his classic and very extensive review of GSD1 phenomena, summarizes the extant literature on the Barisal Guns. (R6)

A report by G. B. Scott based upon his experience on the Indian Survey. "I first heard the Barisal Guns in December 1871, on my way to Assam from Calcutta through the Sunderbans. The weather was clear and calm, no sign of any storms. All day the noises on board the steamer prevented other sounds from being heard, but when all was silent at night, and we were moored in one or other of the narrow channels in the neighborhood of Barisal, Morelgunge and upwards, far from any villages or other habitations, with miles and miles of long grass jungle on every side, the only sounds the lap of water or the splash of earth, falling into the water along the banks, then at intervals, irregularly, would be heard the dull muffled boom as of distant cannon. Sometimes a single report, at others two, three, or more in succession; never near, always distant, but not always equally distant. Sometimes the reports would resemble cannon from two widely separated opposing forces, at others from different directions but apparently always from the southward, that is seaward. We were not very far from the sea when I first heard them, and on mentioning to an old lady on board that I heard distant cannon, she first told me of the mysterious sounds known as the 'Barisal Guns.' For the next two years I was in Upper Assam, above Goalpara, and do not remember ever hearing them there; but in 1874 I was working in the Goalpara district in the tract south of Dhubri, between the Brahmaputra and the Garo Hills; sometimes near the river, sometimes near the foot of the hills, at others between the two. I gradually worked down as far as Chilmari Ghat (I think it is called), the landing-place for Tura, the headquarters of the Garo Hills district, and distant quite 300 miles from the mouths of the Brahmaputra and Ganges. The villages are few and far between and very small, firearms were scarce, and certainly there were no cannon in the neighborhood, and fireworks were not known to the people. I think I am right in saying I heard the reports every night while south of Dhubri, and often during the day. The weather on the whole was fine. Short, sharp 'nor'westers' occasionally burst on us of an evening, with much thunder and lightning; but the days were clear, and, as a rule, the sounds were heard more distinctly on clear days and nights. I specially remember spending a quiet Sunday, in the month of May, with a friend at Chilmari, near the river bank. We had both remarked the reports the night before and when near the hills previously. About 10 a. m. in the day, weather clear and calm, we were walking quietly up and down near the riverbank, discussing the sounds, when we heard the booming distinctly, about as loud as heavy cannon would sound on a quiet day about ten miles off, down the river. Shortly after we heard a heavy boom very much nearer, still south. Suddenly we heard two quick successive reports, more like horse-pistol or musket (not rifle) shots close by. I thought they sounded in the air about 150 yards due west of us over the water. My friend thought they sounded north of us. We ran to the bank, and asked our boatmen, moored below, if they heard them, and if so in what direction. They pointed south. "(R8)

Booming sounds heard in India may have two different origins, for there are two different types: (1) The Barisal Guns along the seacoast; and (2) Detonations heard inland, in the mountains, which are probably seismic in origin. (R10)

Barisal Guns and other natural booming sounds are likely due to ball lightning exploding. (R11) Miners often hear sounds similar to the Barisal Guns, suggesting a seismic source. (R21)

Henry S. Schurr recounts his experiences with the Barisal Guns in his role as District

Superintendent of Police of the region where they are common. "Barisal Guns are heard over a wide range extending from the Twenty-four Pergunnahs through Khulna, Backergunge and Noakhali, and along the banks of the Megna to Naraingunge and Dacca. They are heard most clearly and frequently in the Backergunge district, from whose headquarters they take their name. These Guns are heard most frequently from February to October, and seldom in November, December or January. One very noticable feature is their absence during fine weather, and they are only heard just before, during, or immediately after heavy rain. The direction from which they are heard is constant, and that is the south or south-east. I have heard them west of me when down in the extreme south of the district, but never north of me. On the other hand, I have been told by captains of river-going steamers that they have heard these reports to their north. These gentlemen, however, ply along waters outside the range of my observations, which lie on the mainland and its adjacent waters. These Guns are always heard in triplets, i.e. three guns are always heard, one after the other, at regular intervals, and though several guns may be heard the number is always three or a multiple of three. Then the interval between the three is always constant, i.e. the interval between the first and the second is the same as the interval between the second and the third, and this interval is usually three seconds, though I have timed it up to ten seconds. The interval, however, between the triplets varies largely, from a few seconds up to hours and days. Sometimes only one series of triplets is heard in a day; at others, the triplets follow with great regularity, and I have counted as many as forty-five of them, one after the other, without a pause. The report is exactly like the firing of big guns heard from a distance with this peculiar difference, that the report is always double, i.e. the report has (as it were) an echo. This echo is so immediate that I can best describe its interval by an illustration. Suppose a person standing near the Eden Gardens heard the 9 o'clock gun fired from Fort William, he would first hear the report of the gun and its immediate echo from the walls of the High Court. The Barisal Guns sound exactly like this, only as if heard from a distance of several miles, very much the same as the sound of the Fort gun heard at Barrackpore on a clear night in the cold weather. The report varies little in intensity, and I cannot recollect that there was much difference in the sound, whether heard at Barisal itself or some 70 or 80 miles to the south at the extreme end of the district. The state of the atmosphere may affect it, but to no appreciable extent...... There are two special occasions to which I would draw attention: the first in February, 1891, when from the southermost outpost, Chaltabuni, I followed the reports for some forty miles out to sea; the second, mentioned in my letter to the Surveyor-General of Bengal, when, in August, 1891, for more than six hours, I followed the reports without getting any appreciably nearer, and also never hearing them to the north of me." (R22) This report is obviously at odds with those preceding it. Furthermore, the great regularity of the phenomenon---triplet structure and constant interval---would seem to rule out seismic sources. (WRC)

> Brief mentions of the Barisal Guns. (R26, R38)
>
> By observing the distribution of the alternate zones of audibility and inaudibility, the direction of approach of these sounds, etc., it was easily inferred that they originated in the Bay of Bengal, in the so-called 'swash of no ground.' It was inferred further that they must be subterranean in nature. (R39)
>
> Based upon recent experience with small quakes in California and the sounds they produced, the Barisal Guns could well be seismic in origin. (R57)

X2. Frequent occurrence. Along the coast of northern Europe, including especially the North Sea. Selected accounts of the so-called "mistpouffers" follow in chronological order.

From G.H. Darwin's 1895 letter in Nature. "My attention was for the first time drawn to the subject some days ago by a letter from M. van der Broeck (sic), Conservator of the Museum of Natural History of Belgium. He writes of certain 'curious aerial or subterranean detonations, which are pretty commonly heard, at least, in Belgium and in the north of France, and which are doubtless a general phenomenon, although little known, because most people wrongly imagine it to be the sound of distant artillery. I have constantly noticed these sounds in the plain of Limburg since 1880, and my colleague of the Geological Survey, M. Rutot, has heard them very frequently along the Belgian coast, where our sailors call them 'mistpouffers' or fog dissipators. The keeper of the lighthouse at Ostend has heard these noises for several years past; they are known near Boulogne, and the late M. Houzeau spoke of them to my friend M. Lancaster. More than ten of my personal acquaintances have observed the fact. The detonations are dull and distant, and are repeated a dozen times or more at irregular intervals. They are usually heard in the day-time when the sky is clear, and especially towards evening after a very hot day. The noise does not at all resemble artillery, blasting in mines, or the growling of distant thunder.'" (R3)

Van den Broeck sent a letter to Nature amplifying Darwin's remarks. "This year the mysterious detonations were heard up to the end of September, and even up to the beginning of October, not only by me but by several of my friends and correspondents; this is much later in the year than usual. Now great and unusual heat prevailed this year during the whole autumn, and this coincidence affords a strong support to the theory of an origin arising from certain conditions of rise of temperature. Sailors of the port of Ostend assert that 'Mistpouffers' prevail over the whole of the North Sea as far as Iceland, and they consider them to be a sign of fine weather, with calm and heat." (R4)

Van den Broeck's definitive study of the mistpouffers (almost 200 pages long) presents an immense amount of first-hand testimony from the coastlines of northeastern Europe. (R6)

A brief review of research on natural sounds. (R7)

"S.s. Resolute, Captain W. Deuchars; 8 p.m., July 30, 1883, in 71°9'N., 12°28'W. ---'Six reports like those of guns heard to the westward, supposed to be caused by electricity, as no ships are thought to be in the vicinity.' Wind during the day calm to very light easterly airs; weather foggy; sea smooth, with a very slight south-easterly swell." (R12) The position of the ship was between the European continent and Iceland. Two triplets? (WRC)

November 18, 1905. Somerset, England. "...the sound was as loud as thunder, but not exactly like thunder. It consisted of three reports---one loud, the next very loud, and the last more like a reverberation." (R58)

Several letters describing what seem to be classical mistpouffers. (R25)

A brief note mentioning Van den Broeck's survey and giving, in addition, some interesting local names for the phenomenon: zeepoeffers, mistbommen, paper-bags, rots de mer, bombes de mer, and canons de mer. (R26)

A hypothesis that mistpouffers are simply very distant cannons whose sound is reflected back to earth by the upper atmosphere. (R30)

"Sounds which resemble cannon firing are produced by natural phenomena in the North Sea and the surrounding plains. Such phenomena have been known for many years, and are of interest at present from the fact that people might often imagine that military operations are going on in these regions. It is at sea that they appear to originate, and they are well known to sailors. The French sailors of the Channel region call them bombes de mer or canons de mer (sea bombs or cannon), while in Belgium they are known as mistbommen (fog sounds) or onderaardsche geruchte (underground noises); in Holland, mistpoeffer or fog dispeller. Sometimes on shipboard the sailors hear strange detonations which give a painful impression to the ear; the noise does not seem to come from any definite point of the horizon, but seems to emerge as a muffled tone from the depths of the water about the vessel. Nevertheless, it does not give the impression of being produced near at hand, and seems to originate from a far-off place. Another remarkable point is that the zone in which such sounds are produced does not seem to be confined to the sea region, for numerous observers claim to have heard them at a considerable distance inland, for instance in Italy and in some parts of the Alps. The causes of such phenomena are little known." (R29)

Mistpouffers are probably of seismic origin. (R31)

General discussion of possible origins. (R32)

Distant explosions may sometimes be heard because the sound is focussed by the surrounding terrain. (R40)

Seismic sounds heard recently in California closely resemble the classical mistpouffers. (R57)

X3. Frequent occurrence. Along the coast of Italy and probably other Mediterranean countries. Selected accounts of these brontidi or marina follow.

"The remarkable phenomena known as Barisal Guns has long been a mysterious problem to meteorologists and seismologists. They are most frequently heard in or near the inland provinces of Umbria, and are called by the natives 'marina' under the belief that the sounds come from the sea. The boom is quite distinct and easily recognised, being longer than that of a cannon-shot, and, though more prolonged and dull, not unlike distant thunder. In the current issue of the Bulletin of the Italian Seismological Society, Dr. A. Cancani discusses the cause and origin of these mysterious noises. They cannot, he says, be due to a stormy sea, because they are frequently heard when the sea is perfectly calm; nor can they rise from gusts of wind in mountain gorges, as they are heard on mountain summits and in open plains alike. If their origin were atmospheric, they would not be confined to certain special regions. They are heard by night as well as by day, in countries where the use of explosives is unknown, and they cannot thus have an artificial origin. Under these circumstances, Dr. Cancani considers that they most probably have an endogenous origin. In a seismic series, he says, noises are frequently heard without any shock being felt, and of which we are unable to determine the centre; and this fact, he thinks, disposes of the obvious objection to his theory that there should always be a centre of maximum intensity---which is never found in connection with the Barisal Guns---and that they are rarely accompanied by any perceptible tremor." (R19, R20)

> Detonations resembling the mistpouffers are commonly heard around the lake of Bolsena (Latium) and appear to come from the Tyrrhenian Sea, 24 miles distant. (R24)

"The name <u>brontidi</u> (i.e., 'like thunder') was coined in 1904 by Prof. Tito Alippi in order to facilitate the discussion of a phenomenon known under a bewildering variety of local names in various parts of Italy---<u>marina</u>, <u>bomba</u>, <u>rombo</u>, <u>boato</u>, <u>bonnito</u>, <u>mugghio</u>, <u>baturlio</u>, <u>tromba</u>, <u>rufa</u>, etc. Forty of these names are enumerated in one of Alippi's memoirs, and he has furnished several additions to the list in subsequent publications. Brontidi are usually described as detonations resembling distant and muffled discharges of cannon or peals of thunder, sometimes heard singly and sometimes in groups. They occur chiefly in warm and settled weather, when the air is calm and the sky clear. Their distribution over the Italian Peninsula has been carfully studied and mapped; it appears that while they are common in some localities, they are quite unknown in others not far distant. The peasantry have various explanations for them---natural and supernatural ---but the unaminous opinion, which has been fully confirmed by scientific investigation, excludes the possibility that they are due to any human agency or to thunder. The most curious feature of the phenomenon is that the detonation always appears to come from a distant source.....The trend of recent opinion is toward looking upon the source of brontidi as subterranean in most cases, though perhaps not in all. Movements within the crust of the earth must frequently set up vibrations of such an amplitude as to affect the ear, when communicated to the overlying atmosphere; and as rocks are generally excellent conductors of sound (i.e., of vibrations within the range of audibility) the effects may be transmitted to great distances from their source. Assuming the focus to be far below the surface, the air would be set in vibration over a wide area, giving the indefiniteness as to the direction of the sound that is commonly noted. Prof. W.H. Hobbs, who has made a painstaking study of the seismic geology of Italy, concludes that the brontidi of that country are due to the slow settlement of orographic blocks, and the consequent production of vibration within their marginal zone. Utilizing the reports collected by Alippi, he shows that the places where brontidi occur are also places that are subject to frequent earthquakes; they are arranged in lines which he identifies with seismotectonic lines, and they follow geological contacts and other earth lineaments. In other words, they are fault lines of structure lines of the earth, whose presence is revealed by earthquakes and also by brontidi." (R26)

In the foregoing, only those detonations heard along Italian shores are described. More Italian detonation phenomena are mentioned in GSD2 in connection with well-known seismic areas. (WRC)

X4. Frequent occurrence. Japanese shores, where the detonations are termed "uminari."

June 1896. Japan. "There was nothing to presage the disaster. From 11 in the forenoon until half past 4 in the afternoon heavy rain fell. It was followed by a fine evening and a dark, calm night. At about half past 7 three or four shocks of earthquake were felt; not violent shocks, though of the vertical kind that people in Japan have learned to dread. The barometer gave at the time no indication of anything unusual. Some 20 or 25 minutes later a booming sound became audible from the direction of the sea. It appears to have been variously interpreted. Only a very few suspected the real significance of the sound, and fled inland at the top of their speed. Rapidly the noise increased until it assumed the volume and deafening din of a great park of artillery, and then, in a moment, waves from 20 feet to 30 feet high were thundering against the shore." (R15) These detonations were heard long after the shocks and seem to have been associated with the waves. (WRC)

"Oceanic noises, called 'uminari' in Japanese, are common phenomena among the littoral of Japan. On account of their intimate connection with the cyclonic centers, the sounds are observed and recorded at the meteorological stations and are reported to the central observatory in the daily weather telegrams. The oceanic noises resemble the rumbling of a heavy wagon passing over an uneven road or crossing a bridge. They are more distinctly audible at a distance of a few miles from the coast, rather than on the coast itself. Undoubtedly the oceanic noises are produced by the breakers dashing on the coast, but how the breaking waves produce them is not fully understood. When waves break upon the shore they produce not only aerial vibrations, but also tremors in the ground, which are propagated to some distance; it seems uncertain, however, that these sounds, which are of such relatively short periods, are propagated through the porous ground to considerable distances. The aerial vibrations produced by the tremors of the ground are very small; the noises produced by the air escaping from the breaking waves would have a pretty large amplitude, although they would be somewhat irregular in period. On the shore these noises are confounded with a great variety of other noises, such as the rustling of beach pebbles, the dashing sounds of the water, etc. At a distance from the coast these other noises, having high frequencies, die out, and the oceanic noises, having comparatively long periods, survive." Because the noise sources are linear, the amplitude of the sounds is attenuated only as the reciprocal of the distance, rather then the distance squared. (R27, R28) These Japanese oceanic sounds seem to be qualitatively different from the standard mistpouffer. (WRC)

X5. Frequent occurrence. East Indies. The following descriptions bear some resemblances to musical sounds known to be made by fish, but the context is Barisal Guns and mistpouffers, so they are included here. See GSM for similar oceanic sounds

"Capt. P. Jansen, St. Helens Court, London, E.C.3, has sent us an interesting account of sounds heard by him near the mouths of rivers in the Dutch East Indies. Except in their higher pitch, they seem to resemble the Barisal Guns of the Ganges delta and the brontides of certain districts in Italy. On the roads of Sourabaya in Java, he says, two or three noises, as of foghorns of different notes, were heard at irregular intervals of a few seconds, each lasting for one or two seconds. In the hold of an empty ship, the noise was deafening. After continuing for one or two hours, the noises ceased as suddenly as they began. Capt. Jansen has heard the same noises, but less frequently, at the mouth of the Palembang River in Sumatra. At the mouths of some of the rivers of the Malay Peninsula, other noises were heard, like that of plucking the strings of a musical instrument, all on the same note and at irregular intervals. Although Barisal Guns and brontides have for a long time been carefully studied, their origin is still obscure. They are heard frequently in seismic districts and also in countries free from earthquakes. Possibly they have more than one origin, but their frequent occurrence near the mouths of great rivers seems to connect them with the settling of the delta or of the underlying crust." (R33)

X6. Frequent occurrence. Lough Neagh, Northern Ireland. "Lough Neagh is a sheet of water covering an area of upwards of 150 square miles with very gradually receding shores, excepting at one or two spots. For many years after my settlement here as minister from England, I heard at intervals, when near the lake, cannon-like sounds' but not being acquainted with the geography of the distant shores, or the location of towns, or possible employments carried on, I passively concluded that the reports proceded from quarrying operations, or, on fine summer days, from festive gatherings in Co. Derry, or Co. Tyrone. In time I came to understand that it was not from the opposite shores, but from the lake itself that the sounds proceeded. After questioning many of the local residents, I extended my inquiries to the fishermen, but they could assign no cause. A strange thing about the matter is that the people generally knew nothing of the phenomenon, and that it is shrouded in mystery. I have heard the sounds during the whole year....I have heard the reports probably twenty times during the present year, the last being on a Sunday afternoon a month since, when I heard two explosions;

but with two exceptions they have all seemed to come from many miles away, from different directions at different times. They have come apparently from Toome Bay, from the middle of the lake, and from Langford Lodge Point, about nine miles distant. A fisherman thought they must be the result of confined air that reached the lake by means of springs that are believed to rise here and there on the bottom. But the lake is shallow, seldom more than 45 feet deep. The depression now covered by the lake having been caused, it is believed, by volcanic action when the traprock of Co. Antrim was erupted, there may possibly be subterranean passages, though I confess there occurrence does not seem very probable; while the sounds emanate, as stated, from various parts of the lake. I have as yet spoken to no one who observed any movement of the waters when explosions took place, nor have I spoken to anyone who was close to the spot at the time. Rather every one seems to have heard them only in the distance, which is strange, as fishermen are on the lake during many months in the year, at all hours of the day and night. Last winter the whole of the lake was frozen over, for the first time since 1814. One fine afternoon, when the air was still, I was skating in the neighborhood of Shande's Castle, when these mystical guns boomed forth their reports every five or six minutes. On the last day of the skating, when thousands of people from Belfast and elsewhere were assembled in Antrim Bay, there were two fearful boomings, that startled every one near me. They seemed to think some dreadful catastrophe had occurred, as the sounds appeared to proceed from not more than half a mile away. I never before heard them so near. The ice in Antrim Bay remained as it was, but I afterwards learned that it was then breaking up six miles away, but with no alarming sounds." (R9)

X7. Frequent occurrence. Seneca Lake, New York. "These curious explosive sounds, called 'guns,' while not all of the same origin, take strong hold on the superstition and the wonderment of mankind. That beautiful sheet of water, Seneca Lake, in the State of New York, has achieved quite a local reputation for its mysterious 'lake gun.' A writer in Mrs. Stephen's Monthly, in 1857, speaks thus: 'The lake gun is a mystery. It is a sound resembling the explosion of a heavy piece of artillery, that can be accounted for by none of the known laws of nature. The report is deep, distant, and imposing. The lake seems to be speaking to the surrounding hills, which send back the echoes of its voice in accurate reply. No satisfactory theory has ever been broached to explain these noises." (R16)

Although bubbles of natural gas can be seen rising in the lake waters, explosions of this gas are not known. (R23)

Noting that a few of the occurrences of the Seneca guns have been coincident with surface disturbances and the apparent escape of natural gas, Fairchild maintained that these eruptions were positively the source of the booms. (R34)

Despite the depletion of the nearby natural gas field, the Seneca guns have not ceased, as predicted by proponents of the of the "natural gas" theory. (R35)

A letter to Science suggesting that the Seneca guns may be related to the strange sounds heard around Shoshone Lake in Yellowstone (GSH4). (R36)

"The sound is usually heard on hot, sultry days, though one has heard the ice crack as Dr. Clarke suggests. More often than not they are heard of afternoons by the lake or on it, when the south wind was dying down or had ceased to blow, and the surface of the water had become glassy, or 'oily'... and the sky has gradually become overcast with the haze of a gathering thunderstorm. Again out of the stillness one can hear coming from the south or southeast the solemn, lazy, deep-toned, muffled, unexpected, 'Boom!'" (R37)

Distant, muffled boomings heard for a few seconds one night in August 1940, near Dresden. The frequency of the lake guns is less than it used to be, perhaps because of the drilling for natural gas. (R41)

X8. Frequent occurrence. North American East coast, Canada to the Gulf of Mexico.

February 7-8, 1895. Florida. "The attention of the Editor having been specially called by a correspondent to certain mysterious noises heard at stations in Florida on February 7 or 8, at the time of the remarkably cold weather, it seemed best to investigate this subject, at least far enough to justify one in deciding for or against the various suggestions as to its being an earthquake, or an electrical phenomenon, or a discharge of artillery, or the noise of distant blasting. In reply to a circular sent out by Mr. E.R. Demain, Director of the State Weather Service, about twenty-five reports were received." Selected brief summaries follow:

Kissimmee: February 8, about 5 a.m., very loud sounds resembling artillery.

Orlando: February 7, just before noon, bright meteor seen, followed by a loud explosion.

Tarpon Springs: February 8, between 6 and 10 p.m., detonations strong enough to shake houses. Sky clear. Sounds seemed to come from different directions.

Plant City: February 7, about noon, sounds like distant siege guns.

Clermont: February 7, about noon, several people thought they heard distant cannon, but in various directions.

Amelia: Heavy sounds like distant guns. A good many reports one day, something like shot guns, but sharper and heavier.

Such divergent observations suggest at least two different sources, one meteoric. (R61)

Eastern Canada. "Everybody who has been much upon our Charlotte County coast must remember that upon the still summer days, when the heat hovers upon the ocean, what seem to be gun or even cannon reports are heard at intervals coming from seaward. The residents always say in answer to one's question: 'Indians shooting porpoise off Grand Manan.' This explanation I never believed; the sound of a gun report could not come so far, and, besides, the noise is of too deep and booming a character." Similar sounds are heard on the Kennebecasis, a lake-like section of the St. John River.(R17)

New England coast. "I would say that such phenomena are very common on this coast. My attention was first called to it some twenty or more years ago while acting as engineer of a towboat, it being our custom to lie three or four miles off the mouth of the river (the Piscataqua River), or about half way between Portsmouth light and the Isles of Shoals, and await the appearance of inward bound vessels. At these times I have frequently heard the sounds mentioned occurring at irregular intervals, and so far as my memory serves me, during the prevalence of a light southerly wind or a calm, and in warm, summer weather. They had a dull muffled sound, which appeared very much like the report of a cannon at a very long distance. A former shipmate informs me that he has heard these sounds all along the coast from Cape Ann to the eastern part of Maine, and frequently at the Isles of Shoals, especially a short time before sunset in hot weather; he thinks sometimes as often as three or four reports per minute, but he has never observed it at night or in winter." (R13)

December 28, 1885. Cedar Keys, Florida. "On the evening of December 28, 1885, I was with a companion in a sailboat on the Gulf of Mexico about 20 miles S.E. of Cedar Keys, Florida. We were becalmed. The next morning the sky was cloudless. There was a light fog and no breeze. The atmosphere was bracing but not frosty. We were about ten miles out but in shallow water. Shortly after sunrise we heard reports as of a gun or distant cannon. They came at intervals of about five minutes. We were not certain as to the direction. My companion, who lived several miles further down the coast. said he had often heard the reports on still mornings." (R14)

Eastern Canada. Additional testimony regarding the mistpouffers heard around the shore of New Brunswick and Nova Scotia. Opinion expressed that they are of subterranean origin. (R18)

Cape Fear, North Carolina. Booming sounds have been heard for at least a decade. Scientists conclude they are due to shallow, submarine microearthquakes. (R42)

Late 1977 through 1978. Entire East Coast of North America. "For the past two months, American scientists have been intrigued by things that go bump in the night---and day. A series of atmospheric booms have rattled windows and set off scientific instruments that measure air pressures along a wide swath of the east coast, from Charleston, South Carolina, to the Canadian Province of Nova Scotia. On occasion, flashes of light have accompanied the booms. Explanations for the strange sounds have ranged from supersonic planes to methane gas bubbles ignited by static electricity, but no conclusive evidence has yet emerged to support any explanation of the mystery sounds. The affair started on 2 December, when two loud booms were heard and felt in the coastal town of Charleston. Residents of the New Jersey coast heard their own boom later that afternoon. Thirteen days later Charleston was rocked by five more booms, and explosions were also heard off the coast of Nova Scotia. On 20 December, Charleston had two more explosions and New Jersey one. More followed in the different locations on 22 and 30 December, and 5, 12 and 18 January." (R44-R48, R54) Same sounds were heard along the Texas Gulf Coast. (R60)

A study by the U.S. Naval Research Laboratory concluded that the booms along the East Coast were due to a combination of unusual weather and supersonic military aircraft. (R49-R52, R55) Another analysis by the Federation of American Scientists blamed the supersonic transport Concorde for the bulk of the sounds. (R53) Indeed, similar sounds heard in Europe seemed to originate with the Concorde. (R43) But William Donn, who operated air-pressure instrumentation at Lamont-Doherty Observatory, Wilmington, and Charleston, announced that the mystery booms came from the south and were quite different from the Concorde signals he recorded. (R53) Thomas Gold and Steven Soter of Cornell suggested that some of the booms might be caused by the sudden eruption of gas from high-pressure sources in the ground. (R56) These booms continue. (R59)

Charleston, South Carolina region. Following the great quake of August 31, 1886, the area was subjected to aftershocks for decades. Many of these tremors were accompanied by explosive noises resembling cannon fire. Some detonations occurred without noticeable shocks, and vice versa. (R63)

X9. Frequent occurrence. Several Alpine lakes. English summary by L. Schonherr. The So-Called "Lake Roar." "This article by Sinwel discusses possible causes for the so-called 'lake-roar', a collective term for various noises like thunders, roars, bangs, cracks, cannon shots, etc., allegedly originating in, or on the surface of, lakes. The 'lake-roar' is or has been attributed to a great number of lakes in Tirol and Switzerland. Lakes named in this article are: Tirol; Achensee, Bodensee (not Tirol but Vorarlberg); Hechtsee, Pillersee, Wildalpsee, Zireinersee; Switzerland, Thunersee, Brienzersee, Zugersee, Luganersee, Hallwylsee, Murtensee. The following explanations are discussed: freezing in connection with wind, atmospheric disturbances, seismic effects, wind currents in underground caves, resonance effects. According to the author, it is significant that most of the roaring lakes are situated in limestone mountains where karst caverns are common. Meusburger reports that sometimes observers had the impression that the sounds didn't originate in the lake but came from the interior of the mountain. The Pillersee, between Fieberbrunn and Waidring in Tirol, has apparently got its name from this roar. 'Pillen' is Tyrolean dialect (probably derived from 'bellen' = barking) and another name for the lake-roar. In the years 1922 and 1923, some farmers in the Piller-Valley were so frightened by seismic shocks and thunders coming from the interior of the earth that they considered selling their property and migrating." (R62)

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GSD2 Detonations Heard in Seismically Active Areas

Description. Loud explosions, roarings, rumblings, and rushing sounds heard in seismically active areas but with small or no attending shocks. These booms are generally sharper---more like gun fire---than the waterguns (GSD1) and can often be associated with specific geological features. Typically, the noises are episodic, occurring several times per day for a few weeks and then disappearing for long periods. Triplets of detonations are surprisingly common. Each region where such sounds are common seems to have its own characteristics in terms of diurnal maxima, weather influences, tidal effects, etc. Although minor shocks may accompany the sounds, most do not register on seismographs.

Background. Some localities are famous for recurring episodes of strange sounds; viz., East Haddam, Connecticut, and Haiti. In Connecticut, for example, the sounds have a history going back centuries and are part of Indian lore.

Data Evaluation. The data for this phenomenon are profuse and generally of good quality. It seems that several scientists have become interested in these sounds and have studied them rather carefully. The older data, of course, are predominantly testimonial. Rating: 1.

Anomaly Evaluation. The great majority of the sounds in this category seem to have seismic origins, with a few possible cases of gas eruptions. The only anomalous features seem to be the triplet structure of some sounds, which also occurs with the waterguns (GSD1), and the tendency of some sounds to peak during a specific part of the day. Rating: 3.

Possible Explanations. Microearthquakes, including fault slippage, rockbursts, cracking of strata, etc. Eruptions of natural gas and meteor detonations may contribute some examples, especially those with associated luminous phenomena. Apparently some types of seismic activity manifests itself acoustically in preference to vibrations detectable by seismographs and human observers.

Similar and Related Phenomena. The sounds heard during ordinary earthquakes are little different from those described here; it is probably all a single phenomenon with different levels of intensity. Also, the Barisal Guns, mistpouffers, and other "waterguns" of GSD1 are essentially identical, pointing to a common origin. Detonating meteors, supersonic aircraft, volcanic eruptions, artificial explosions, and gunfire emulate this phenomenon.

Examples of Detonations Heard in Seismically Active Areas

X1. 1822-1825. Meleda, an island in the Adriatic Sea. "At the village of Babinopoglie in the centre of a valley in the Island of Meleda, in the Adriatic Sea, remarkable sounds were heard for the first time on the 20th March, 1822. They resembled the reports of cannon, and were loud enough to produce a shaking in the doors and windows of the village. They were first attributed to the guns of some ships of war, at a distance, in the open sea, and then to the exercise of Turkish artillery, on the Ottoman frontiers. These discharges were repeated four, ten, and even a hundred times in a day, at all hours and in all weathers, and continued to prevail until the month of February, 1824, from which time there was an intermission of seven months. In September of the same year, the detonations recommenced, and continued, but more feeble and rare, to the middle of March, 1825, when they again ceased. These noises have been accompanied by no luminous phenomena or meteors of any kind." A Dr. Stulli thought the sounds might be due to the sudden emissions of gas in the caverns beneath the island. (R2) But the Island's governor and others went down into the caverns and found perfect silence reigning. (R1) Some of the detonations were accompanied by perceptible shocks, but many others were not. (R51)

X2. Frequent occurrence. East Haddam, Connecticut. Here are heard the famous Moodus Noises. A representative description of them follows.

"It is stated that the disturbances of the lower Connecticut Valley, which produce what from early colonial times have been called the 'Moodus Noises,' have begun again, after a period of rest of twelve years. For twenty years, up to 1729, the villagers of the town of East Haddam heard these noises almost continuously. The Rev. Mr. Hosmer, in a letter written August 13, 1729, says, in speaking of the phenomenon: 'Whether it be fire or air distressed in the subterraneous caverns of the earth cannot be known; for there is no eruption, no explosion perceptible, but by sounds and tremors, which are sometimes very fearful and dreadful. I have myself heard eight or ten sounds successively, and imitating small arms, in the space of five minutes. I have, I suppose, heard several hundreds of them within twenty years; some more, some less terrible. Sometimes we have heard them almost every day, and great numbers of them in the space of a year. Oftentimes I have observed them coming down from the north, imitating slow thunder, until the sound came near or right under, and then there seemed to be a breaking like the noise of a cannon shot or severe thunder, which shakes the houses and all that is in them.' The center from which the noises proceed seems to be Mount Tom, situated at the junction of Moodus and Salmon Rivers. The severest shocks have been felt as far northeast as Boston and as far southwest as New York, and have there been noticed as earthquakes. In 1816 and 1817 these noises were more than usually loud. On the recent recurrence there was a sound resembling a clap of thunder, followed for a couple of hours by a roar like the echoes of a distant cataract. A day later there was heard a crashing sound like that of heavy muffled thunder, and a roar not unlike the wind in a tempest. The ground was so shaken as to cause houses to tremble and crockery to rattle as though an earthquake were in progress. The Indians, familiar with these noises long before the advent of the whites among them, called the region now embraced in the town of East Haddam, and particularly that situated in the vicinity of Mount Tom, Matchemadoset, or 'at the place of bad noises.' This name, corrupted and contracted to Machamoodus, and finally to Moodus, gives name to a branch of Salmon River and to a manufacturing village. The region where these subterranean disturbances have occurred from time immemorial is one of deformed crystalline rock." (R3, R9, R17, R23, R25, R26) Two small earthquakes occurred on March 2 and 13, 1940. Many householders thought minor explosions had taken place in their furnaces or coal bins. (R49) From August through October 1981, an intense microearthquake swarm, comprising over 500 events, was detected near Moodus. The quakes were very small, but surprisingly events down to at least magnitude 0 were heard by people in the area. (R53)

X3. 1838 and occasionally thereafter. Comrie, Scotland. "On October 3, 1839, a remarkable series of shocks commenced at Comrie, in Perthshire. 'The shocks were in general very slight, but sometimes rather severe, and were generally accompanied by subterranean noises, variously described as like distant thunder, the reports of artillery, the sound of a rushing wind, etc. The noise .... was often heard without any sensible shock at the time.' It would appear from these examples that subterranean sounds without any accompanying earthquake especially characterise those districts where slight shocks are very frequently felt, as if the sounds and shocks were manifestations, differing only in degree and the method in which we perceive them, of one and the same class of phenomena." (R8, R17)

From earthquake catalogs, which list many of the Comrie events, two selections: "The shock of the 23d, at half past 10. P.M., which was by far the most severe of any remembered in this neighbourhood, and was attended with greater tremor or heaving of the earth, was accompanied with a noise in nature and intensity indescribably terrific, ---that of water, wind, thunder, discharge of cannon, and the blasting of rocks, appeared combined. Giving a short warning by a distant murmur, it gradually increased in intensity for some seconds, when at length becoming louder than thunder, and somewhat similar to the rush of the hurricane, it suddenly changed, and a noise resembling that of a blasting rock thrice repeated followed, which again died away like distant thunder." (R6) Note the triplet at the end. (WRC) "A shock was felt at Comrie about $9\frac{1}{2}$ A.M. Very awful shock. More so than for twenty years past. The weather very cold that day and previously, but became warm the day after. Accompanied by two loud reports, one apparently above our heads, the other which followed immediately under our feet. The noise lasted 30", and was much louder than any thunder." (R4, R5) Curiously, earthquake sounds often seem to come from overhead. (WRC)

X4. 1834 to at least 1846. Deerfield, New Hampshire. "During the last twelve years, certain curious, not to say alarming phenomena in the town of Deerfield, N.H., have excited the fears of the inhabitants, and we think should, ere this, have attracted the attention of the scientific. These are reports or explosions in the ground, apparently of a volcanic or gaseous nature. When first heard they were attributed to the blasting of rocks in Manchester, a new town some ten miles distant; but from the frequency of the reports at all hours in the night as well as the day, from the consideration that they were so loud, and were heard in all seasons, winter as well well as summer, it was soon concluded that they had some other origin. The explosions, if they may be so called, commenced on a ridge of land running S.E. and N.W. some five miles in length, and principally on that portion called South Road. They have, however, extended, and are now heard in a northerly direction. The sounds have become louder, and during the last fall and the present spring or summer, as many as twenty have been heard in one night. Many of them jar the houses and ground perceptibly, so much so, that a child whose balance is not steady, will roll from one side to the other. They are as loud as a heavy cannon fired near the house, with no reverberation, and little roll., ... There is no regularity in these reports, as they are heard at intervals of a day, a week, and sometimes of months; but for the last year they have become very common, and are heard almost every week more or less." (R7)

X5. January 1784. Guanaxuato, Mexico. "It has occasionally happened that loud and long-continued subterranean noises have been heard, without their having been accompanied either by earthquake shocks or any other outward indications of internal disturbance. One of the most remarkable examples of this kind occurred at Guanaxuato, in Mexico, and is described by Humboldt in his 'Cosmos.' This city is situated in a mountainous district, but far from any active volcano. The sounds were first heard at midnight, on the 9th of January 1784, and they continued more than a month. The loudest reports occurred from the 13th to the 16th of January, when they seemed like slow rolling thunder, with intervening short thunderclaps. Both before and after this period the sounds were neither so loud nor so frequent, and after the 16th they gradually died away. The phenomenon was confined to a limited space under the city and its immediate neighbourhood. Great alarm was excited among the inhabitants; but no shocks of earthquake were felt, nor did any other consequences follow. What is still more remarkable, in the neighbouring mines, which are 1598 feet deep, not the slightest trembling of the ground was perceived." (R10, R16, R20, R17, R27, R40)

X6. Frequent occurrence. Bald Mountain, North Carolina. "So far as direct observation upon the disturbances there in progress was concerned, my trip to the Bald Mountain region was a failure, for there was not the least disturbance during our visit. But from an examination of the present condition of the mountain, on both sides and at the top, we were able to come to an understanding of the phenomenon reported to us by residents of the region. And here I would remark that the reports heretofore published have grown rapidly in proportion to their distance from home, there having been, apparently, no foundation for the stories of yawning crevices and smoking pits. The phenomena actually observed seem to have consisted simply of noises within the mountains, more or less loud, and shakings of the surface. The sounds are variously described as resembling continuous musket firing, or heavy cannonading, or 'the rumble of a heavy iron-axled wagon rolling rapidly over a rocky road.' The shakings were wave-like vibrations of the surface, moving laterally from the center of the disturbance, and causing cracks in walls and chimneys, and occasionally throwing down loose articles." (R11, R20, R24)

X7. Frequent occurrence. Himalaya Mountains. "Similar phenomena are described by Mr. Horne, in his report on the villages of the Himalayas---viz., exceedingly powerful noises heard in the early morning among the highest mountain peaks, and which can neither be ascribed to avalanches nor otherwise explained by the natives. Above the town of Koimbatur, in Madras, some 4,000 ft. high is a pond from which the Lirivani springs, and which the natives carefully shun, because very frightful noises rise out of it, and roll away among the hills. The pond is very deep. Some of the phenomena may be of electric, some of volcanic nature." (R12)

X8. 1868-1872. British Guiana. During Barrington Brown's explorations of the interior. "At 5 P.M. we heard a very loud noise, which sounded like that of a large cannon; such reports are frequently heard by the Indians, who declare they proceed from the mountains. I heard such reports while on the Mazaruni river, where the Indians have the same ideas regarding them. Sir R. Schomburgk speaks of them. I cannot account for this phenomenon, but suppose it is caused by some electric agent in the rarefied atmosphere that pervades the higher lands in these districts." There was no sensible vibration of the earth. (R13, R20)

X9. August 26, 1883. Caiman-Brac, Carribean Sea. "On Sunday, August 26, the inhabitants of Caiman-Brac were astonished by a noise like the rolling of a distant thunderstorm; the sky was fine, and they at first thought it was a skirmish between a Spanish cruiser and some Cuban smugglers. On the south side of the island nothing was to be seen; they ran across the island, and northward all was quiet too; no smoke was in sight. The cannonade still continued, and going back again they recognised that the noise came from underground. They were much afriad, and expected that their island would soon subside into the sea, or be turned into a volcano. By degrees the detonations ceased, and their fears were quieted. But the phenomenon was not forgotten, and was still talked about when the first news of the Krakatoa eruption came. They made the remark that the Caimans and Sunda Strait are nearly at the antipodes of each other, and the hypothesis of a correlation between the two phenomena was propounded." (R14, R15) See GQG1 for more on antipodal earthquakes. (WRC)

X10. Frequent occurrence, at least in the 1800s. Rocky Mountains. "On July 4, 1808, the expedition of Captains Lewis and Clark was at this place. Under that date we find the following entry in their Journal: 'Since our arrival at the Falls, we have repeatedly heard a strange noise coming from the mountains in a direction a little to the north of west. It is heard at different periods of the day and night, sometimes when the air is perfectly still and without a cloud, and consists of one stroke only, or five or six discharges in quick succession. It is loud, and resembles precisely the sound of a six pound piece of ordnance at the distance of three miles. The Minnatarees frequently mentioned this noise like thunder, which they said the mountains made, but we paid no attention to it, believing it to be some superstition or falsehood perhaps. The watermen also of the party say that the Pawnees and Recaras give the same account of a noise heard in the Black Mountains (Black Hills) to the west of them.' The mountains towards which these noises were heard were the main range of the Rockies, and distant about eighty miles. In 1854, Mr. Doty, of Governor Stevens's party, heard similar noises. He was near enough to the mountains to be certain that the noises came from them." (R18)

X11. Frequent occurrence. The Black Hills, Wyoming and South Dakota. From the report of the 1810 party outfitted by John Jacob Astor. "In the most calm and serene weather, and at all times of the day or night, successive reports are now and then heard among these mountains, resembling the discharge of several pieces of artillery." (R18, R19)

X12. Frequent occurrence. Australia. It seems that detonations have occurred fairly regularly in at least three sections of Australia: Victoria (where they have been called Hanley's Guns), Western Australia, and New South Wales. Brief descriptions follow.

Victoria (Hanley's Guns). Referring to a June 1943 article in the Australian Monthly Weather Report: "The writer of this article, S.H. Ebury, tells us that peculiar explosive sounds, known locally as 'Hanley's Guns', were heard from time to time in the districts lying between Daylesford and Maryborough in the Talbot county of Victoria. It was originally thought in Daylesford that the noises were merely those ordinarily caused by people shooting rabbits on an estate owned by Mr. Hanley, which lay eight miles to the north-west of the town; but this explanation was shown to be wrong when it was discovered that people living to the north-west of Hanley's property also heard the noises in a north-westerly direction. Neither were the noises due to blasting in the mines of Moolort, for they did not cease when the mines eventually closed down. During the years 1912-1914 Mr. Ebury listened for the noises at Sandon South, recording the time of occurrence and the direction from which the sound appeared to come, and he collected similar observations from residents of the Kooroocheang district. The Weather Bureau of Melbourne also gathered information from various localities and placed it at Mr. Ebury's disposal. It appears that the noises could be heard at any hour of the day or night, but that they were most frequent in the forenoon, the average time of occurrence during 1913 and 1914 being about 11 a.m. The chart which accompanied Ebury's article shows the direction from which the explosive sounds appeared to come in various parts of the area. It is seen that the majority of the observations indicate an origin of the sounds in the district known as Stony Rises, lying two miles to the north-west of Mount Kooroocheang." (R21, R44, R45, R50)

Western Australia. A notice of a paper by J. Burton Cleland, published in 1911 in the Journal and Proceedings of the Royal Society of New South Wales. "The author of this paper calls attention to, and asks for explanations for, the occasional booming noises heard by himself and others in various parts of central and northwestern Australia. He quotes from his own notes and from the observations of others, and adds many references to similar phenomena reported from other parts of the world. These sounds are variously described as resembling the distant firing of cannon, rumbling like the blowing off of steam from a large boiler, galloping of a herd of cattle, rumbling of thunder, blasting in mines, and gunshots. The explanations suggested and rejected are earthquakes, caving of riverbanks, electric discharges, displacements of rocks by frost, breaking of surf rollers, firing of bombs, subaqueous volcanic disturbances, falling meteors. The explanation for these phenomena in Australia that appears to be regarded with most favor by the author is that in the dry interior the hot days and cold nights cause expansion and contraction of the rocks which result in their buckling and cracking. Movements along faults and the cracking of the ground in dry weather are also appealed to." (R30, R34) On June 26, 1908, a triplet of detonations was heard high in the air followed by a rushing noise like steam escaping. It was a beautiful clear evening but no luminous phenomena were noted. (R54)

New South Wales. From Sturt's records of exploration in 1829 along the Darling River. "About 3 p.m. on the 7th (February) Mr. Hume and I were occupied tracing the chart upon the ground. The day had been remarkably fine, not a cloud was there in the heavens, nor a breath of air to be felt. On a sudden we heard what seemed to be the report of a gun fired at the distance of between five and six miles. It was not the hollow sound of an earthly explosion, or the sharp cracking noise of falling timber, but in every way resembled the discharge of a heavy piece of ordnance. On this all were agreed, but no one was certain whence the sound proceeded. Both Mr. Hume and myself had been too attentive to our occupation to form a satisfactory opinion, but we both thought it came from the N.W. I sent one of the men immediately up a tree, but he could observe nothing unusual." (31, R40)

X13. Occasional occurrence, especially on October 10, 1896. Franklinville, New York. While on the Cuba Road, October 10, 1896, the author heard a loud explosive sound that appeared to come from East Hill. More detonations were heard at intervals of about five minutes. They closely resembled the sounds from blasting rocks with coarse black powder. Single sounds of the type described are heard from time to time in the region. They appear to be due to the breaking up of subterranean rock strata. (R22)

X14. Frequent occurrence. Mountainous regions of central Italy. (Detonations of the mistpouffer variety heard along Italian shores, sometimes called marinas, are covered separately in GSD1.) "An interesting acoustic phenomenon called, in Italy, 'brontidi,' has been investigated by Prof. T. Alippi, of the meteorological and seismical observatory of Urbino, Italy. These brontidi are mostly hollow noises, resembling the echo of a distant explosion, and are usually observed with a bright sky and calm air, occurring rather seldom in windy or rainy weather. They usually occur in the afternoon, both in winter and summer. These noises would seem to be of atmospheric origin. They do not produce any physiological effects of their own, nor do they seem to be connected with local earthquakes, though they sometimes cause window panes to vibrate. They are nearly everywhere considered as presage of bad weather, and are popularly supposed to be due to strong tides or storms at sea, whose echoes are transmitted to a distance. Prof. Alippi has obtained his results by means of a circular letter to which 217 observers have replied, and 135 of whom had noticed the sounds. The observers in question were distributed throughout the whole of Italy and its African colonies. These noises do not appear to be due to artificial causes, such as mine explosions or gun shots, as they mostly occur in central mountain regions, where such causes are absent, while in some populated valleys where mines are common their existence is never noticed. The author is not inclined either to ascribe this phenomenon to natural causes such as winds, while the hypothesis sometimes suggested of thunderbolts under the horizon cannot be maintained either, owing to equal distribution of brontidi over summer and winter." (R28, R29, R32, R39) Later, Alippi showed that brontidi were most common in areas where seismic activity was high. (R40)

X15. Frequent occurrence. Haiti. In contrast to other examples in this section, the gouffre are notable for their unusually great variety. "The sounds are described variously as resembling the noise of a 'heavy wagon passing over pavement, of thunder rolling in the distance, of dynamite exploding or of cannon being fired off, of water falling on dry leaves, of the wind blowing through high forest trees in a tempest. Yet all these different sounds may be heard without any appearance of storm.' The region where the <u>gouffre</u> appears to be most commonly heard is the range of La Selle, which is of Tertiary limestone, lies in an east to west direction, and has a mean altitude of 2200 meters. The region is very unstable, and the mountains give much evidence of past volcanic activity. Abrupt depressions are very numerous, and a river in one place flows for some distance underground. On the north the range is bordered by a steep cliff along the line of dislocation caused by the subsidence of the northern plain. This displacement is believed to be constant though slow and imperceptible, and the noises may be caused by these adjustments or bradyseisms. The sounds are apparently the same as those accompanying noticeable earthquakes, and the people of Haiti apply the name gouffre to both. Where the sound is a local phenomenon, however, the place of origin seems to be definitely recognized. Thus it is always from the base of the cliff bordering the range of La Selle that the inhabitants of the neighboring villages declare the sounds to come..... The vicar at Croix-des-Bouquets, ten to fifteen miles north of the range of La Selle, gives a very interesting account: 'From November 7 to 13, 1911, the sound of the gouffre was heard every day, but it was very different at night from what it was in the daytime. During the day the sound was heard from the southeast, and seemed to come from a great depth. It was like a deep roaring, and then at times like the howling of a dog. From time to time it stopped with a hollow boom, which might be taken for a distant cannon-shot. According to the inhabitants the noises were simply warnings of earthquakes or of some other disaster; sometimes they were thought to be connected with the weather. It was frequently said that the gouffre had not been heard so distinctly for a long time, nor in a manner so prolonged and persistent, as during the three weeks that had just passed. During the night it was different, although the sound came from the same direction; there was a perfect tumult; rumbling of thunder, howling, and a sound like the rushing of a strong wind. There was no wind, however. Sometimes one heard all the noises at once. Generally, and above all from seven to ten o'clock at night, the sound ended with a loud detonation much stronger than in the day, followed by a long echo. Then again would be heard an outburst that cannot be imagined. It was as if a mountain of glass were shattered, and the noise seemed echoes in all directions. At times it seemed as if one could hear the roar of surf or even the dead thud of objects falling, such as blocks of stone rolling down precipices. During the night there was something very sinister in these phenomena.' The gouffre is heard elsewhere on Haiti but to a lesser degree. (R33, R35-R38, R41-R43, R46, R47)

X16. Frequent occurrence. Northern California. In Marin, Sonoma, and Mendocino counties, brontidi are often heard during the warm summer months, particularly in the mountains. In September 1896, a tremendous explosion was heard. (R4)

X17. Occasional occurrence. Lake Bosumtwi, Ghana. "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.' The Chief of Abonu however gave Rattray the equally matter-of-fact and convincing explanation that these mysterious lights were deliberately caused by thieves robbing other people's nets at night and taking fire in a bowl to scare away the highly superstitious and easily frightened lake dwellers. Chemical analyses of the waters of Lake Bosumtwi showed them to be of the alkaline-carbonate type according to information received from Dr. Jenner. Although these periodic upheavals of the lake bottom might give rise to minor local explosions, it is impossible that these small detonations should be heard far away from the lake as has been reported frequently." (R48) Some light flashes were observed in conjunction with the booms heard along the east coast of North America (GSD1-X8). (WRC)

X18. Frequent occurrence. Egyptian desert. Loud rumbles and booms accompany microearthquakes. Bedouins shun the region because of the strange sounds. (R52)

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GSE ANOMALOUS ECHOS

Key to Phenomena

GSE0 Introduction

Echos have always delighted humans. Even the crankiest person will clap his hands to hear the sound bounce off a barn or hillside. Double echos are common, for they require only two reflectors at different distances. Some echos, particularly in man-made structures with repeating columns and walls, may repeat scores of times. Then, there are whispering galleries, where the slightest of sounds are carried long distances. Fascinating as these phenomena are, there are also well-explained and cannot occupy space here.

More interesting are aerial echos, which possess no obvious reflector. Musical echos are also grist for the anomaly mill, for not only are they curious and sometimes startling but they also possess unappreciated features, such as a peculiar throbbing and omnipresence. In the final analysis, though, even the startling siren-like echos of the Big Horn Canyon are more curious than anomalous.

GSE1 Aerial Echos

Description. Echos of a sound source located on an island or ship which are returned from the sea horizon. The intensity of the echo is independent of weather conditions. Experiments indicate that the reflector(s) are distributed over azimuth and distance but not elevation.

Background. At least two eminent scientists (Tyndall and Henry) investigated this interesting phenomenon. Despite this attention, no explanation has been found in the literature so far.

Data Evaluation. Although this is evidently a well-known phenomenon, only two rather old references have been discovered. Rating: 2.

Anomaly Evaluation. Since aerial echos are independent of sea state and atmospheric conditions, no other obvious reflectors exist. Rating: 2.

Possible Explanation. The most likely reflector is the sea itself---some property not dependent upon sea state.

Similar and Related Phenomena. Analyzed sound (GSE2).

Examples of Aerial Echos

X1. Permanent phenomenon. All bodies of water. "During the year 1877, and also in 1876, a series of experiments was made on the aerial echo..... These experiments were made principally at Block Island, but also at Little Gull Island. Especial attention has been given to this phenomenon, which consists in a distinct echo from the verge of the horizon in the direction of the prolongation of the axis of the trumpet of the siren, because the study of it has been considered to offer the easiest access to the solution of the question as to the cause of all the abnormal phenomena of sound, and also because it is in itself an object of much scientific interest." The author next pointed out that the phenomenon was independent of water conditions and therefore could not be due to sound reflected from waves. He next described his experiments during which the axis of the siren was pointed vertically. No aerial echos were heard, even when a cloud passed over. "From these experiments it is evident that the phenomenon is in some way connected with the horizon, and that during the continuance of the experiments of sounding the trumpets while directed toward the zenith, no acoustic cloud capable of producing reflection of sound existed in the atmosphere above them." The next experiment involved sending an observer on a steamer along the axis of the siren. As the ship pulled away from the siren, the loudness of the echo, as perceived by the shipboard observer, diminished. This and other results of this experiment strongly indicated that the source of the aerial echo consists of many separate points at various distances from the siren. Observations over a period of two years, under all weather conditions, indicated that the echo was constant regardless of the wind, sea state, fogginess, temperature, etc. In sum, the true source of the echo could not be found but was thought to be connected somehow with the sea itself. (R1) A later article merely states that the echos are from invisible acoustic clouds in the atmosphere. (R2) But what are acoustic clouds? (WRC)

References

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R2. "The Romance of Echoes," Scientific American, 106:69, 1912. (X1)

GSE2 Musical Echos (Analyzed Sound)

Description. Echos which convert specific musical notes into notes of higher pitches. Included in this category are those situations where discordant sounds, such as the roar of an engine, are echoed as pleasing music.

Background. The proper conditions for musical echos doubtless exist in many places. Those recorded below necessarily represent only a sampling.

Data Evaluation. The phenomenon is apparently rather common, and several scientists (including Rayleigh) have investigated it superficially. Many good observations exist. Rating: 1.

Anomaly Evaluation. Good explanations exist for most features of the phenomenon (see below). The anomalous characteristics are the throbbing, pulsating property and the tendency of the echo to be pervasive and omnipresent; that is, coming from all directions. These rather unscientific features may be due to the distributed nature of the reflectors. Rating: 3.

Possible Explanations. Small-area reflectors tend to return high-frequency sounds more efficiently. A distributed reflector consisting of many small areas (trees, rocks, corrugated buildings, etc.) will thus tend to emphasize the high frequencies, including the harmonics, of the original sound. Coarse sounds will return more "musical", having been "analyzed" or shifted towards higher frequencies. The common throbbing or pulsating of musical echos may well be due to the topography of the surroundings and the different distances of the distributed reflectors.

Similar and Related Phenomena. Musical sounds in nature (GSM); the Yellowstone Lake Whispers (GSH4).

Examples of Musical Echos

X1. Permanent feature. Roseneath, Argylshire, Scotland. When 8-10 notes are played on a trumpet, they are returned on a key a third lower and, later, on a still lower key. (R1) This first example differs from all that follow in that the frequency shift of the echo is downward rather than upward. (WRC)

X2. Permanent feature. Fairfax County, Virginia. "The echo had long been observed as an interesting and striking phenomenon, and gives three distinct reflections. The second echo or return is much the most distinct. It gives thirteen syllables with great distinctness, and a very amusing effect is produced by uttering a question and answer in the same breath, and at the same in a different tone. For instance, how do you do? pretty well I thank you, how are you? Twenty notes played upon a flute are returned with perfect clearness. But the most singular property of the echo is, that some notes in the scale are not returned in their places, but are supplied by notes which are either thirds, fifths, or octaves. When the second F in the scale is sounded by itself upon a flute, the first reflection gives the same note, the second likewise, and sometimes, though rarely, the last reflection gives C the fifth above. But when the low F is sounded, the first return is always the same note, the second return generally the octave above, and the last invariably the fifth C in the octave above the note played." Many more examples are given with various notes, but the echos are always a harmonic of the original note or the note itself. (R1)

X3. Permanent feature. Paisley, England. In the cemetery of the Abercorn family. A note of music is returned with ascending tones. (R2)

X4. Permanent feature. Eagle's Nest on the banks of Killarney, Ireland. A bugle call seems to be repeated by a hundred instruments. (R2) Bugle notes are repeated an octave higher than the original. (R10)

X5. Permanent feature. Rhine Province, Germany. The Singing Valley of Thronecken. Notes of a horn are returned like swelling organ or harp music. (R3)

X6. Permanent feature. Bedgebury Park, England. The sound of a woman's voice is returned from a plantation of firs located across a valley with the pitch raised by an octave. (R4)

X7. Permanent feature. Saddleback Mountain, Maine. A geological survey party. "The huge mountain range covered with snow stretched away for a great distance and presented so magnificent a sight as to call forth a shout from my party. The echo, after some moments, came back in musical tones, though the shout was anything but musical. A fierce Indian war whoop was returned to us in the softest musical tones, not one of the discords being heard. A gun was fired and the report came back in a feu de joie of long continuance and decidedly musical in its effect." (R5, R10)

X8. Permanent feature. Along the wooded shore of Lake Superior. In one spot, a melodious and solemn dirge in slow, cathedral-like music. Since the time was 1844 and no one else was in sight, it was concluded that the sound of the waves was analyzed by the trees of the forest, which returned the higher harmonics. (R5, R10)

X9. Permanent feature. Slave and Athabasca Rivers, Alberta, Canada. When running close to the wooded shores in a motorboat, the engine sound is echoed as pulsating, harp-like music. (R5)

X10. Permanent feature. Bighorn Canyon, Montana. "As I was walking down one of the sandy beaches on the river's edge I heard a howl, beginning at a high pitch and sweeping down into the bass clef. I stopped short and looked around; I could hear nothing but the roar of the river. I took a step backward and the howl reversed itself, starting low and rising to a high pitch. I then moved back and forth over the same ground and found the noise to be no more than the roar of the river, rising and falling like a siren. It seems the rocks around me formed a sort of sounding board, treating the roar as a prism treats sunlight, placing the tones according to their pitch, the high in one place and the low in another."(R5) "Years ago Indians in the neighborhood used to shun the spot for fear of 'evil spirits.' Today we know that the various wavelengths in the sound of the river are reflected by different parts of the jagged cliff, reaching the ear separately, instead of all at once. If the observer takes another position, he can cause the order of the sounds to be reversed, so that the echo begins with the deep tones, and rises to the treble." (R10) Other anecdotes of the Bighorn Canyon echos may be found in R9.

X11. Permanent feature. Oxford, Massachusetts. "As an early train passed by this morning, I noted a most remarkable echo every time it whistled. The first echo was immediate, sharp and distinct, appearing to rebound from a neighbor's buildings nearby. Some seconds after all was quiet, another faint, far-away musical echo came stealing up the valley, apparently emanating from a wooded hillside far away. The echo ever increased in intensity until it seemed to pervade every corner of the landscape, filling it with a wonderful harmony of sound that beat upon the air in ever fainter waves, ever becoming farther away, until the sounds could no longer be heard. At no time were the sounds loud but seemed to fall upon the ear in infinite waves, as if thrown back from some invisible dome overhead." (R6) Note the resemblance to descriptions of the Yellowstone Lake Whispers. (GSH4). (WRC)

X12. Permanent features. Many musical echos exist in the Mt. Desert area of the Maine coast. (R7)

X13. Permanent features. Lapland. Cliffs around lake converted the roar of a motorboat engine into sweet, cathedral-like music. (R8)

X14. Permanent feature. Stockholm, Sweden. The corrugated metal walls of a factory building echo a handclap as a chirp. (R11)

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R9. Forbes, Alexander; "Analyzed Sound," Science, 62:204, 1925. (X10)

R10. Carr, Albert; "Answer, Echo, Answer," Scientific American, 161:342, 1939. (X4)

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GSH ANOMALOUS HISSING AND RUSHING SOUNDS

Key to Phenomena

GSH0 Introduction

Detonations intrude upon our sensory apparatus more readily than hums and hisses. Civilization's background of traffic noise, aircraft, and air-conditioners conceals natural hums and hisses very effectively. If one strips away such artificial sources, nature is found to generate a variety of curious murmurs, sighs, swishes, and buzzes. Some of these sounds are readily attributed to insects, the sighing of wind in trees, and so on. Happily for this Catalog, not all hums and hisses are explained away so neatly.

Swishes, hums, and cracklings have long been associated with both auroras and meteors. In both cases, these sounds have been synchronous with the motions of the phenomena. These phenomena, however, are too far away (typically 50-100 miles) for the sounds to reach the observer nearly instantaneously. Scientists long regarded such observations as auditory illusions or the consequence of inexperience, mainly because no acceptable physical mechanisms existed to explain the data. Nevertheless, high quality observations kept accumulating. Many investigators now accept the reality of these sounds and ascribe them to; (1) Electromagnetic radiation perceived as sound by a special class of people; or (2) Surface electrical discharges (brush discharges) induced by the auroras and meteors.

More mysterious are the hums and hisses not associated with any obvious physical event. Blowing sand, running water, microseismic activity, insects, and similar agents are usually blamed for sounds that seem to come from nowhere. Hums and hisses of this kind are generally perceived only where man-made noises are far-removed. A famous example in this category is the curious acoustic phenomenon at Yellowstone Park termed the Yellowstone Lake Whispers. These aerial phantoms have been heard for generations.

Geophysical disturbances, such as storms and earthquakes, are known to generate very-long-wavelength sound (infrasound) that propagates many hundreds of miles. Auroras, meteors, and winds gusting over mountain crests also create infrasound. Although infrasound frequencies are too low for humans to hear, it is possible that some infrasound sources may also generate shorter wavelengths that some of us may perceive as hums and hisses that seem to come out of thin air. (See GSI.)

GSH1 Hissing and Rushing Sounds Preceding Earthquakes

Description. Rushing, wind-like sounds observed prior to and during earthquakes. In some instances, the sound begins in the distance and approaches the observer.

Background. A great variety of grating, rattling sounds and detonations normally precede and accompany earthquakes. The rushing sounds (which are relatively rare) are included here with unidentified sounds of a similar nature, because they may help decide whether these other sounds are seismic, too.

Data Evaluation. A few old, rather subjective reports. Rating: 3.

Anomaly Evaluation. Although correlated with earthquakes, the physical mechanism by which these wind-like sounds are produced is unknown. It seems unlikely, though, that it can be anything very anomalous, for there are several likely explanations. Rating: 3.

Possible Explanations. Underground movement of faults; the subterranean flow of high-pressure gases and liquids; audible microseisms; electrical discharges caused by the piezoelectric effect.

Similar and Related Phenomena. The Yellowstone Lake whispers (GSH4); sudden winds accompanying earthquakes(GQW4).

Examples of Rushing Sounds Heard Prior to Earthquakes

X1. September 1812. Los Angeles County, California. Just before the quake that destroyed the Mission San Juan Capistrano. "The day was clear and uncommonly warm; it being Sunday the people had assembled at San Juan Capistrano for evening service. About half an hour after the opening of service, and unusually loud, but distant rushing sound was heard in the atmosphere to the east and over the water, which resembled the noise of a strong wind, but as the sound approached no perceptible breeze accompanied it. The sea was smooth and the air calm. So distant and loud was this atmospheric sound that several left the building on account of it. Immediately following the sound, the first and heaviest shock of the earthquake occurred, which was sufficently severe to prostrate the Mission church almost in a body, burying in its ruins the most of those who remained behind, when the first indication of its approach was heard." (R1)

X2. August 31, 1886. Charleston, South Carolina. "And there was yet another peculiar sound, heard both before and after the main shock, usually occurring at the moments of minor shock and tremor, which seemed to resemble the rush of a great (subterranean) wind, or rather as of the passage of a whirlwind or aerial vortex, sweeping through the earth below. Its resemblance to the peculiar rush of wind was most striking, as was also its no less marked subterranean character. All these strange occurrences took place in a period of profound calm---not a leaf moving nor a breath of air stirring. These events were subterraneous, not aerial." (R3)

X3. 1887. Somerset, England. "On Wednesday evening last, at a little after 7 o'-clock, I was somewhat startled at hearing a most peculiar noise. It began with a rushing sound as if a sudden gust of wind were shaking the trees. It being quite calm at the time, I looked in every direction, but could see no indication of the least disturbance. In a few seconds the noise changed to a very deep and subdued roar, and in a few seconds more with two or three distinctly separate sounds, with intervals of not more than half a second between each. It was quite impossible to judge from what direction the sounds came; in fact, there was something so peculiar about them, that although they were far from loud, I stopped to listen, and at once came to the conclusion that they were subterranean noises, and made the remark to one or two friends, who also heard them, that we must expect either an earthquake, or that we should soon hear of one having occurred elsewhere." The only quake reported at the appropriate time was in Central Asia. (R2)

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R3. Roberts, T. N.; "'Barisal Guns'---Reminiscences of the Charleston Earthquake of August 31, 1886," Scientific American, 75:219, 1896. (X2)

GSH2 Hissing and Buzzing Sounds Correlated with High-Altitude Meteors

Description. Hissing, whizzing, buzzing, and rocket-like sounds heard before and simultaneous with the appearance of high-altitude meteors. These sounds should not be confused with the whirring noises made by low-level meteors. There is also a qualitative difference between the instantaneous sounds and the roaring, rattling and explosive noises created by the disintegration of the meteors, and which are delayed several minutes after the visual event.

Background. It is a physical impossibility for real sound to travel nearly instantaneously the scores or hundreds of miles from the meteor to the observer. For this reason, instantaneous meteor sounds were first dismissed as psychological in nature. Scientists were, in fact, rather insistent about the illusory character of the observations---no matter how many good records were collected. Within the past 20-30 years, however, it has been discovered that very low frequency (VLF) electromagnetic waves may be perceived by some (not all, or even most) people as sound, although the biological mechanism is unknown. With a potential physical mechanism at hand, the subject has become "respectable."

Data Evaluation. A small collection of observations is presented here from a massive body of testimony---many observations are by individuals who heard the meteor before they saw it. Rating: 1.

Anomaly Evaluation. If instantaneous meteor sounds are biologically converted electromagnetic waves, only a minor biological anomaly exists. On the other hand, if the stimulus is not electromagnetic we are left without a recognized physical mechanism. Rating: 2.

Possible Explanations. Meteors may generate strong VLF electromagnetic radiation, which is registered by some human observers as sound; brush discharge at the surface induced by the meteor (some meteors do appear to cause surface electrical effects).

Similar and Related Phenomena. Unusual human perception (BH), a category which includes biological detection of radio waves. The "sound of the aurora" (GSH3) has an almost identical scientific history. Note that other anomalous meteors are filed in AY; and anomalous meteorites and tektites in ER.

Examples of Hissing Sounds Correlated with High-Altitude Meteors

X1. November 13, 1833. A colossal meteor shower over the U.S. East Coast. A few reports of hissing and rushing sounds, but most observers heard nothing. (R1) Apparently few meteors in this great spectacle were large. (WRC)

X2. 1838. Monroe County, New York. "Early in the evening, sometime between sundown and dark, I was alone in the yard on the south side of the house, when suddenly I heard a humming or whizzing noise as of some solid body moving with great velocity through the air. Quickly looking up in the direction from which the sound came I saw directly south of me and at an elevation of about 45 degrees two meteors, the larger one ahead and the smaller following directly in the larger one's path and so close that they apparently touched each other." (R5) As in this instance, many anomalous meteor sounds are heard before the meteor is seen.

X3. December 5, 1863. Beaumaris, England.

A hissing sound. (R2)

X4. July 19, 1871. Wilmington, North Carolina. "On Wednesday night, July 19th, between 8 and 9 o'clock, we were very much startled by a blaze of light, followed by a hissing noise like a fire roaring. Our first thought was that the house was on fire, but, in a second, a large ball of fire came rolling through the air, immediately over the house, from the south toward the north, and broke into the northern heavens, throwing off three large stars of crimson fire. Almost a minute after, there came a loud report, as of a cannon, only followed by a roll too long for a gun and not quite long enough for thunder." (R3)

X5. September 14, 1875. Faringdon, England. Several observers heard a hissing sound as the meteor passed overhead, (R9)

X6. Circa 1887. England. Three people hear a rushing sound simultaneously with the meteor sighting. (R14)

X7. Circa 1880. Indiana. Observers first hear a hissing sound, then look up to see a fireball passing overhead. (R28)

X8. December 12, 1882. North Atlantic Ocean. A loud, rushing noise was heard, like a large rocket. It proved to be a meteor. (R4)

X9. 1890. England. High meteor accompanied by a rushing sound. (R6)

X10. July 17, 1900. Yeadon, England. A soft hiss, as the fireball travelled through the air. (R9)

X11. December 7, 1900. Pinkhampton, Colorado. Many heard sounds of anomalous character from this meteor: like papers thrown on a fire; like something rolling on the roof. (R7)

X12. December 4, 1901. Burnham and several other localities in England. A hissing sound. (R9)

X13. April 10, 1902. Dunsink, Ireland. An observer's attention was captured by a rushing noise overhead. It was a pear-shaped meteor. (R8-R9)

X14. September 15, 1902. Ohio, Michigan, Ontario. Many observers reported anomalous sounds: a loud sizzling noise, a sound like an electric car running, a hissing sound as loud as a bee. (R10)

X15. August 7, 1906. Sudbury, England. A sound like a rocket passing overhead drew attention to a shooting star. (R11)

X16. May 9, 1909. New South Wales, Australia. "Several reliable witnesses state that they unquestionably heard a hissing sound as the meteor passed through the upper atmosphere; in two cases attention was drawn to the phenomenon by the sound. This simultaneous sound impression, if not pure suggestion, implies the emission of waves other than those recognised by the theory of acoustics, since the meteor was 25 miles distant from the observer at the time." (R15)

X17. November 23, 1912. Urbana, Illinois. A dull swish as the meteor passed by. (R16)

X18. October 1, 1917. Texas. Several parties up to 200 miles away heard a buzzing or swishing sound simultaneous with the visible sighting. (R17, R28)

X19. June 23, 1928. Southwest Texas. Sellards thoroughly investigated this event, finding five observers whose attention was directed to the meteor by the sound. Some claimed to have heard whining, whizzing, and sizzling sounds. (R19, R28)

X20. August 8, 1928. Texas (again). Hissing and whirring noises. One observer, who had considerable astronomical experience, heard a distinct and long-drawn-out 'pop' just as the object appeared. (R28)

X21. November 30, 1928. Northern England. Two observers distinctly heard a fizzing sound as the meteor passed over. But W. F. Denning, a meteor authority, said, "Errors of this kind are often made, however, by persons who lack experience in observing such phenomena." (R18)

X22. July 25, 1929. Illinois. Many observers reported hearing a swishing or hissing sound at the same time they saw the meteor. Nevertheless, others heard nothing. (R28) Because the interval between seeing and hearing the meteor should have been measured in minutes, C. C. Wylie, a meteor expert, stated that 'none of these sounds can be accepted as from the meteor.' (R20)

X23. March 24, 1933. New Mexico. A man inside a house heard a sound and on going outside to investigate saw the meteor. Other reported humming, crackling, and rustling. (R26, R28)

X24. July 11, 1933. Athens, Georgia. A farmer and his son working in a field heard a peculiar humming or singing noise, 'like an airplane flying high.' The noise grew louder for about five minutes, changed to a whizzing sound, and ended with a swish and thud. A nine ounce meteorite was found nearby. (R21)

X25. August 8, 1933. Crawford, Nebraska. "Bruer, an implement merchant, was indoors uncrating a piece of machinery for a customer when he suddenly ceased hammering, hearing a noise which he believed to be an airplane banking steeply over the town. The large door, 10 by 10 feet, in the south end of the building, was open. Bruer started walking to the door to investigate the source of the noise, and as he approached it, the meteor, which was traveling from the southeast, came into view. He called to his customer, but he was too late to see it. The huge fireball burst and disappeared, leaving only a 'trail of gray smoke,' and the sound ceased. The two men stood in the doorway discussing the mysterious phenomenon for an estimated two or three minutes before returning to resume their business. Then came the detonations, loud and rumbling like a heavy truck rolling by on the rather bumpy street." Subsequent investigation revealed that the detonation occurred 30-50 miles away. (R29)

X26. November 6, 1934. South central states. Hissings and swishes heard by some in Kansas, Oklahoma, and Texas. The majority of the witnesses heard nothing. (R22)

X27. January 19, 1936. Madera, California. Swishing sound attracted attention to the meteor. (R23)

X28. October 22, 1935. New York and Connecticut. "Many say that it burst at the end of its path; at any rate it ended with a considerable increase in brightness. Nobody heard an explosion, but we have several, as usual, who report that their attention was called to the meteor by a crackling or hissing sound. As pointed out formerly, this 'sound' if interpreted in the ordinary sense of the word could not be caused by the meteor, as what is 'heard' is coincident with the appearance of an object which for most observers is from 50 to 200 miles away. If it is not psychological, perhaps some sort of electical effect is responsible for the reported sensations. The matter should not, however, be dismissed as incredible merely because we cannot assign a certain cause for it, as apparently reliable observers have vouched for its reality on many occasions." (R24)

X29. October 13, 1936. Hyderabad, India. Hissing noise simultaneous with the appearance of the meteor. (R27)

X30. April 12, 1938. Central New York. Four reports of a simultaneous swishing sound. (R25)

X31. March 25, 1944. Hyderabad, India. Simultaneous hissing sound. (R27)

X32. August 6, 1944. Hyderabad, India. Simultaneous hissing sound. Author states that X29, X31, and X32 leave no doubt whatever that this simultaneous sound is real and not psychological. (R27)

X33. February 18, 1948. Kansas and Nebraska. 'Unearthly whizzing sounds.' (R28)

X34. September 1, 1962. The 'Mad Ann' fireball, seen in Virginia, West Virginia, and Ohio. An observer near Covington stated that a hissing noise made him look up and see the fireball. (R30)

X35. 1966. England. Rushing sounds. (R31)

X36. April 7, 1978. New South Wales, Australia. "A notable feature of the 1978 fireball was the high number of witnesses reporting hissing, humming, swishing or crackling sounds simultaneous with the passage of the fireball; these were mentioned in 10 of the 22 high quality reports and 15 of the full total of 33 written reports describing the fireball. Similar sounds accompanied the 1969 fireball." (R34, R35)

X37. General observations. The scientific attitude towards anomalous meteor sounds has changed drastically over the years, as the following items will demonstrate. (WRC)

1907. "But in regard to the hissing and similar noises often alleged to have been heard simultaneously with the passage of ordinary shooting stars and fireballs athwart the sky, these may be dismissed as imaginary." (R12)

1907. "Many instances of similar observations have been recorded. The only probable explanation is that the observer, startled by the suddeness of the phenomenon, unconsciously attributes to the meteor the hissing sound with which in the case of the rocket he is doubtless quite familiar." (R13)

1932. "The swish, hiss, or sound like a sky-rocket, heard simultaneously with the appearance of the meteor is due primarily to suggestion, but real sounds misinterpreted probably account for a large number of such reports. (R20)

1939. "The writer is convinced of the reality of sound which is produced, under favorable conditions, by the natural transformation of ether waves into ordinary sound, somewhat as in the radio, and proposes that the adjective ethaerial be used to designate such sound. If such sound exist, then the noises which are frequently heard at the same time as a meteor is seen and which have been reported by many observers, may be explained as ethaerial---in contradistinction to true aerial---sounds." (R26) The writer here was H. H. Nininger, a self-taught expert on meteors. (WRC)

1969. "At one time it was believed that people who observed bolides imagined the sounds, as a psychological association with noise from sparklers and other fireworks. Meteor sounds are now regarded as physical effects. On several occasions the observer first heard the noise and then looked upward to seek the cause. (Similar noise has also been reported during times of auroral activity.) One hypothesis is that low frequency electromagnetic radiation is emitted by bright bolides and detected by human sense organs. Human subjects exposed to radar beams of low intensity have perceived sensations of sound described as buzzing, clicking, hissing or knocking, depending on the transmitter characteristics." (R32) Similar information found in R30 and R33.

1980. "An investigation of the phenomenon indicates that bright fireballs radiate considerable electromagnetic energy in the very-low-frequency (VLF) region of the spectrum. A mechanism for the production of VLF emissions from the highly energetic wake turbulence of the fireball is proposed. Trials with human subjects revealed a very extended range of thresholds for the perception of electrically excited sounds among a sample population, particularly when the VLF electric field excites surface acoustic waves in surrounding objects. This fact, together with variable propagation effects and local conditions, can account for the sporadic distribution of reports of anomalous sounds from fireballs and auroras." (R35)

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GSH3 Swishing and Crackling Sounds Associated with Auroras

Description. Swishing, rushing, crackling, and hissing sounds heard during auroral displays. Many similies have been offered, including like rustling tissue paper, like fine snow hitting against a window pane, and like a fine spray of water hitting a hot surface. Very often the sounds wax and wane in step with the motions of the aurora. Auroral sound is frequently associated with what are thought to be very low auroras (GLA4).

Background. Folklore and the testimony of native inhabitants of the arctic are emphatic that auroral sounds exist. Although some scientists have heard the sounds, many famous arctic explorers have not. As with meteor sounds (GSH2), the sound of the aurora has long been denied by most scientists despite abundant positive testimony. More recently, however, the subject has become more respectable, for it has become apparent that auroras do generate infrasound and strong currents in terrestrial conductors and, in addition, that human subjects sometimes perceive electromagnetic radiation as sound. In short, auroral sound does not seem physically impossible any longer.

Data Evaluation. The mass of testimonial evidence is very large and includes many observations be experienced scientists. In many instances, the observer was attracted to the aurora by its sound or heard it indoors or even blindfolded. Some observations are likely clouded by psychological effects, for it seems as if the auroral pulsations should be accompanied by faint sound! Nevertheless, the sheer abundance of observations gives this phenomenon a high rating. Rating: 1.

Anomaly Evaluation. Auroral theory places auroral displays so high (over 50 miles) that the near-vacuum of the atmosphere should not transmit audible sound efficiently. Further, the distance from the observer is theoretically so great that sounds in synchronism with auroràl motions would be impossible due to the slow speed of sound. Thus, conventional sound generation and transmission seem out of the question, as in the case of meteor sounds (GSH2). Several reasonable mechanisms for generating auroral sounds haven been suggested (see below), so that auroral sounds no longer seem so anomalous. No one knows, of course, which mechanism prevails. Rating: 2.

Possible Explanations. The direct perception of electromagnetic radiation from the auroras as sound (see GSH2); brush discharge at the earth's surface induced by the aurora; the sound of frozen breath crystals; psychological effects produced by the motion of the auroras.

Similar and Related Phenomena. Instantaneous meteor sounds (GSH2); the detection of, electomagnetic radiation as sound (BH).

Examples of Auroral Sounds

X1. December 1563. Bergen, Norway. Noise came from clouds running back and forth in the sky. (R23, R62)
X2. October 8, 1726. Little Chelsea, England. (R62)

X3. 1762. Paris, France. (R62)
X4. 1766. Norway. (R62)
X5. 1767. Norway. (R62)
X6. 1770. Canada. On Samuel Hearne's expedition to the Arctic Ocean. "I can positively affirm, that in still nights I have frequently heard them (the Northern Lights) make a rustling and crackling noise, like the waving of a large flag in a fresh gale of wind. This is not peculiar to the place of which I am now writing, (Great Slave Lake), as I have heard the same noise very plain at Churchill River; and in all probability it is only for want of attention that it has not been heard in every part of the Northern Hemisphere where they have been known to shine with any considerable degree of lustre. It is, however, very probable that these lights are sometimes much nearer the earth than they are at others, according to the state of the atmosphere, and this may have a great effect on the sound; but the truth or falsehood of this conjecture I leave to the determinations of those who are better skilled in natural philosophy than I can pretend to be." (R49, R62)

X7. January 18, 1778. Spydeberg. (R23, R62)
X8. Winter 1781-1782. New Haven, Connecticut. (R62)
X9. 1781. Dover, New Hampshire. (R62)
X10. March 31, 1783. Dover, New Hampshire. (R62)
X11. May 24, 1788. Kendal. Wales. (R62)

X12. Winter 1796-1797. Reindeer Lake, Canada. "In the rapid motions of the Aurora we were all persuaded that we heard them, reason told me that I did not but it was cool reason against sense. My men were positive that they did hear the motions of the Aurora, this was the eye deceiving the ear; I had my men blindfolded by turns and then enquired of them if they still heard the motions of the Aurora. They soon became sensible that they did not and yet so powerful was the illusion of the eye on the ear that they still believed that they heard the Aurora." (R49, R62) Doubtless illusion plays a role, but other blindfold tests (X55) have yielded opposite results. (WRC)

X13. December 5, 1801. Orkney, Scotland. (R62) Also seen at Edinburgh, where observers heard a whizzing noise. (R2)
X14. October 22, 1804. Dorpat, Estonia. Sounds like sparks or falling hail. (R1)
X15. Winter 1814. Reykjavik, Iceland. (R62)
X16. Summer 1815. Scotland. A rustling sound, like that produced by shaking a handful of tissue paper. (R7)
X17. 1818. Skien, Norway. (R62)
X18. November 1818. North Atlantic Ocean between Iceland and Shetland. (R62)
X19. 1820. Nijnei Kolymsk, Russia. (R62)
X20. December 1821. Winter Island, arctic Canada. (R62)
X21. March 11, 1821. Fort Enterprise, Canada. (R62)
X22. August 28, 1827. Utica, New York. (R62) Also elsewhere in New York.
X23. 1828. Greenland. (R62)
X24. 1833. Fort Reliance, Canada. (R62)
X25. November 18, 1835. Dunse, United Kingdom. (R4, R62)
X26. October 31, 1838. Bossekop, Norway. (R62)
X27. January 10, 1839. Bossekop, Norway. (R62)
X28. March 5, 1839. Fort Confidence, Canada. Like the rustling of silk. The display and sound lasted only 10 minutes. (R5, R16, R62)
X29. September 3, 1839. Dunse, United Kingdom. (R4, R62)
X30. September 4, 1839. Dunse, United Kingdom. A "whiffling" sound. (R4, R62)
X31. September 20, 1839. Livland, northern Europe. (R62)
X32. January 28, 1840. Kaafjord, Norway. Like the rustling of silk. (R3)
X33. March 10, 1840. Kaafjord, Norway. (R62)
X34. March 22, 1840. Kaafjord, Norway. (R3, R62)
X35. November 21, 1840. Kaafjord, Norway. (R3)
X36. March 16, 1842. Lapland. (R62)
X37. Fall 1842. Strafford, New Hampshire. Like the crackle of a burning hemlock broom. (R20 R62)
X38. Winter 1846. New Hebrides, United Kingdom. (R62)
X39. July 11, 1848. Bas Granada, Canada. (R60)
X40. December 1848. Northern Indiana. (R8)
X41. 1849. Fort Franklin, Canada. (R62)

X42. December 2, 1850. Canadian Rockies "The Phenomenon was evidently very near the earth, for it appeared between me and the trees on the opposite bank of the river, which could not have been forty feet above the level of the stream, the trees toward the top of the hill being high above it. Large compact masses were moving from E. to W. and bright streamers passing in the same direction in quick and vivid flashes, then returning to the zenith would from thence spread out to the N. and S. in beautiful waves or clouds, and sheets of light of the most beautiful colors until they disappeared and left the sky entirely clear. Every time the streamers passed from E. to W. they were accompanied by a bustling noise, such as would proceed from the gentle waving of a silk flag. But in returning from the W. to E. I am not conscious of having heard any sound proceed from them." (R26, R62)

X43. September 7, 1851. Okso. (R62) No further geographical data given
X44. February 19, 1852. Okso. (R62)
X45. April 21, 1852. Okso. (R62)
X46. February 24, 1854. Okso. (R62)
X47. November 1856. Alten, Norway. A faint crackling. (R23, R62)
X48. August 28, 1859. Grafton, Canada. (R62)
X49. 1860. Iceland. (R62)
X50. November 1865. Aloukuk, Alaska. (R62)
X51. January 1866. St. Michaels, Alaska. (R62)
X52. 1866. Dumfriesshire, United Kingdom. Like the switching of silk. (R10, R62)
X53. Summer 1870. Ingersol, Canada. (R62)
X54. November 24, 1870. Norway. The balloonist Rollier descended on a mountain during an aurora and heard "an incomprehensible muttering" and smelled sulphur. (R62) December 1870 given in (R9).

X55. August 15, 1882. Fort McLeod, Canada. "The night was calm and bright. Lying awake in the tent, I heard a mild crackling noise which brought me outside quickly, fearing that our fire had not been thoroughly extinguished. The fire was dead, but the heavens to the north were showing a greater display than I had ever seen. The aurora was shooting upwards and receding with almost lightning rapidity and with varying colours. A broad yellowish splash of flame spread across from the west to the east, ascending from the horizon and proceeding with what I can best describe as a swishing noise, while at the same time a crackling noise accompanied the darting and shooting of the aurora. The whole display seemed near. Its immanency impressed me and together with the very clear audibility inspired something bordering on fear. I have been near to pine forest fires and the flames running through the branches made a crackling noise which impressed me as similar to that accompanying the aurora which I am endeavouring to describe." (R33, R62) Note that the sound of the aurora was heard before its presence was realized. (WRC)

X56. November 18, 1882. Canada. "As to the aurora making an audible sound, although I often listened when there was a brilliant display, and despite the profound stillness which is favourable to hearing the sound, if any sound occurs, I cannot say that I ever even fancied I heard anything. I have often met people who said they could hear a slight rustling noise whenever the aurora made a sudden rush. One man, a member of my party in 1882, was so positive of this that on the 18th of November when there was an unusually brilliant and extensive display, I took him beyond all noise of the camp, blindfolded him and told him to let me know when he heard anything, while I watched the play of the streamers. At nearly every brilliant rush of the auroral light he exclaimed: 'Don't you hear it?' All the time I was unconscious of any sensation of sound." (R49, R62)

X57. July 31, 1883. Near Montreal, Canada. Streamers accompanied by a sharp crackling sound. (R17, R62)
X58. 1884. Durham, Canada. (R29 R62)
X59. February 1884. Kingston, Canada. (R33, R62)
X60. January 1888. Saskatchewan, Canada. (R62)
X61. Fall 1892. Northern Minnesota. Crisp rustling sounds. (R33, R62)
X62. August 6, 1893. Randolph, Ohio. Leaping flames and tongues of fire, with a roaring like a distant fire. (R21)
X63. October 11, 1893. At sea, probably the North Atlantic or Arctic Ocean. Whizzing and crackling sounds, like firearms fired a short distance away. (R40, R62)
X64. 1893. Brampton, Canada. (R29, R62)
X65. Winter 1894-1895. Quebec, Canada. The sound resembled music produced when harp strings are touched lightly. (R55, R62)
X66. Winter 1894. Arny, Norway. (R62)
X67. January 1898. Iditarod, Alaska. The popping sounds of the aurora scared the dogs. (R24, R25, R62)
X68. Winter 1898. Fort Graham, Canada. (R62)
X69. 1898. Strathaven. (R62) No further geographical information given.
X70. January 1899. Yukon, Canada. Twistings of aurora accompanied by swishing sounds. (R32)
X71. Winter 1901. Eagle, Alaska. (R62)

X72. 1901 or 1902. At sea off Norway, North Atlantic Ocean. "While our ship was crossing Vaags Bay, a little north of Harstad, a brilliant aurora in rapid motion, was seen so low down in the air that it barely cleared the tops of the masts. It flamed forth in all the colors of the rainbow and was followed by a peculiar sound, precisely such a sound as would be produced by rubbing together a well-dried skin in the hands. It was neither imagination nor the mistaking of any sound on board, but undoubtedly the result of the movement of the aurora." (R23, R62)

X73. 1903. Canada. (R62)
X74. 1904. Sackville, Canada. (R39, R62)
X75. August 1904. Southwest Minnesota. Observer was attracted to the aurora by its noise. (R22, R62)

X76. July 1905. Cartwright, Canada. "While in charge of the Labrador station of the Lick Observatory-Crocker Eclipse Expeditions of 1905, much of the work of adjusting the instruments was necessarily done at night. The station was located at Cartwright (latitude 53°42'), and auroral displays were frequent and bright during July and August. On several nights I heard faint swishing, crackling sounds which I could attribute only to the aurora. There were times when large faintly luminous patches or 'curtains' passed rapidly over our camp; these <u>seemed</u> to be close and not more than a few hundred feet above the ground, though doubtless much higher. The faint hissing and crackling sounds were more in evidence as such luminous patches swept over us." (R29-R31, R49, R62)

X77. September 1907. St. Lawrence River, Canada. (R62)
X78. January 1908. Discovery and Sulphur Creek, Canada. (R49, R62)
X79. September 10, 1908. Miami, Canada. (R62)
X80. Winter 1908-1909. Hartford, Connecticut. Low-level aurora made swishing sound. (R51)
X81. January 26, 1911. Dawson, Canada. (R62)

X82. October 10, 1911. Lake Enare, Finland. "Little by little the aurora lost its strength and I sat down to supper. Some time after---unfortunately I can not tell the exact instant---I heard in the north a peculiar, even insistent, rumbling noise not unlike distant thunder. It was so characteristic that I jumped up to see what was going on. The aurora appeared like a bow in the north. It struck me at once that this must be the much-talked-of mysterious auroral sound, and in order to make sure of it I asked my two attendants if it proceeded from the aurora. They replied in the affirmative and continued their work as if it were a well-known and common occurrence." (R23, R62) Again the sound was heard when the aurora was out of sight. (WRC)

X83. 1911. Antarctica. (R62)

X84. Winter 1911. Framheim, Antarctica. "Amundsen told me that when he was at Framheim, at the east end of the Barrier Reef, just before his famous dash to the South Pole, he was called out of his winter quarters one very cold night by Johannsen, in order to hear what Johannsen described as the crackling of the Aurora Australis. It was a very cold and very still night, Amundsen distinctly heard a very faint rhythmically repeated rustling noise in the air. After a time he discovered that this was due to the rapid freezing of the moisture from his breath, and the tiny tinkle made by the minute crystals as they slowly descended under gravity close to his face, sufficiently close for the ear just to catch the faint sound. He said there was no doubt about it that the rustling noises exactly coincided with the periods when he exhaled air from his lungs. He said that he was now confident that this was the true explanation of what the poets call the 'Crackling of the Northern Lights.'" (R62) Although some auroral sound events may yield to this explanation, there are many others that have transpired when the weather was too warm for the breath to freeze. Further, this theory does not account for sounds coincident with auroral motion. (WRC)

X85. Winter 1914-1915. Gold Run Creek, Canada. (R62)
X86. 1916. Spencers Island, Canada. "S"-like sound heard in synchronism with auroral motions. (R43, R62)
X87. August 1916. Victoria, Canada. Like the swish of fine snow against a window pane. (R28, R62)
X88. February 1919. Cumberland House, Canada. (R62)
X89. October 15, 1919. Broadview, Canada. (R33, R62)
X90. Summer 1920. Alvarado, Minnesota. (R62)
X91. Autumn 1920. Labrador, Canada. (R62)
X92. October 1921. Fort Fitzgerald, Canada. (R62)
X93. Winter 1924-1925. Norman, Canada. (R62)
X94. Winter 1925-1926. Simpson, Canada. (R62)
X95. August 8, 1924. Valparaiso, Canada. Northern lights were waving close to the

ground with a sound like rustling silk or tissue paper. (R49, R62)

X96. Winter 1925-1926. Bering Strait, Alaska. Powerful beams of white light were passing low overhead. "The spectacle was so awe inspiring that the dog team was stopped and I sat upon the sled for more than an hour absorbing the marvelous beauty of this most unusual display. As we sat upon the sled and the great beams passed directly over our heads they emitted a distinctly audible sound which resembled the crackling of steam escaping from a small jet. Possibly the sound would bear a closer resemblance to the crackling sound produced by spraying fine jets of water on a very hot surface of metal." (R44, R62)

X97. September 16, 1926. Norway. A faint undulatory, whistling sound. (R49) See X99.

X98. October 1926. Shetland, United Kingdom. (R34)

X99. October 15, 1926. Oslo, Norway. A splendid aurora. "But what is of preponderant interest is the following fact: When, with my assistant, at $19^h 15^m$ Greenwich Civil Time, I went out of the observatory to observe the aurora, the latter seemed to be at its maximum; Yellow-green and fan-shaped, it undulated above, from zenith downwards ---and at the same time both of us noticed a very curious faint whistling sound distinctly undulatory, which seemed to follow exactly the vibrations of the aurora." (R35, R62) This item seems identical with X97 except for the date. (WRC) In R35, Carl Stormer added a note to Jelstrup's letter to Nature to the effect that the sound probably did not come from the aurora itself but rather from ground-level discharges of electricity induced by the aurora.

X100. January 10, 1927. Wellington Bay, Canada. An active aurora, close to the ground. "By active I mean it was very vibratory and quick moving in form. I then heard a very loud swishing noise and the aurora seemed to take a downward sweep when the noise occurred, also there were two distinct streamers that seemed to come in contact with the tops of the range of hills about 15 miles north of me. After a few seconds the streamers disappeared and the noise ceased, the aurora was again natural. This was so unusual that I watched for some time, but there was no recurrence of noise or streamers. At this time my dogs were unharnessed and lying curled up in the snow. When the swishing noise came so suddenly and apparently so close, most of them immediately jumped up and commenced to growl. On going into the snow house again I asked the native who was with me if he had heard any noise, and he stated that he had heard the northern lights move a short time ago." (R49, R62)

X101. July 1928. Pittsburgh, Pennsylvania. (R62)

X102. July 1928. Smiley, Canada. (R62)

X103. August 10, 1928. Fort Smith, Canada. A low hissing or swishing noise. (R41)

X104. Winter 1928-1929, Langton Bay, Canada. (R62)

X105. Winter 1928-1929. Magnetic pole, Canada. (R62)

X106. Winter 1929. Ontario, Canada. When his radio receiver apparently failed, the observer stepped outside and found himself immersed in a low-level aurora. The display scintillated to the accompaniment of snapping sounds. (R60)

X107. March 20, 1933. Chesterfield Inlet, Canada. (R45, R62)

X108. January 25, 1938. Much of northern Europe. The following observation is from Norway. "During the imposing display of this big corona, where the whole heavens was like an ocean of flames, my assistant and I heard a curious sound which came from above, first from the south-west, then from the zenith and at last from the north-east. The sound lasted about ten minutes, rose to a maximum and fell down again, following the intensity of the aurora. I had the impression that it had something to do with the white rays. At that time I had taken off the earphones from my ears (when I had them on, I heard nothing of this sound) and went some steps outside to hear it better; that the sound came from the telephone is quite excluded. The sound is difficult to describe, it was similar to the sound from burning grass and spray. On the mountain it was absolutely quiet, no sound coming from wind, waterfalls, telegraph lines or motors. Both my assistant and I heard it and are quite convinced that the sound was real." (R53, R54, R57, R59, R62) Sounds were recorded elsewhere during this spectacular display.

X109. September 18, 1941. Maniwaki, Canada. (R62)

X110. September 25, 1951. Chester, England. (R58)

X111. November 1971. Edmonton, Canada. (R62)

X112. No date given. Many undated reports exist. Since they add nothing to the data presented in the dated reports, only references will be given here. (R27, R36, R37, R38, R48, R52, R62) It should also be noted that some of the reports providing dated examples also include undated ones. (WRC)

X113. General observations. Low-frequency mircobarographs have recorded many infrasonic events in the range 0.001-1 Hz. These events can be attributed to auroras. The ranges of the microbarographs and human ears do not overlap; that is, human ears do not hear the infrasonic auroral waves and the microbarographs have very poor response at audio frequencies. (R61) Yet the acknowledged production of infrasound by auroras suggests that auroras also may generate audio frequencies. (WRC)

Audio-frequency atmospherics, as heard through the medium of radio receivers, have been correlated with auroral activity. Furthermore, they often have the "swish" structure associated with true auroral sounds. (R50)

Intense auroral displays may induce strong earth currents. Sparking, permanent arcs, and burnt-out fuses are common in telephone lines and other communication gear. The author suggests that some auroral sounds may simply be induced terrestrial electrical discharges. (R63, R64) Others have also suggested that terrestrial brush discharge is an important contributor to auroral sound. (R13, R14, R62)

Some scientists attribute auroral sounds to misidentified natural sounds and a "psychological" effect, in which the rapid motions of auroras, which seem as if they should generate swishing sounds, are actually thought to. (R11, R46, R47)

Auroral sounds are sometimes attributed to the "frozen breath" phenomenon, described in X84. (R42, R62)

Many scientists who have spent years in the polar regions have never heard auroral sounds. Such persons naturally express sincere and grave doubts about the reality of the phenomenon. (R6, R62) In fact, some auroral research programs, in which the detection of auroral sounds was a specific objective, have come up with nothing. (R65)

Some references to miscellaneous subjects, such as the different kinds of auroral sounds, are included below. (R12, R15, R18, R19)

X114. September 27, 1938. Toronto, Canada. (R56, R62)

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GSH4 Overhead Rushing Sounds of Undetermined Origin

Description. Rushing, moaning, wind-like sounds heard moving across the sky overhead. Some observers claim the sounds are harp-like and even musical. The most notable site of this phenomenon is Yellowstone Park, Wyoming, where they are often called the Yellowstone Whispers. Most commonly heard on fine, still mornings, the sound approaches from one horizon, passes overhead, and in a few seconds is lost on the opposite horizon. At Yellowstone, the phenomenon seems to take different "flight paths."

Data Evaluation. Early explorers first remarked on the Yellowstone acoustic phenomenon. Many more recent observations have also been recorded. But away from Yellowstone, the phenomenon seems extremely rare. Rating: 1.

Anomaly Evaluation. The Yellowstone acoustic phenomenon could be anything from an unusual manifestation of seismic sounds to a totally unappreciated natural phenomenon. There is that little known about it. Although experience tells us that prosaic explanations generally prevail in such situations, these sounds are so bizarre that a high rating is warranted. Rating: 2.

Possible Explanations. The most popular suggestion is that the Yellowstone sounds are seismic in origin---Yellowstone is of course very active with almost daily tremors. Geyser activity and even wind blowing across the high peaks may contribute such sounds, although such mechanisms cannot explain the apparent motion across the sky.

Similar and Related Phenomena. Earthquake sounds on rare occasions emulate wind in the distance (GSH1); instantaneous meteor sounds (GSH2); the sound of the aurora (GSH3); humming in the air (GSH5).

Examples of Overhead Rushing Sounds

X1. Occasional occurrence. Yellowstone Park, Wyoming. Several descriptions of the famous Yellowstone Lake "whispers" follow.

By Professor S. A. Forbes, in 1890. The lake referred to here is actually Shoshone Lake, very close to Yellowstone Lake. "Here we first heard, while out on the lake in the bright still morning, the mysterious aerial sound for which this region is noted. It put me in mind of the vibrating clang of a harp lightly and rapidly touched high up above the tree tops, or the sound of many telegraph wires swinging regularly and rapidly in the wind, or, more rarely, of faintly heard voices answering each other overhead. It begins softly in the remote distance, draws rapidly near with louder and louder throbs of sound, and dies away in the opposite distance; or it may seem to wander irregularly about, the whole passage lasting from a few seconds to half a minute or more. We heard it repeatedly and very distinctly here and at Yellowstone Lake, most frequently at the latter place. It is usually noticed on still bright mornings not long after sunrise, and it is louder at this time of day; but I heard it clearly, though faintly, once at noon when a stiff breeze was blowing." (R1, R2, R4)

This account was attributed to General H. M. Chittenden's 1915 book on Yellowstone National Park. "A most singular and interesting acoustic phenomenon of this region, although rarely noticed by tourists, is the occurrence of strange and indefinable overhead sounds. They have long been noted by explorers, but only in the vicinity of Shoshone and Yellowstone Lakes. They seem to occur in the morning and to last for only a moment. They have an apparent motion through the air, the general direction noted by writers being from north to south. They resemble the ringing of telegraph wires or the humming of a swarm of bees, beginning softly in the distance, growing rapidly plainer until directly overhead, and then fading as rapidly in the opposite direction." (R3)

"The myserious acoustic phenomenon over Yellowstone and Shoshone Lakes, recorded rarely but nevertheless intermittently during the past 44 years, has again been heard this summer on two succeeding days. The descriptions of the weird sounds vary. To some they are 'musical'. Others describe them as resembling the whirring sound made by the wings of many birds flying through the air, and to yet another they resemble moans. Among the latest to hear the mysterious noises are Harold P. Fabian, Republican national committeeman from the State of Utah, and Edward E. Ogston, assistant chief ranger of Yellowstone. While fishing on Grebe Lake, with the breeze blowing in a northerly direction, they heard sounds similar to that coming from an airplane, originating in the east, passing over the lake, and dying in the west. The following day Chief Ranger George Baggley, while standing within 200 yards of the shore of Lake Yellowstone, heard the sounds, similar to that of many birds in flight, occur at three diffrent times." The final paragraph of this item notes that once a boat on Yellowstone Lake was struck by lightning out of a clear sky, killing one person, and goes on to wonder if the sounds might have an electrical origin. (R5)

"The following quotation, concerning strange noises over Yellowstone Lake, is taken from 'Haynes Guide', by Jack Ellis Haynes: 'Strange overhead noises at Yellowstone Lake have been reported many times from the earliest days of exploration to the present. These occur when the sky is cloudless, and the air perfectly still and usually early in the morning. This strange noise, heard only occasionally, is not like the sound of a distant flight of birds nor any shore noise, but is weird and startling. A description of this unusual phenomenon reported by the author in 1924 follows: Our small boat was approaching Pelican Roost island. The surface of the lake was mirror-like in the stillness of early morning. A sound rose overhead apparently from the west beginning with a low roar which gradually became louder and rose in pitch, then gradually faded away as the pitch lowered again, while the sound seemed to soar rapidly to the southward as it faded into silence. Then from another direction a similar sound was heard, and again from still another direction, the whole phenomenon lasting only half a minute. Although I am familiar with most of the sounds common to wilderness areas, this was unlike anything I had ever heard before." (R8)

Several more testimonies may be found in R6. In R7, G.R. Wieland wonders if the sounds at Yellowstone Lake might not be related to the Seneca "Guns" in that both phenomena may be due to the release of gas from the earth. (See GSD1 for descriptions of the Seneca "Guns."

X2. February 8, 1928. Seskin, Ireland. "A sound locally known as 'wind in the mountains,' was heard here all day. When first noticed before 8h. it sounded like the noise of a motor running, and distinct from the noise of the wind. It was persistent, unvarying except in the degree of loudness and without anything like throbbing. In the afternoon its volume of sound was like that of the rush of a heavy train through a tunnel nearby. (There is no railway tunnel within about twenty miles.) It seemed to come from the Comeraugh mountains, a few miles to the south-west. One man who has lived in the district all his life had thought it was the noise of the Millvale stream, but as that is a slow-flowing, shallow stream more than a mile away, such an explanation does not seem likely. Locally it is considered a presage of storm and rain." (R9)

X3. April 15, 1974. North Pembrokeshire, England. "Some correspondence has come into my possession concerning the noise of rushing winds on hot, still days. The first letter appeared on 9 May 1974, in Country Life, from Mrs. Judith Eagle, describing how, on 15 April, she was walking in the Preselly Hills in North Pembrokeshire. The day, Easter Monday of that year,was hot and still, but at about 3 00 pm she and her two companions heard a loud rushing noise, as if made by a 'mighty wind', which lasted for about 25 secs. Apparently nothing moved; the short heather and grass remained still and neither Mrs. Eagle nor her companions felt any wind, while horses grazing not far away were undisturbed by the noise." (R10)

X4. No date given. Lake District, England. A sound like a mighty wind. (R10)

X5. Circa 1972. Dorset, England. A noise like that of a small whirlwind approached, passed, and disappeared, but not a leaf or blade of grass moved. (R10)

X6. Autumn 1828. The Pyrenees, Spain. "....we were most forcibly struck with a dull, low, moaning, Aeolian sound, which alone broke upon the deathly silence, evidently proceeding from the body of this mighty mass (a large mountain), though we in vain attempted to connect it with any particular spot, or assign an adequate cause for these solemn strains. The air was perfectly calm. The sky was cloudless, and the atmosphere clear." (R11)

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GSH5 Unidentified Humming Sounds

Description. Steady humming sounds appearing to emanate from overhead or the general environment. Because these hums are so faint, reports are concentrated in areas where noise pollution is low. The general environmental hums seem to be heard by only some people. Overhead hums from unseen sources are rather common phenomena to those who spend considerable time in forest and field. Environmental hums seem to be concentrated in certain areas; viz., Bristol, England.

Data Evaluation. Scientific literature on hums is scarce, possibly because they are automatically assigned to insects and the operation of motors, aircraft, etc. Few people would consider making an issue out of faint noises in today's world. Nevertheless, these unidentified hums seem to be legitimate phenomena. Rating: 2.

Anomaly Evaluation. Positive identifications elude us here, for both overhead and environmental hums. Although plumes of insects may account for some overhead hums and despite the omnipresence of 60-cycle power grids, it would be unscientific to assume they are the sources of all hums. Further, the Bristol environmental hums are permanent in character and restricted to a small portion of the populace. Enigmas thus persist. We may have both a biological anomaly (unusual sensitivity) and an unrecognized source of sound. Rating: 2.

Possible Explanations. Insect plumes and swarms; electrical power grid apparatus (transformers in particular); human sensitivity to power grid radiation; sounds created by the jet streams interacting with lower atmospheric strata.

Similar and Related Phenomena. Insect plumes (BI); the other hums and swishing sounds presented in this section (GSH).

Examples of Unidentified Humming Sounds

X1. Frequent occurrence. Rural areas. "It is observed by the author of one of the most delightful minor works (Journal of a Naturalist) of modern date, that the 'purely rural, little noticed, and, indeed, local occurrence, called by the country people Hummings in the air,' is annually to be heard in one or two fields near his dwelling. 'About the middle of the day, perhaps from twelve o'clock till two, on a few calm sultry days in July,' he says, 'we occasionally hear, when in particular places, the humming of apparently a large swarm of bees. It is generally in some spacious open spot that this murmuring first arrests our attention. As we move onward, the sound becomes fainter, and by degrees is no longer audible. That this sound proceeds from a collection of bees, or some such insects high in the air, there can be no doubt; yet the musicians are invisible. At these times a solitary insect or so may be observed here and there, occupied in its usual employ; but this creature takes no part in our aerial orchestra.'" (R1, R6) Several additional items on this subject all express the opinion that insects must be the source of the hums. (R2-R5) Still, the insects responsible are not seen in many instances. (WRC)

X2. Common occurrence, possibly a permanent feature of the environment. England. "Many people is rural or quiet suburban areas can hear a constant throbbing hum, something like the bass frequency of a heavy lorry with its engine on 'idle'. They describe the noise as coming from a kilometre or so away, although exactly in which direction they cannot say. Most of them blame factories, power stations, oil refineries and so on---but only in the vaguest sense as no one has been able to locate one source as the definite cause of the trouble. In some instances, the complainants are driven to getting up in the early hours of the morning---when the hum seems loudest---to walk or drive round to look, without success, for the offending source. The hum causes them anxiety and, worse still, alienation from other people who cannot hear it." Tests of people who can hear this hum indicate that the hum is approximately 40 Hz, possibly modulated at 1.6 Hz. (R9) The Bristol area seems to be badly afflicted in particular. (R10)

Noisy electric-power-grid substations may be a prominent source of the hum. (R7) One scientist has looked at the possibility that the jet stream shearing against lower, more slowly moving air strata might generate enough sound at about 40 Hz to account for the hum. (R8)

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GSH6 Nighttime Hums in the Desert

Description. Far-off hums and sighing sounds, sometimes throbbing, occasionally musical, emanating from desert regions.

Data Evaluation. Merely a few "travellers tales" have been collected. Rating: 3.

Anomaly Evaluation. A faint hiss from large areas of blowing sand is scarely anomalous, but the pulsating character of the desert hums is more puzzling. No ready explanation is at hand. Rating: 2.

Possible Explanations. Blowing sand, especially of the musical variety; microseismic activity; electrostatic discharges from sand dunes, as described in GLD5.

Similar and Related Phenomena. Musical sands (ER); the other natural hums and hisses presented in this section (GSH).

Examples of Desert Hums

X1. Frequent occurrence. Desert of Lop, China. "Marco Polo relates the weird noises, as of troops of demons, heard by the dwellers on the skirts of the great desert of Lop. Old Du Bartas gives the circumstance very graphic expression:---'And round about the desert Lop, where oft/ By strange phantasmas passengers are scoft.'" (R1)

X2. Frequent occurrence. Libyan Desert. "At a camp in the north-eastern corner of the plateau the curious 'song of the sands' was heard. This was on April 19, 1909. The week before had been unusually hot, and this was followed, on the 19th, by a cool, almost cold, day, with an overcast sky and slight showers at intervals. Towards sunset this was followed by a regular downpour, which, however, only lasted about a quarter of an hour. After sunset there was frequent vivid summer lightning. The sound began about 7.30 p.m. and continued at intervals until about 8. The sound was very faint; in fact, two of my men were unable to hear it. There were two distinct sounds; the one somewhat resembled the sighing of the wind in telegraph wires, and the other was a deep throbbing sound that strongly reminded me of the after reverberation of 'Big Ben.'.... It was difficult to determine the direction from which the sound came, but apparently it came from a place about a mile distant where the sand poured over a low scarp. The sound was a distinctly musical one, as opposed to a mere noise. Some of the dunes we crossed, which happened to be covered with a hard crust, gave out a hollow almost bell-like sound when trodden on, and I have heard of a place on the top of the plateau, to the north of Kasr Dakhl, that gives out a loud musical note when struck, but I was never able to visit it." (R2) Musical sands are covered in the geology portion of this Catalog (ER).

X3. Frequent occurrence. Deserts of Chile and Peru. "Shortly after darkness sets in the mysterious sound begins. At first it is a sort of hum, fairly high pitched, but weird, eerie, and almost beautiful. Soon, mingled with the hum at regular intervals, there is a deep bass boom, like the far off beating of a great drum. Sometimes the sound lasts for an hour or two, sometimes all night. I have heard it as often as three or four times a month. I have been told that the phenomenon is brought about by the movement of sand under certain conditions of wind, temperature, and humidity producing the proper vibrations. I know that on the nights when the sound occurs, there is a moderate southwest wind blowing, sufficient to move a film of sand along the surface. But whatever the cause, the phenomenon is certainly very real and very astonishing." (R3)

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GSI INFRASOUND

Key to Phenomena

GSI0 Introduction

Infrasound is generally defined as that portion of the sound spectrum below about 15 Hz. Such low frequency sound cannot be heard by most human observers, although it is associated with human irritability and other poorly defined physiological reactions (See BH.). The identification and study of infrasound sources is a rather recent scientific endeavour. The low energies and long wavelengths of infrasound signals require sensitive detectors arranged in large arrays. Already rather primitive instrumentation has revealed a large variety of infrasound sources. Many of these generators of unheard sounds turn out to be well-known natural phenomena (auroras, severe storms, etc.), but some persistent sources remain unidentified. Listening to the earth at infrasound wavelengths is analogous to infrared astronomy; and evolving technology is permitting us to observe phenomena that have hithertofore been hidden.

GSI1 Unidentified Infrasound Sources

Description. Sources of infrasound that cannot be correlated with any of the several recognized natural generators. (See X0 below.)

Data Evaluation. Most of the data are from arrays of infrasound detectors and thus under direct scientific control and highly reliable. The long wavelengths of infrasound make source location and resolution difficult with present-day equipment. Rating: 2.

Anomaly Evaluation. When all known sources of infrasound (X0) have been eliminated, those remaining are bound to be of particular interest and likely to involve unusual types of sound generation. Even so, it is doubtful that they will be of revolutionary character; rather, they will probably be only curious or bizarre. Rating: 3.

Possible Explanations. Many natural phenomena and manmade devices have the potential for generating infrasound; viz., hydrothermal areas (including powerplant equipment), microseismic activity, large waterfalls and cataracts, wind interacting with power lines and arrays of buildings and crops, geysers, and releases of natural gases from the earth.

Similar and Related Phenomena. Pressure-wave phenomena (GSW); low-frequency hums and hisses (GSH); human reactions to infrasound (BH).

Examples of Unidentified Infrasound Sources

X0. Scientists recognize many natural sources of infrasound. Some of these are rather unusual though hardly anomalous. Because some of these recognized sources may be related to anomalies cataloged in other sections and volumes, a listing is in order:

- Volcanic eruptions (R2, R3)
- Surf action (R11)
- Winds blowing across mountain ranges (R6, R11, R13, R14)
- Auroras and geomagnetic storms (R1, R4, R9, R16)
- Meteors (R15)
- Severe storms (R5, R10)
- Earthquakes (R12)

X1. Permanent feature. Southern Hemisphere. "Statistical data on infrasound arrival directions at Washington, D. C., and Boulder, Colorado, for a number of years have strongly indicated a source on the South American continent. New data from Penas, Bolivia; Huancayo, Peru; Washington, D. C.; and Boulder, Colorado, suggest that the source is in Argentina. The apparent source location changes with time, from triangulation based on the acoustical data. Some of this change could well be due to changes in circulation of ozonospheric winds in the southern hemisphere. (R7) In view of the date of this report, it is possible that this source may have been identified already. (WRC)

X2. Permanent feature. Western Hemisphere. Four unknown sources of infrasound in the Western Hemisphere are described. (R8)

X3. Permanent features. Worldwide phenomena. Abstract. "During the past several years many sources of naturally occurring infrasound have been identified. These include magnetic storms, severe weather, volcanic eruptions, large meteors, earthquakes, and microbaroms. Records from eight infrasonic stations throughout the world have been analyzed and show the presence of considerable infrasound which is not caused by the known sources mentioned above. In order to identify the locations of these sources, we have made a complete analysis of the data from July through December 1972. The results have established a number of new source locations and emission patterns which will provide important data for investigation of these sounds and ultimately of the mechanism of this generation." (R12)

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GSM MUSICAL SOUNDS IN NATURE

Key to Phenomena

GSM0 Introduction

A patient observer of nature soon discovers many sources of musical tones and bell-like notes---all above and beyond the common sounds of birds, trees creaking in the wind, and the like. A frozen lake, for example, is a whole orchestra of squeaks and throbbing notes. But here we restrict ourselves to those musical sounds whose sources are difficult-to-identify or are strange because of their mode of production. Also excluded are musical sands and ringing rocks, which are assigned to the Catalog volumes on geology.

Mysterious sounds near water are often created by fish and other marine ogranisms, which possess a surprising repertoire of vocal talents. Unlike bird calls, the sounds of fish and shellfish are not well-identified in the field guides. Recognizing this ignorance, it is likely that some of the oceanic music reported below is due to acquatic life. As for the rest, who knows? The wind, moving ice, electrical discharges, and other natural agents are probably at work.

The wind in particular adds to natural melody by converting properly configured rocks, plants, and even man-made structures into wind instruments. These natural aeolian harps, organs, and reed instruments are understandably rather rare because the dimensions and and character of the structures have to be precisely right for music to result.

GSM1 Underwater Musical Sounds

Description. A wide variety of harp-like, bell-like, organ-like and similar musical sounds emanating from natural bodies of water. These sounds, all possessing musical qualities, are usually heard near the shore, especially aboard ships, but sometimes directly from the shore. Heard mostly at night, the marine orchestras often continue for hours.

Background. Drumfish and other denizens of fresh and salt water produce decidedly unmusical sounds. These fish and their sounds are rather common.

Data Evaluation. The literature of science contains many accounts of this phenonenon. Rating: 1.

Anomaly Evaluation. Aside from their curiosity, the sources of oceanic music are not all positively identified. That these sounds have biological origins seems beyond question. It is only that the music makers have not been pinpointed. The enigma, therefore, is not a very deep one. Rating: 3.

Possible Explanations. Fish, shellfish, and other marine and freshwater organisms.

Similar and Related Phenomena. Some animals in almost all biological classifications make musical sounds. Where these animals have been identified and their sound production is of more-than-passing interest (viz., earthworm music), they have been described in the Biology volumes of this Catalog.

Examples of Underwater Musical Sounds

X1. Frequent occurrence. Gulf of Mexico, especially near the mouth of the Pascagoula River, Mississippi. "The mystic music sometimes heard at the mouth of the Pascagoula river, on a still night, is one of the wonders of our coast. It is not confined, however, to the Pascagoula River, but has often been heard at other places. At the mouth of the Bayou Coq del Inde and other inlets opening into the Gulf along the coast of our own country, the curious listener, lying idle in his boat, with lifted oars, when every other sound is hushed, may sometimes hear its strains coming apparently from beneath the waters, like the soft notes of distant Eolian harps. We have always supposed that this phenomenon, whatever its origin might be, natural or supernatural, was peculiar to our coast. It appears, however, from Sir Emerson Tenant's recent work on Ceylon, something very like it is known at Battialloa, in that island, and it is attributed to rather less poetical and mysterious origin---that is is a peculiar species of shellfish. They are said to be heard at night, and most distinctly when the moon is nearest the full." (R1, R2)

"While cruising on the west coast of Florida, we lay at anchor one night at Rocky Point in Old Tampa Bay, and heard most distinctly a very curious musical note of some denizen of the water. The sound consisted of a single note and was continuous for a long time. It recalled the singing of telegraph wires, or the hum of a planing-mill, or the music of an Aeolian harp. It occasionally approached or receded, and more than one such note---apparently from different animals---could be heard at once. In our cabin the sound seemed very distinct, but it was in reality probably faint, as it was hardly, or not at all, audible on deck. My companion and myself have both cruised along the Gulf coast south of that point before, but had not heard this sound anywhere else; our captain, also, had never heard it anywhere else, but said it was always to be heard at Rocky Point, which is a principal oystering ground for Tampa. The sound bore no resemblance to that of the drum, which is very common in Florida, and which is a booming, interrupted noise. Its most remarkable peculiarity was its steady continuance---it certainly often lasted without interruption for several minutes." (R9)

X2. Frequent occurrence. Central American waters. "Grey Town is a small place, containing but few inhabitants, situated at the mouth of the river St. Juan, which separates Nicaragua from Costa Rica, and empties itself into the Atlantic, lat. 10° 54' N., and long. 83° 41' W. In this town there are no belfries or factories of any kind. Owing to a shallow bar, vessels cannot enter the harbour or river, and are therefore obliged to anchor in from seven to eight fathoms of water, about two miles from the beach, the bottom consisting of heavy dark sand and mud containing much vegetable matter brought down by the river. Now, while at anchor in this situation, we hear, commencing with a marvelous punctuality at about midnight, a peculiar metallic vibratory sound, of sufficient loudness to awaken a great majority of the ship's crew, however tired they may be after a hard day's work. This sound continues for about two hours with but one or two very short intervals. It was first noticed some few years ago in the iron-built vessels Wye, Tyne, Eider, and Danube. It has never been heard on board the coppered-wooden vessels Trent, Thames, Tamar, or Solent. These were steamers formerly employed on the branch of the Company's International service, and when any of their officers or crew told of the wonderful music heard on board at Grey Town, it was generally treated as 'a yarn' or hoax. Well, for the last two years the Company's large Transatlantic ships have called at Grey Town, and remained there on such occasions for from five to sixdays. We have thus all had ample opportunity of hearing for ourselves..... By English sailors it was considered to be caused by the trumpet fish, or what they called such (certainly not the Centriscus scolopax, which does not even exist here). They invented a fish to account for it. But if caused by any kind of fish, why only at one place, and why only at certain hours of the night? Everything on board is as still from two to four, as from twelve to two o'clock, yet the sound is heard between twelve and two, but not between two and four. The ship is undoubtedly one of the principal intruments in its production. She is in fact for the time being converted into a great musical sounding board. It is by no means easy to describe this sound, and each listener gives a somewhat different account of it. It is musical, metallic, with a certain cadence, and a one-two-three time tendency of beat. It is heard most distinctly over open hatchways, over the engine-room, through the coal-shoots, and close round the outside of the ship. It cannot be fixed at any one place, always appearing to recede from the observer. On applying the ear to the side of an open bunker, one fancies that it is proceeding from the very bottom of the hold. Very different were the comparisons made by the different listeners. The blowing of a conch shell by fishermen at a distance, a shell held to the ear, an aeolian harp, the whirr or buzzing sound of wheel machinery in rapid motion, the vibration of a large bell when the first and louder part of the sound has ceased, the echo of chimes in the belfry, the ricocheting of a stone on ice, the wind blowing over telegraph wires, have all been assigned as bearing a more or less close resemblance; it is louder on the second than the first, and reaches its acme on the third night; calm weather and smooth water favour its development. The rippling of water alongside and the breaking of the surf on the shore are heard quite distinct from it." The sounds are unknown elsewhere along these shores. (R2, R7)

"I am glad to see that the vexed question of the noise heard from under the sea in various parts of the Atlantic and Pacific has been re-opened by a gentleman so accurate and so little disposed to credulity as Mr. Dennehy. The fact that this noise has been heard at Grey Town only on board the iron steamers, not on board the wooden ones, is striking. Doubtless if any musical vibration was communicated from the water below, such vibration would be passed on more freely to an iron ship than to a wooden one. But I can bring instances of a noise which seems identical with that heard at Grey Town being heard not only on board wooden ships, but from the shore. I myself heard it from the shore, in the island of Monos, in the Northern Bocas of Trinidad. I heard it first about midnight, and then again in the morning about sunrise. In both cases the sea was calm. It was not to be explained by wind, surf or caves. The different descriptions of the Grey Town noise which Mr. Dennehy gives, will each and all of them suit it tolerably. I likened it to a locomotive in the distance rattling as it blows off its steam. The natives told me that the noise was made by a fish, and a specimen of the fish was given me, which is not Centriscus scolopax, the snipe-fish, but the trumpet-fish, or Fistularia. I no more believe that it can make the noise than Mr. Dennehy believes (and he is quite right) that the Centriscus can make it. This noise is said to be frequently heard at the Bocas, and at Point á Pierre, some twenty-five miles south; also outside the Gulf along the Spanish main as far as Barcelona. It was heard at Chagreasancas (just inside the Bocas) by M. Joseph, author of a clever little account of Trinidad, on board a schooner which was, of course, a wooden one, at anchor. "Immediately under the vessel,' he says, 'I heard a deep and not unpleasing sound, similar to those one might imagine to proceed from a thousand Aeolian harps; this ceased, and deep and varying notes succeeded; these gradually swelled into an uninterrupted stream of singular sounds, like the booming of a number of Chinese gongs under water; to these sounds succeeded notes that had a faint resemblance to a wild chorus of a hundred human voices singing out of time in deep bass.'" (R3)

X3. Frequent occurrence. Shores of the Indian Ocean. "One moonlit night in 1854, on board a steamer anchored near the Tavoy river (Tenasserim) we were struck by an extraordinary noise which appeared to proceed from the shore about a quarter of a mile off, or from the water in that direction. It was something like the sound of a stocking loom, but shriller, and lasted perhaps five or six seconds, producing a sensible concussion on the ear like the piercing scream of the cicada; and this gave an impression as if the vessel itself were trembling, or reverberating from the sound. One or two Burmans on board said simply, the noise was produced by 'fishes,' but of what kind they did not describe. It was repeated two or three times. I never heard it before or after the occasion referred to, nor have I ever met with any allusion to this singular phenomenon...." (R4, R5)

"In the harbor of Bombay there is a fish, resembling the ordinary perch, which makes long drawn musical notes like the dying cadence of an aeolian harp; and in Ceylon two mollusks are found, called 'creeping shells,' which evolve similar sounds." (R6)

"Lieutenant White, of our Navy, relates that, when at the mouth of a river in Cambodia in 1824, he and the crew of his vessel were struck by hearing extraordinary sounds, like a mixture of the bass of an organ, the ringing of bells, the gutteral cries of a large frog, and the tones of an enormous harp, which they heard around the bottom of their vessel. The interpreter said they were produced by a troop of a kind of fish." (R7)

X4. Frequent occurrence. Coast of Chile. Sounds like those heard off the coast of India and at Grey Town, Nicaragua, are also observed along the coast of Chile. (R4)

X5. Frequent occurrence. Southern coast of France. Sounds like those around the Pascagoula River, Mississippi (X1). (R8)

X6. Frequent occurrence. East Indian Waters, South Pacific Ocean. "On the roads of Sourabaya in Java, he (Capt. P. Jansen) says, two or three noises, as of foghorns of different notes, were heard at irregular intervals of a few seconds, each lasting for one or two seconds. In the hold of an empty ship, the noise was deafening. After continuing for one or two hours, the noises ceased as suddenly as they began. Capt. Jansen has heard the same noises, but less frequently, at the mouth of the Palembang River in Sumatra. At the mouths of some of the rivers of the Malay Peninsula, other noises were heard, like that of plucking the strings of musical instruments, all on the same note and at irregular intervals." (R10, R11)

X7. Frequent occurrence. Atlantic and Pacific oceans. "A certain type of high-level, pulsed, underwater noise has been observed over extended areas of the Atlantic and Pacific oceans. The power spectral distribution for a single pulse, which typically lasts about one second, is strongly peaked, with energy being confined to a narrow band centered in the vicinity of 20 cps. The pulses normally occur in trains, or groups, characterized by remarkably regular repetition rates. A common rate is one pulse approximately every 10 seconds, although others are observed. A typical pulse train is several minutes long; separated by silent periods of two to three minutes it often repeats for many hours. On the continental shelf south of New England scores of sources of this noise have been pinpointed by remote acoustic ranging and found to move. Speeds are typically a few knots; sound level is so high that the sources are audible many tens of miles away. Source densities of one per several hundred square miles are common. Movements are random, suggesting something biological; low areal density and high sound level suggest something large. Characteristics possibly correlated with the sounding cycles of whales are apparent; a certain correspondence is noted between pulse rates and the timing, reported recently, on the electrocardiogram of a finback whale." (R12) This type of oceanic music, as suggested above, is likely due to whales; but since it is labelled "unidentified" it is included here. Whale "songs" are incredibly complex and long-sustained. See BM for more on this subject. (WRC)

References

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R3. Kingsley, C.; "Strange Noises Heard

at Sea off Grey Town," Nature, 2:46, 1870. (X2)
R4. Evans, F.J.; "Strange Noises Heard at Sea off Grey Town," Nature, 2:46, 1870. (X3, X4)
R5. Oliver, S.P.; "Noises at Sea off Grey Town," Nature, 4:26, 1871. (X3)
R6. "Finny Musicians," Scientific American, 32:102, 1875. (X3)
R7. "Musical Fishes," Popular Science Monthly, 23:571, 1883. (X2, X3)
R8. Chidsey, Charles E.; "The Mysterious Music of Pascagoula," Popular Science Monthly, 36:791, 1890. (X1, X5)
R9. Meigs, William M.;'The Mysterious Music of Pascagoula," Popular Science Monthly, 37:410, 1890. (X1)
R10. "Earth-Sounds in the East Indies," Nature, 134:769, 1934. (X6)
R11. "Sounds Made by Fishes in the East Indies," Nature, 135:426, 1935. (X6)
R12. Walker, R.A.; "Some Low-Frequency, High-Amplitude Underwater Noise Pulses of Wide Geographic Distribution, Apparently of Biological Origin," American Geophysical Union, Transactions, 44:59, 1963. (X7)

GSM2 Subterranean Organ-Like and Horn-Like Sounds

Description. Organ-like and horn-like sounds heard on land and apparently issuing from rock and ice formations or the ground itself.

Data Evaluation. Reports are very scarce, except for the oft-repeated observation of von Humboldt on the banks of the Orinoco. Further, the reports are generally of rather poor quality. Rating: 3.

Anomaly Evaluation. Since these sound sources remain unidentified, it is difficult to estimate the anomalousness of this phenomenon. The availability of several reasonable explanations suggests that a low rating is merited. Rating: 3.

Possible Explanation. Microseisms, fracturing ice, musical sand (ER), gases erupting from the earth as in weather wells (GHG2), natural melody (GSM3), anomalous hums (GSH5).

Similar and Related Phenomena. Musical sand (ER), vibrations of polar ice sheets (GQV3), natural melody (GSM3).

Examples of Strange Subterranean Sounds

X1. Frequent occurrence. "M. Humboldt was informed by the most credible witnesses, that subterraneous sounds, like those of an organ, are heard towards sunrise, by those who sleep upon the granite rocks on the banks of the Oroonoko (sic). He supposes them to arise from the difference of temperature between the external air and the air in the narrow and deep crevices of the shelves of rocks. During the day, these crevices are heated to 48° or 50°. The temperature of their surface was often 39°, when that of the air was only 28°. Now, as this difference of temperature will be a maximum about sunrise, the current of air issuing from the crevices will produce sounds which may be modified by its impulse against the elastic films of mica that may project into the crevices." (R1-R6)

X2. Occasional occurrence. Greenland. "During the month of August 1932, when setting up the French Expedition of the International Polar Year in Scoresby Sound, on the East Greenland coast, some of my colleagues and I heard four times the mysterious sound called by the late A. Wegener the 'Ton der Dove-Bai'. The sound was heard in the morning, generally at 11 a.m. (G.M.T.), and also during the afternoon. It was a powerful and deep musical note coming far from the south, lasting a few seconds. It resembled the roaring of a foghorn. After that it was not heard during the course of the Polar Year. A. Wegener and five of his companions heard it eight times in five different neighboring places, both during the day and the polar night. It lasted sometimes a few minutes and Wegener ascribed it to the movements of inland ice. In fact, it seemed, in Scoresby Sound, to come from beyond Cape Brewster, precisely from the part of the coast where the inland ice flows into the sea from the large glaciers. Is this vibrating sound really caused by the detachment of icebergs or is it it similar to the 'desert song', that strange musical note produced by the sand? In fact, there is a close analogy between the fields of powdery dry snow of the inland ice and the fields of sand of the Arabian Desert." (R7) See GSH6 for the "desert song."

X3. Occasional occurrence. Swedish Lapland. Summer. "Both I and my friend believed we heard music one night which I thought sounded like an organ, but, as we were at least 50 km from the nearest church, it is unlikely that we could have been hearing a distant service. There was the usual unwelcome hum from misquitoes, wind blowing the guy ropes, and a distant waterfall which may have been partly responsible. My friend also heard atmospheric musical sounds at the time of another visit to Lapland when there were no misquitoes. Neither of us can give a satisfactory explanation." (R8)

References

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R2. "On Peculiar Noises Occasionally Heard in Particular Districts.....," Edinburgh New Philosophical Journal, 8:258, 1830.
R3. "On the Subterranean Sounds Heard at Nakous, on the Red Sea," Franklin Institute, Journal, 3:257, 1827. (X1)
R4. Rosenfeld, Georg; "Singing and Speaking Stones," Scientific American Supplement, 66:395, 1908. (X1)
R5. "Mysterious Sounds," Eclectic Magazine, 23:740, 1875. (X1)
R6. Springer, Robert; "The Mysterious Sounds of Nature," Popular Science Monthly, 17:772, 1880. (X1)
R7. Dauvillier, A.; "Strange Sounds from Inland Ice, Greenland," Nature, 133:836, 1934. (X2)
R8. Tyssen-Gee, R.A.; "Atmospheric Music," Journal of Meteorology, U.K., 2:373, 1977. (X3)

GSM3 Natural Melody

Description. The production of musical notes and combinations thereof by the action of wind upon passive natural and artificial structures.

Background. It is difficult to separate some of the music-makers in this category from musical echos or analyzed sound (GSE2). The initial sounds may be nonmusical in the case of analyzed sound, but small reflecting surfaces nearby quickly convert it into more pleasing tones.

Data Evaluation. The scientific literature is all but silent on this phenomenon. Most of the data are travellers' tales. Rating: 3.

Anomaly Evaluation. It is probably only fortuitous that nature has arranged natural wind intruments for us. If the phenomenon were more common, we might legitimately look for deeper meanings. Rating: 3.

Possible Explanations. Natural and artificial structures behave like wind instruments.

Similar and Related Phenomena. Musical echos or analyzed sound (GSE2). Also GSM2.

Examples of Natural Melody

X1. Permanent feature. Aegean Sea. "Pausanias speaks of the tuneful waves of the Aegean Sea; Professor Bruder has perceived the chord of the third of C sharp in them." (R1)

X2. Permanent feature. Black Forest, Germany. "Some soldiers, encamped in a valley in the Black Forest toward the end of the seventeenth century, heard charming sounds in the tops of the fir-trees, accompanied by the rustling of the wind as it blew through the narrow valley." (R1) This account resembles somewhat those of "singing valleys" (GSE2).

X3. Permanent feature. Haute Saone, France. A sound similar to that of X2 can be observed in a wood near Cithas. (R1)

X4. Permanent feature. Island of Bourbon. "The filao, a tree of the island of Bourbon, emits soft, melancholy tones when its slender boughs are shaken by the wind. An avenue of such trees is the source of wonderfully touching harmonies." (R1)

X5. Permanent feature. Island of Sylt. "The reeds and rushes of the island of Sylt, with their supple stems and interlaced roots, give forth, whenever the lightest wind is blowing, tones which are at times like whispers, like a subdued singing, or like a loud whistle." (R1)

X6. Permanent feature. Hungarian steppes. The wind blowing on the innumerable thistles produces a mournful sound akin to that of X5. (R1)

X7. Permanent feature. Roderbacherthal, Germany. "M. Renlaux reports a singular instance of the production of sound by natural causes. During a hunt upon the Roderbacherthal he passed through a valley, broad upon the eastern side, but narrowing rapidly towards the west, so as to form a kind of defile. The wind was blowing from the southwest, and the observer was marching upon the eastern declivity, when he seemed to hear repeated strokes of a fine, deep-toned bell. There was no bell in the neighborhood, and other sounds which he heard soon proved that the phenomenon was meteorological. The sounds increased in intensity, and then diminished after having passed through a maximum. They resembled at times those of an organ, and at other times those of a harp or violin. At the entrance of the defile, from which the sounds seemed to come, there arose a strange agitation of the air, when the sounds became confused, and some of the notes suddenly ceased. M. Rendaux supposes that currents of air were forced through the gorges, and that the sound was due to a conflict between the exterior and interior air, which produced musical vibrations. There was a very marked difference of temperature between the upper and lower portions of the valley, so that the upper cold current pressed upon the lower and warmer air, thus closing the gorge so as to make a kind of tube." (R2)

X8. Occasional occurrence. South Tottenham, England. A heavy morning thunderstorm. "During the storm I noticed that two of the peals began with a musical note of distinct and definite pitch. The 'musical' portion of the peal lasted for about two seconds in each case, and the frequency of the note was both times about 400 per second. This sound closely resembled a foot-fall in a narrow alley between high walls, and was only heard in two consecutive peals, separated by an interval of about a minute, the first being much more definitely musical than the second. In each case the interval between the flash and the first sound of thunder was about five seconds." (R3) This could well be an instance of musical echos (GSE2). (WRC)

X9. Permanent features. The Pyrenees, Spain. "Sounds of a very different character and origin are emitted by certain rocky cliffs in the Harz Mountains and in the Pyrenees. Two precipitous cliffs in the Harz, near Schierke, are called 'The Snorers,' from the peculiar sounds which the southwest wind draws from them. The faces of these cliffs are marked by deep gullies, which roughly resemble organ pipes open in front, and occasionally the front is practically closed by a stratum of air held motionless between the cliff and the trees which graze it, while the wind blows freely through the gullies, or organ pipes, behind. Similar phenomena, due probably to a similar cause, are observed on Mt. Maladetta, in the Pyrenees, where at sunrise certain cliffs emit plaintive sounds, which resemble those of a harp, and are known locally as 'the matins of the damned.' (R4)

X10. October 8, 1932. Angmering-on-Sea, England. "On the evening of October 8, I was at Angmering-on-Sea, and my host, Mr. Kenneth Barnes, called me to listen to the wind playing, and took me to the bathroom, which faced down wind. The wind was blowing hard and gustily, and was producing an amazing effect---exactly as though a flageolet were being played by a human performer. The melody was in E, major, with A-sharp substituted for A-flat, and it ranged over five semitones, of approximate frequency 1290, 1448, 1625, 1824, 1932. The melody did not slur up and down, as when the wind whistles through a cranny, but changed by sharply defined steps from note to note. The melody included runs, slow-trills, turns and grace notes, and sounded so artificial that I felt bound to open the window and make sure that the tune was not being played by a human performer out of doors. The sounds were traced to the overflow pipe of the bath, through which the air was rushing in at the rosette (of six holes, each 9 mm. diameter, set in a circle) covering the inner end of the pipe where it joined the bath." (R5)

X11. Permanent feature. Harz Mountains, Germany. Two musical cliffs called 'The Snorers.' See description in X9. (R4)

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R1. Springer, Robert; "The Mysterious Sounds of Nature," Popular Science Monthly, 17:772, 1880. (X1-X6)

R2. "Curious Acoustic Phenomenon," Franklin Institute, Journal, 113:232, 1882. (X7)

R3. Martyn, G. H.; "Musical Thunder," Nature, 74:200, 1906. (X8)

R4. Rosenfeld, Georg; "Singing and Speaking Stones," Scientific American Supplement, 66:395, 1908. (X9, X11)

R5. Paget, R. A. S.; "Natural Melody," Nature, 130:701, 1932. (X10)

GSW UNUSUAL BAROMETRIC DISTURBANCES

Key to Phenomena

GSW0 Introduction

Atmospheric pressure waves, like water waves, are set into motion by various energy releasing phenomena of both transient and continuous characters. Potential transient sources include earthquakes, volcanos, exploding meteors, and, of course, man-made detonations. More-long-lived sources are weather phenomena, especially steady winds blowing across topographical features. This list of potential sources is, in fact, almost the same as the list of infrasound generators (GSI). The phenomena do overlap in frequency, with the pressure waves possessing longer wavelengths, corresponding to periods of minutes and even hours. Both atmospheric pressure waves and infrasound travel immense distances with little attenuation. The Krakatoa pressure waves, for example, circled the globe several times. The instrumentation is similar, too, being microbarographs in most instances.

GSW1 Unidentified Air Waves

Description. Unidentified, wave-like variations in atmospheric pressure. The pressure waves may consist of merely a small train of several waves, typical of a transient event, or they may be a regular diurnal feature of the environment. Excluded here are such pressure waves as sonic booms and similar well-known phenomena.

Data Evaluation. Only two observations of pressure waves have been found which have no obvious explanations. The data, however, are from scientifically monitored recording microbarographs and are of good quality. Rating: 1.

Anomaly Evaluation. Long-wavelength pressure waves, like infrasound, travel thousands of miles with little attenuation. Since there is always a substantial worldwide background of natural and artificial detonations and energetic weather events, there is always a good probability that currently "unidentified" air waves will ultimately be associated with some recognized source. Rating: 3.

Possible Explanations. Artificial and natural explosions (bombs, cannon-fire, volcanos, detonating meteors, etc.); meteorological sources, such as winds blowing across mountain ridges.

Similar and Related Phenomena. Infrasound (GSI), audible detonations of mysterious origins (GSD), earthquake and meteor pressure waves (GSW2, GSW3).

Examples of Unidentified Air Waves

X1. May 29, 1934. Nottingham, England. "During May last, there were three occasions when firing in West Bay near Portland was anticipated and microphones were in operation at the recording stations. On the last occasion, May 29, the firing which was arranged to take place between 10 and 10.30 B.S.T. had been postponed for several hours but this was not known to the operators. No air waves were recorded at any of the stations except Nottingham, but there, in an interval of less than two minutes, from 10.59.35 to 11.1.19 B.S.T. nine distinct air waves were recorded. The spacing of these was rather irregular and there was a decrease in intensity from the first to the last.... There are three microphones at Nottingham, so that, from estimates of the intervals, between the receptions of waves, the bearing of the source of the waves and the inclination of the trajectory to the horizon can be determined. In this case the bearing of the source was 36° west of south, and the angle of descent was 51°. Such a large angle of descent has never been recorded before and therefore the identification of the source is much to be desired." (R1)

X2. Frequent occurrence. Brisbane, Australia. "Summary. Continuous and very regular pressure oscillations with periods ranging from 15 to 120 sec and having magnitudes of 1 to 6 μbar were observed on clear and calm nights at two of the three microbarograph stations near Brisbane, Australia. Their dependence on the topography and the stability of the lower atmosphere resembles that for lee waves behind ridges." (R2)

References

R1. Browning, H. Mary, and Whipple, F. J. W.; "Air Waves of Unknown Origin," Nature, 134:532, 1934. (X1)

R2. Shrestha, K. L.; "Continuous Regular Pressure Oscillations in the Atmosphere at Night," Royal Meteorological Society, Quarterly Journal, 93:254, 1967. (X2)

GSW2 Earthquake-Generated Air Waves

Description. Very-long-wavelength pressure waves correlated with specific earthquakes. The periods of such waves may be several minutes.

Data Evaluation. So far, the literature has yielded only one example of an earthquake-generated pressure wave. Rating is therefore difficult. The observation, however, was from an array of recording instruments and seems reliable. Rating: 2.

Anomaly Evaluation. The scientific issue here seems to be whether large areas of the earth's surface really do vibrate like a drum to generate long-period air waves of sufficent magnitude to be detected thousands of miles away. The phenomenon is really more unexpected than anomalous. Rating: 3.

Possible Explanations. Drum-like crustal vibrations.

Similar and Related Phenomena. Upthrow of objects during quakes (GQH1), ionospheric disturbances associated with earthquakes (GE), unexplained detonations (GSD), rushing sounds and wind gusts connected with quakes (GSH1 and GSH4), pressure waves correlated with meteors (GSW3), infrasound (GSI).

Examples of Earthquake-Generated Air Waves

X1. March 28, 1964. Berkeley, California. "Exceptional atmospheric waves, resembling those from large nuclear explosions, have been recorded at Berkeley after the Alaskan earthquake of March 28, 1964. This severe earthquake occurred 3,130 km away from Berkeley near the head of Prince William Sound. A preliminary determination made by the U.S. Coast and Geodetic Survey gives an origin time of 03 h 36 min 13 sec G.M.T.; the geographic latitude and longitude are 64.05° N., 147.50° W. Displacements of the adjacent sea-bed generated a damaging tsunami which was observed at numerous places around the Pacific. Changes in sea-level indicate that the mainland in the disturbed region along the coast rose about 7 ft., while a portion of Kodiak Island subsided by about 5 ft.... In addition to the seismic waves recorded by pendulum seismographs, two distinct wave trains were recorded by a microbarograph in the seismic vault. The instrument is a Davies Marion barovariograph designed to respond to pressure fluctuations with periods down to 10 sec.....The microbarograph commenced to respond to short-period pressure variations 14 min after the earthquake. The onset of this wave train is a sharp compression which corresponds to a pressure variation of 0.021 millibars; the first variations have periods near 1 min. The arrival time corresponds closely to the arrival of the large amplitude part of the seismic surface-wave train. These air-pressure fluctuations are evidently coupled to the Rayleigh waves, which had a frequency spectrum rich in harmonics with periods of 10 sec-2 min.....The most interesting feature on the barogram is a large pressure pulse which arrives as a compression with an emersio onset of about 2 h 30 min after the earthquake..... The pressure pulse may be explained as a seismic air wave which was generated by sudden vertical displacement or tilting of the Earth's surface near the epicentre of the earthquake." (R1)

References

R1. Bolt, Bruce A.; "Seismic Air Waves from the Great 1964 Alaskan Earthquake," Nature, 202:1095, 1964. (X1)

GSW3 Meteor-Generated Air Waves

Description. Very-long-wavelength air waves correlated with specific meteors and other major geophysical events.

Data Evaluation. Excellent pressure-wave data exist for the 1883 Krakatoa and 1908 Tunguska events. Rating: 1.

Anomaly Evaluation. In contrast to the pressure waves correlated with great earthquakes (GSW2), there is no question here as to the generating mechanism; nor is there argument over how the pressure waves are created. This category is added primarily for historical interest and curiosity value. Rating: 4.

Possible Explanations. Meteor detonations and other violent geophysical events.

Similar and Related Phenomena. Infrasound (GSI), audible detonations (GSD), other pressure-wave phenomena (GSW).

Examples of Meteor-Generated Air Waves

X1. August 26-27, 1883. England. "Nearly twenty-five years ago, towards the close of August, 1883, the Javan island of Krakatoa was rent asunder by a terrific explosion, and one-half of the island disappeared in the sea. Such was the violence of the outburst that both the air and the sea all round the earth were affected. The aerial waves set up swept across the continents, and were recorded by the self-registering barometers, so that the late Sir Richard Strachey was able to trace the whole wave movement round and round the globe." (R1)

X2. June 30, 1908. England. "The abnormal barometrical changes last Sunday have attracted the notice of many meteorologists. During the forenoon and first part of the afternoon there was a very slight decrease of pressure connected with the shallow cyclonic depression lying over the country. At three o'clock there was a sudden, though slight, dip, amounting to 0.01 in (the one-hundredth part of an inch of mercury, then a rise of 0.02 inby half-past three. In the next half hour there was a very rapid fall of 0.05 in, followed immediately by a bound up of 0.04 in. in a quarter of an hour, and a slower rise of 0.02 in. in three quarters of an hour, up to five o'clock. Then came the most remarkable change of the day, a drop of 0.1 in. (one tenth of an inch) in half an hour, and this was succeeded by a brisk ascent of 0.04 in. in the next half hour, up to six o'clock, when on the stroke of the hour the curious movement suddenly ceased, and the barometer became stationary." These data were followed by a recounting of the Krakatoa air-wave phenomena (X1) and concern that some great natural disaster had occurred somewhere on the globe. (R1) Later analyses of several sets of English barograph data for June 30 showed similar disturbances. The cause, of course, was the Tunguska event or Siberian Meteor, a phenomenon not fully appreciated until years after the 1908 barometer disturbances. (R2, R3)

References

R1. English Mechanic, 87:551, 1908. (X1, X2)
R2. "The Siberian Meteor of June 30, 1908," Nature, 127:719, 1931. (X2)
R3. "The Siberian Meteor of June 30, 1908," Nature, 134:816, 1934. (X2)

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	Mar 22	GSH3-X34
	Nov 21	GSH3-X35
1842	Mar 16	GSH3-X36
	Apr 18	GQM1-X4
	Aut	GSH3-X37
1844	Oct 18	GQB1-X7
1845	Jan 19	GQM1-X5
1846	Win	GSH3-X38
1847	---	GHW1-X2
1848	May 13	GQH3-X1
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1854	Feb 24	GSH3-X46
1855	Nov 11	GQB1-X8
		GQM1-X6
1856	Nov	GSH3-X47
1859	Aug 28	GSH3-X48
1860	---	GSH3-X49
1861	Dec 26	GQM1-X7
1863	Dec 5	GSH2-X3
1865	Nov	GSH3-X50
1866	---	GSH3-X52
	Jan	GSH3-X51
1867	Jan 8	GQH2-X4
	Oct 29	GQM1-X8
1869	---	GQM1-X28
		GQS3-X11
1870	Sum	GSH3-X53
	Nov 24	GSH3-X54
1871	Jul 19	GSH2-X4
1875	Sep 14	GSH2-X5
1878	Jun 12	GQH3-X2
1880	---	GQB1-X9
		GSH2-X7
1881	---	GHW1-X3
1882	---	GHW1-X4
	Aug 15	GSH3-X55
	Nov 18	GSH3-X56
	Dec 12	GSH2-X8
1883	Mar 31	GHW1-X22
	Jul 30	GSD1-X2
	Jul 31	GSH3-X57
	Aug 26-27	GQG1-X1
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		GSW3-X1
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1885	Oct 9	GQW2-X19
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1886	Aug 31	GSH1-X2
	Nov 27	GHW1-X6
1887	---	GSH1-X3
		GSH2-X6
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		GQM1-X9
1888	Jan	GSH3-X60
1890	---	GHW1-X8
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1892	Jun	GHW1-X9
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	Win	GSH3-X65
		GSH3-X66
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		GQM1-X10
	GQW5-X9	
1898	Jan	GSH3-X67
	Win	GSH3-X68
		GSH3-X69
1899	Jan	GSH3-X70
	Jan 24	GQW5-X10
	Sep 25	GQW2-X20
1900	Jul 17	GSH2-X10
	Dec 7	GSH2-X11
1901	---	GSH3-X72
	Nov 16	GQM1-X11
	Dec 4	GSH2-X12
	Win	GSH3-X71
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	May 8	GQM1-X12
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	May 28	GQW2-X21
	Sep 15	GSH2-X14
1903	---	GSH3-X73
	Jun	GQV2-X2
1904	---	GSH3-X74
	Aug	GSH3-X75
1905	Jul	GSH3-X76
	Sep 8	GQM1-X14
1906	Apr 18	GQB1-X11
		GQM1-X15
	Aug 7	GSH2-X15
1907	Sep	GSH3-X77
	Oct 20	GQB1-X12
1908	Jan	GSH3-X78
	Jun 30	GSW3-X2
	Sep 10	GSH3-X79
	Dec	GQH1-X3
		GQM1-X16
	Win	GSH3-X80
1909	May 9	GSH2-X16
1910	Jul 3	GQB1-X13
1911	---	GSH3-X83
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