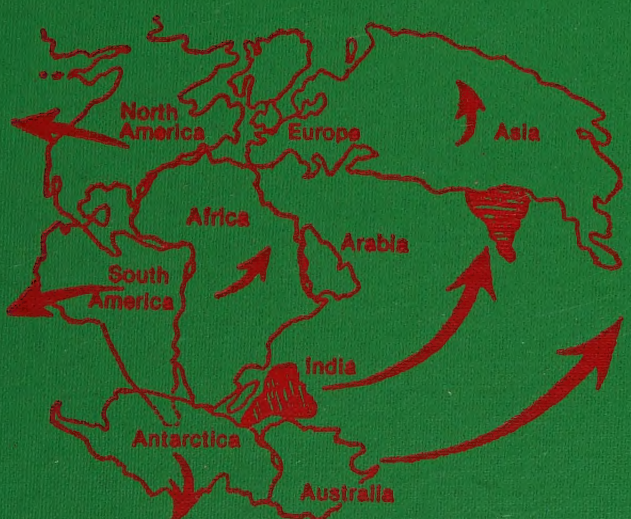
CAROLINA BAYS, MIMA MOUNDS, SUBMARINE CANYONS

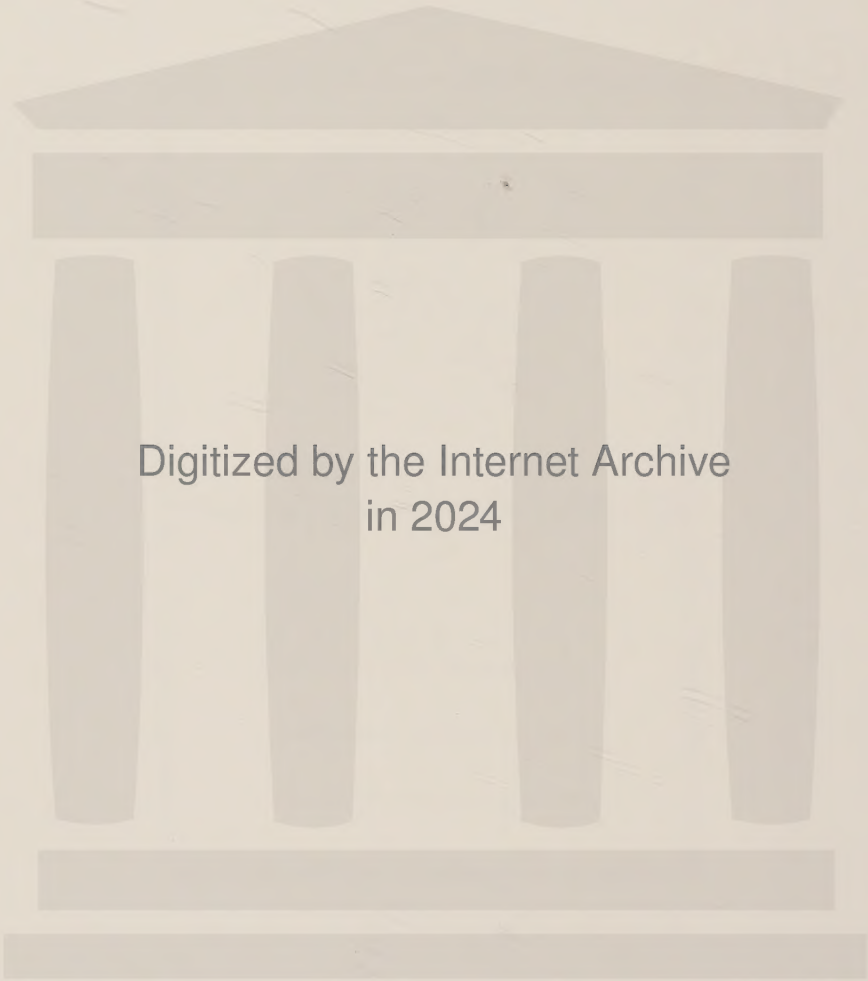
AND OTHER TOPOGRAPHICAL PHENOMENA

Compiled by:

William R. Corliss



A CATALOG OF GEOLOGICAL ANOMALIES



CAROLINA BAYS, MIMA MOUNDS, SUBMARINE CANYONS

AND OTHER TOPOGRAPHICAL PHENOMENA

A CATALOG OF GEOLOGICAL ANOMALIES

Compiled by:

William R. Corliss

Published and Distributed by

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

Library of Congress Catalog Number: 87-63408

ISBN 0-915554-22-4

First Printing: January 1988

Printed in the United States of America

TABLE OF CONTENTS

LIST OF PROJECT PUBLICATIONS

CATALOGS:

Carolina Bays, Mima Mounds, Submarine Canyons (category ET)

Stars, Galaxies, Cosmos (categories AO, AQ, AT, AW)

The Sun and Solar System Debris (categories AA, AB, AC, AE, AS, AX, AY, AZ)

The Moon and the Planets (categories AG, AH, AJ, AL, AM, AN, AP, AR, AU, AV)

Lightning, Auroras, Nocturnal Lights (category GL)

Tornados, Dark Days, Anomalous Precipitation (category GW)

Earthquakes, Tides, Unidentified Sounds (categories GH, GQ, GS)

Rare Halos, Mirages, Anomalous Rainbows (category GE)

HANDBOOKS:

The Unfathomed Mind: A Handbook of Unusual Mental Phenomena

Incredible Life: A Handbook of Biological Mysteries

Unknown Earth: A Handbook of Geological Enigmas

Mysterious Universe: A Handbook of Astronomical Anomalies

Ancient Man: A Handbook of Puzzling Artifacts

Handbook of Unusual Natural Phenomena

SOURCEBOOKS:

Strange Phenomena, vols. G1 and G2

Strange Artifacts, vols. M1 and M2

Strange Universe, vol. A1 and A2

Strange Planet, vols. E1 and E2

Strange Life, vol. B1

Strange Minds, vol. P1

NEWSLETTER:

Science Frontiers (current anomaly reports)

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

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

PREFACE

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

Under the aegis of the Sourcebook Project, I have already published 24 volumes, totalling well over 8,000 pages of source material on scientific anomalies. (See page iv for a list of titles.) As of this moment, these 24 volumes represent only about 30% of my data base. New material is being added at the rate of about 1,200 new items per year, about 500 of which are from the current literature. These rates could easily be multiplied several-fold simply by spending more time in libraries. Even after fifteen years, only the scientific journals of the United States and England have received my serious attention. There remain the English-language journals of the rest of the world, those journals in other languages, university theses, government reports, the publications of scientific research facilities, conference papers, untold thousands of books, and an absolutely immense reservoir of newspapers. The cataloging task has just begun. The anomalies residing in the world's literature seem infinite in number. Every library foray uncovers new anomalies.

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

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

William R. Corliss

P.O. Box 107
Glen Arm, MD 21057
January 1, 1988

"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 of more interesting ones in more detail. Finally, all examined references are listed. Thus, the Catalog is a descriptive guide as well as a compendium of examples and references. Scientific researchers have a substantial foundation for beginning further studies of these intriguing phenomena. This is the basic purpose of the Catalog: the collection and consolidation of the unknown and poorly explained to facilitate future research and explanation.

General Plan of the Catalog

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

Most catalogs boast numbering systems, and this one is no exception. Rather than employ a purely numerical system, the first three classification levels are designated by letters. The triplets of letters selected have some mnemonic value. Thus, an ETM anomaly is easily recognized as being in the geology class (E), involving topography (T), and concerning mound morphology (M). The number added to the triplet of letters marks the fourth classification level, so that ETM1 signifies mounds of the Mima-type, the first type of anomalous mound. Every anomaly type has such a unique alphanumeric code. All indexes and cross references are based on this system. Catalog additions and revisions are also made easier with this scheme.

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

A glance through this volume will reveal that each example of a specific anomaly bears an X-number, and each reference an R-number. ETM1-X2 therefore specifies the second example of Mima-type mounds; and ETM1-R4, the fourth reference to this phenomenon. Indexes and cross references can consequently be made very precise.

How Data and Anomalies Are Evaluated

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

Data Evaluation Scale

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

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

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

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

Anomaly Evaluation Scale

1 Anomaly cannot be explained by modifications of present laws. Revolutionary.

2 Can probably be explained through relatively minor modifications of present laws.

3 Can probably be explained using current theories. Primarily of curiosity value.

4 Well-explained. Included only for purposes of comparison and amplification.

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

Catalog Coding Scheme

First-order classification	Second-order classification	Third-order classification	Fourth-order classification
A Astronomy	C Geochemistry	B Small depressions	(1) Mima-type mounds
B Biology	G Gravimetry	C Craters, astroblemes	2 Gilgai mounds
C Chemistry & physics	Q Seismology	E Raised beaches, terraces	3 Mudlumps and mud islands
(E) Earth sciences	S Stratigraphy	H Guyots, plateaus	4 Drumlins
G Geophysics	(T) Topography	L Planet-scale features	⋮
L Logic & math	Z Magnetism	(M) Mounds, hills	
M Archeology		P Patterned ground	
P Psychology		R Ridges, eskers	
X Unclassified		S Crevicular structure	14 Beach pyramids
		V Valleys, seafloor channels	

Anomaly Examples

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

The References and Sources

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

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

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

The Indexes

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

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

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

All five indexes use the catalog codes described above rather than page numbers. The codes

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

Supporting Publications of the Sourcebook Project

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

Catalog Addenda and Revisions

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

Request for Additions and Corrections

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

ET INTRODUCTION TO TOPOGRAPHICAL PHENOMENA

Key to Categories

ETB BAYS, LAKES, SMALL DEPRESSIONS
ETC CRATERS, ASTROBLEMES, LARGE CIRCULAR STRUCTURES
ETE RAISED BEACHES, FOSSIL CORAL REEFS, INLAND TERRACES
ETH GUYOTS, PLATEAUS, UNUSUAL MOUNTAINS
ETL PLANET-SCALE TOPOGRAPHIC ANOMALIES
ETM MOUNDS AND HILLS
ETP PATTERNED GROUND, SOIL POLYGONS
ETR ANOMALOUS RIDGES, MEGARIPPLES, ESKERS
ETS CREVICULAR CRUSTAL STRUCTURE
ETV VALLEYS, CHANNELS, FURROWS

This Catalog volume, the first of four on geology, deals with topographical phenomena---from mountains to patterned ground to seafloor channels. The general approach employed in the Catalog of Anomalies is a form of categorization which avoids theoretical prejudices. When further classifying topographic anomalies, we use value-free morphology: depressions, mounds, ridges, valleys, etc.; common, every-day forms. Perhaps this approach is a bit simplistic, but it avoids classifications such as meteor craters and glacial moraines, which assume a particular mechanism of formation. All of the Catalog volumes use this somewhat unorthodox approach. It avoids, for a time at least, making classification judgments based upon hypotheses-of-the-moment.

Almost 70 types of geological anomalies are recognized in this volume. Many more have doubtless eluded our initial sweep through the literature. Experts will certainly disagree with some of our assertions of anomalousness. Reviewers of the already-published volumes often challenge the anomalousness of Catalog entries, and then go on to mention anomalies we have missed! Cataloging is always a risky business.

Geology is mainly the study of the consequences of events or processes of the distant past. Almost always in geology, the question is about origin. How were the Mima Mounds sculpted? How were the submarine canyons excavated? Was it fluvial erosion, turbidity currents, the impacts of meteors, or even industrious rodents? So it goes for more than three-score anomalies. Obviously, the science of geology will not be undermined if the Mima Mounds are the product of water erosion rather than pocket gophers. However, geologists would be greatly disturbed if several topographical anomalies (including, possibly, the Mima Mounds) pointed toward extreme, catastrophic marine flooding of the continents, due perhaps to a large meteor impact in an ocean. In the long run, the purpose of the Catalog of Anomalies is the challenging of major geological dogmas, such as the now-ascendant hypothesis of plate tectonics, the Ice Ages scenario, and the belief that ocean levels and volumes never changed much over the geological eons. But, as usual, we moderate such heavy fare with stone polygons, walled lakes, blue holes, and sundry curiosities.

ETB BAYS, LAKES, SMALL DEPRESSIONS

Key to Phenomena

ETB0 Introduction

Aerial views of the Carolina Bays and the Alaskan oriented lakes will impress the most blasé observer. Certainly, these topographical features must be one of Nature's grandest spectacles. It is not just their sheer abundance---about a half million Carolina Bays from Florida to New England---but their common orientation. Some directional force must have been at work over an immense area. Were these groups of depressions excavated in a single night by clouds of meteorites, or are they the patient work of wind and water?

Rivaling the Carolina Bays in number, but "seen" only by sonar are the shallow pockmarks strewn across the North Sea floor, the Bering Shelf, and the bottoms of other shallow seas. Here the question is: Are the pockmarks the consequences of natural gas venting, the feeding activities of whales, or some other unrecognized force?

The most accessible of the depressions covered in this section are undoubtedly the potholes, which are so familiar to hikers in those regions considered to have once been glaciated. Surely these holes are merely the work of rushing water aided by sand and gravel. Perhaps! But potholes are not the simple structures we automatically assume. It's not so much size, although some reach almost 100 feet in depth, but "incompatibilities" with theory. Some are not even vertical; many are wider at their bottoms; and whence the internal "fluting" on their walls?

We also catalog here some oddities that appeal to the popular imagination, but which still retain some unexplained characteristics: the "cookie-cutter" holes; the Devil's hoofprints, and "bottomless pits."

ETB1 Large Groups of Oriented Lakes and Shallow Depressions

Description. Large groups of shallow depressions, often water-filled, and largely oriented in common directions. Most assemblages of depressions are located on sandy, coastal plains and/or in regions once glaciated. Dimensions range from puddle-size to several miles across. The largest groups may contain hundreds of thousands of depressions.

Background. Whenever one thinks of oriented lakes, the famous Carolina Bays come to mind. These half million depressions or "bays" pockmarking the Atlantic coast stimulated much controversy during the middle of the century. Popular magazine articles related how a fierce rain of meteorites blasted out the bays. Of course, the meteoritic hypothesis was just one of many, but it appealed to the popular imagination. This publicity impelled scientists to look elsewhere for similar phenomena; and they found them. It is unlikely that all examples can be meteoritic in origin. Whatever the explanations, these large groups of depressions constitute one of nature's grandest spectacles---at least from the air.

Data Evaluation. Of the dozen examples cataloged here, only a few have been studied in any detail. It is also highly probable that more examples exist. Except for the Carolina Bays and the Alaskan oriented lakes, data remain very sketchy. Rating: 2.

Anomaly Evaluation. Over a score of geological processes have been proposed to account for the assemblages of oriented depressions. Even the most sensational of these---meteoritic bombardment---challenges no geological dogmas. There is no general consensus as to which geological processes explain which groups of lakes and depressions, but such a situation does not constitute a serious anomaly. Rating: 3.

Possible Explanations. Meteoritic bombardment, although this mechanism is weakened by the widespread occurrence of phenomena similar to the Carolina Bays. Other processes include: wind scouring (deflation); water erosion, spring sapping, collapse due to solution, the venting of natural gases, shoaling fish.

Similar and Related Phenomena. Gas-vent and gas-explosion craters (ETB3); gilgaies (ETB4); sink holes and collapse phenomena; bona fide meteor craters (ETC1).

Examples

X1. The Carolina Bays. "It is surprising to discover on the gentle terrain of the Atlantic Coastal Plain, with no concealing cover or topography, one of the earth's most immense, spectacular, and intriguing topographical phenomena. Seen from the air, the Carolina bays are an astounding, unforgettable revelation. But though hundreds of thousands lie clearly visible, scattered across the Atlantic Coastal Plain from Maryland into Northern Florida, they are often all but unrecognizable to the uninitiated eyes of groundlings." (R51) This quotation is from the first chapter of a modern history of the Carolina Bays. It conveys the geographical scope as well immense number of these enigmatic structures. The detailed facts about the Carolina Bays, obtained over a century of study, are not any less fascinating.

1895. Early observations of the Bays. "Having noted on a surveyor's map of my school district of Darlington, S.C., several lake-like expanses usually represented as being at the head of some very small stream, I began inquiries concerning them and followed this up by visiting several of the largest.

Parenthetically, I may say that Darlington is well out on the loose sands and clays of the coastal plain, and while the main streams have cut down 30 to 40 feet beneath the general level of the country, yet their streamlets are small, and much of the interstream surface is poorly dissected and but slightly changed from the condition in which it was uplifted from sea bottom. This interstream surface is very level, the slope being about one foot per mile; the streamlets are weak; and extensive systems of ditches are necessary to keep the upland drained for cultivation.

To the lake-like expanses the term 'bay' is usually applied, and by it is meant a perfectly flat, clayey area with a surface some two to four feet below the general level of the country and varying from a few acres to stretches a mile or two long and a half mile

A typical group of Carolina Bays. (X1)

or more in width; the smaller ones being much more numerous and having usually an area of 20 to 30 acres. They are in some cases approximately round in shape, though they are usually ovoid or elliptical, and are covered with vegetation-stained water from a few inches to a foot or two deep, according to the season. Growing in this water, where the 'bay' is uncleared, are cypress, juniper or black-gum trees with a moderately thick swamp undergrowth.

Except when overflowed in a rainy season, there is often in the smaller 'bays' no permanent drainage. In the larger ones a small streamlet usually rises. When cleared for cultivation, the first requisite is to dig a ditch to the nearest stream or main ditch sufficiently deep for thorough drainage.

A sand ridge borders each 'bay' on the east and southeast and sometimes extends fairly well round toward the south, but is never found, so far as I could ascertain, on the west or north. The size of this sand ridge varies with the size of the 'bay,' rising in some well-pronounced cases 5 or 6 feet above the general level in the highest part and thinning out near both ends. In the usual case, however, it rises only some 2 or 3 feet above the general surface level. The width of the ridge varies from a rod to three or four rods. The transverse surface curvature is most often uniform, or if more precipitous on one side than the other no law could be found governing such variation.

A gentleman owning large tracts of land containing 'bays,' and having been a close observer of them, gave me much information and went a number of times to visit them with me. He called my attention to the fact that on first attempting to drain them for cultivation he had tried cutting ditches through this sand ridge, but found that the sand caved so easily (being, in a few cases, very quick) that it was very difficult to dig and keep such ditches open. The sand I thus found extended down below the surface of the adjacent sands and clays. How deep I could not find by direct test, probably not deeper at farthest than 15 to 25 feet, if nearly as deep as that, which I doubt. It is a rounded sand and, though used in Darlington for mortar, is very poor for building purposes. No fossils could be found in it so far as I searched. No stratification was visible. It is agriculturally very poor, and from its characteristic whiteness may be detected in a field that has been tilled for years. It seems to be a beach sand." (R2)

A 1952 summary of bay features by a proponent of the meteorite-origin theory. The following 38 observations, although perhaps tedious reading to a non-geologist, demonstrate the intensive research invested in attempting to explain the bay phenomenon.

"(1) Bays are geographically restricted to the coastal plain area between southern New Jersey and northeastern Florida, with most of the bays in the two Carolinas and northeastern Georgia.

(2) Bays are very irregular in their distribution and size.

(3) Bays have no relationship to geological formations, geological age (older or younger terraces), or topography. Some bays are on interstream flatlands, others on valley slopes or older stream terraces, and a few on the older portion of the present flood plain of streams.

(4) Toward the northeast and southwest extremities of their occurrence, the bay groups are less numerous and smaller, but as variable in their distribution and size as they are near the center of the area.

(5) No bays have been found outside of the sand-covered coastal plain or its erosional remnants, and none should be expected there according to the air-shock wave meteoritic theory. Large rimmed depressions would not have been formed as readily in the clay soil of the Piedmont as in the sandy Coastal Plain and such rimmed depressions in clay soil would be more readily destroyed by both erosion and sedimentation. On the other hand, buried meteorites would be better preserved in the clay soil than in the previous, sandy soil. The area to the northwest of the known bay country has yielded more meteorites than any other equal area of the United States.

(6) An estimate of the probable number of bays, large and small, in the Atlantic Coastal Plain Area is about half a million.

(7) The direction of elongation of the bays is controlled, seemingly, by a force which varies slightly and more or less regularly between the two extremities (northeast-south southwest) of the occurrence area.

(8) An area of unusually large bays and elliptical lake basins, which includes parts of Cumberland and Bladen counties, North Carolina, is elongated in a direction about parallel to the direction of elongation of the individual bays. This pattern is repeated elsewhere.

(9) Bays have sand rims which stand above the general level of the land and are best developed generally at the southeast end of the bay, especially the eastern portion of the southeastern end. The poorest development, as a rule, is along the west and northwest sides, although even there some bays have fairly well developed rims.

(10) Rimmed depressions of similar ellipticity can readily be formed by the air-shock waves created by a rifle bullet shot at an angle into a light powder, such as plaster of paris powder, resting on plastic clay. The rimmed shock-wave depression made in the powder is many times the diameter of the hole made in the plastic clay by the projectile. The ellipticity of the depression depends upon the angle of penetration.

(11) The larger bays generally have larger rims, but local conditions modify the size. Rims are better developed where a bay is located in a high and dry sandy area rather then in a low and wet sandy area.

(12) The deepest part of the bay is usually toward the southeast end and a little west of the axial line.

(13) The similarity of development and the condition of preservation of bays in all parts of the 'bay country' seems to indicate that they are all of about the same age.

(14) Similarity of rock character, climate conditions, ground water, and topography seem to be as favorable for the formation of bays in bordering areas as in the areas of known occurrence.

(15) Elliptical sand-rimmed bays are not being formed anywhere in the world at the present time as far as known.

(16) There are no well developed bays or beach ridges for a distance of 7 miles northwest from Myrtle Beach, South Carolina. This area was either covered by the ocean at the time of the formation of the bays, or else the ocean returned to cover and destroy the bays formed in the area. In many low, near-coast areas, the bays have apparently been considerably effaced by by marine or lagoonal sedimentation and erosion.

(17) Most bays are associated with other bays of slightly different age. These associated bays frequently overlap. The overlapping younger bay completely obliterates that portion of the older bay overlapped. Occasionally a small bay is contained wholly within the area of the larger bay. The rim of the smaller bay usually rises above the level of the swamp or lake of the larger bay. Some unusually elongated or unusually broad bays are found to have been formed by a number

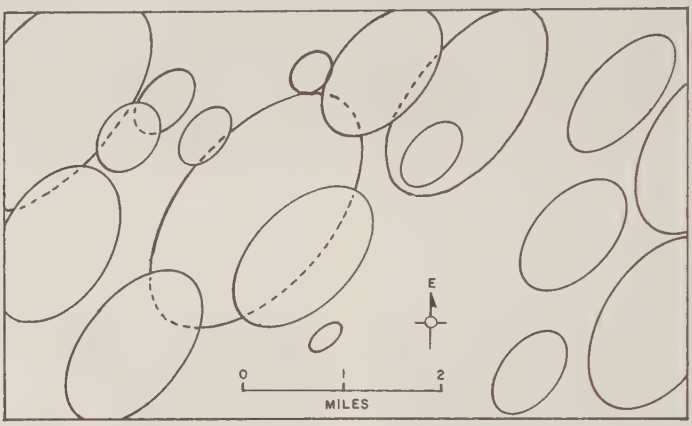
of associated and overlapping bays. The overlap direction or twin or multiple bays in North Carolina is generally more to the northwest than to the west, thus creating some unusually elongated multiple bays in that area. Toward the southwest in the South Carolina-Georgia area, such overlap direction is frequently more toward the west, so that the multiple bays in that area are broadened rather than lengthened. Some oval or heart-shaped bays appear to derive their shape from two or more overlapping bays which have a slight convergence of their long axial directions toward the southeast; in such cases, the bay unit on the west has the smaller azimuth (counter-clockwise rotation) of orientation.

the forces forming the larger and outer rims.

(19) In a number of cases, a later-formed bay has cut across earlier-formed outer and inner rims of a single bay, thus indicating that the two types of rims were closely associated in time of formation, if the meteoritic theory of origin is assumed.

(20) In soluble rock areas, many of the bays are being modified by solution and some can now be classified as sinks---'bay sinks.' Sand rims are being lowered in some regions by groundwater moving from the bay underneath the rim to a stream which is 'heading up' toward the bay and at a lower level than the water table in the bay.

(21) A very small proportion of bays drained by streams are drained from the



Concentration of bays in part of Bladen County, North Carolina. About 65% of this region is covered by bays, including overlap. Bays smaller than 1900 feet not shown. (X1)

(18) Many bays have more than one rim usually along the southeast and east sides. In some cases where rims are broad and high, these successive rims are the result of multiple bay formation. In these bays, each newer overlapping bay is formed slightly more to the west or, in other cases, to the northwest or north of its predecessor. In many cases of overlap, the only portion of the older bay not concealed by the overlap is a small crescent portion of one side. Where the inner rims are comparatively small and appear more or less symmetrically placed in respect to the plane of symmetry of the bay and with development limited to the southeastern two thirds of the bay, the origin of the rims may be associated with

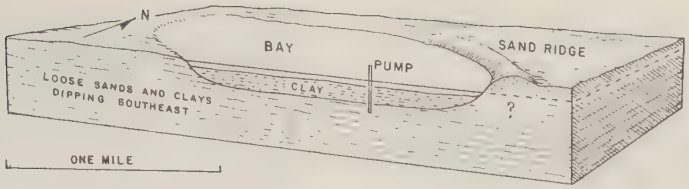
southeast end, but more often from the southwest, west, and northwest, or east sides, indicating drainage by normal headward erosion of tributary streams.

(22) Many bays have been partially filled by stream deltas, more often entering from the northwest, north, or northeast sides.

(23) Many bays have been partially filled by windblown sand from the southwest, west, and northwest. In such cases the sand is usually finer-textured than that of the average rim.

(24) Sand dune areas in many cases extend northeastwardly from the east and northeast sides of the bay.

(25) Samples taken from one medium-sized bay just beneath the thick peat depo-



Section through a typical Carolina Bay (X1)

sits show a gradation from medium-coarse sand near the sides of the bay to silt in the central portion of the bay.

(26) Near Myrtle Beach, South Carolina, the inland waterway cuts through the north-central portion of two small contiguous bays to a depth of about 25 feet. The two continuous shell beds found elsewhere along the canal are absent in the central portion of the section through each of these two bays. These shell beds must have been removed by either chemical or physical means. Nowhere else along the canal beneath the peat deposits, former swamp areas but not bays, have the shell beds been removed.

(27) In Bladen and bordering counties, North Carolina, where large bays and bay lakes are numerous, it is not unusual to find large areas with more than 50 per cent of the surface covered by bays, and in much of this area the bays will also have an overlap of 10-25 per cent or more.

(28) Practically every bay, large or small, surveyed by magnetometer has a well defined spot magnetic high or highs associated with it. If there is a single spot high, it usually occupies a position a little east of south from the southeast end of the bay at a distance about that of the short axis of the rim from the southeast end (the 'Prouty Rule,' so-called by Douglas Johnson, 1942). If there are two or more associated spot magnetic highs, the distance of each from the southeast end of the bay is considerably less than in the case of a single spot high. There is considerable variation in the direction of the spot highs from the bays as well as in the size of the spot highs in relation to the size of the associated bay. This variation seems logical from the variable conditions encountered.

(29) In some parts of the coastal plain area, linear magnetic highs are present. These usually trend in a northeast-southwest direction and tend to swell and diminish along the strike, making it difficult to entirely eliminate their effects from the spot high magnetic readings.

(30) Many of the bays have a slightly flattened elliptical border on the southwest side. In some cases this may be accounted for by eastward- or northeastward-drifting sand; in other cases, the reason is not clear but may have some connection with the development of the deeper part of the bay, which is toward the southeast end and to the west of the median line. Also, in multiple bays, the later-formed bay usually is responsible for the northwest portion of the bay rim and this later-formed unit of the multiple bay has a slight counter clockwise orientation from that of the earlier-formed unit of the bay responsible for the southern portion of the west rim. These conditions result in a somewhat flattened southwest rim.

(31) The rim sand of bays is in general a little coarser than the average sand of the area. This is to be expected according to almost every theory, including the meteoritic air-shock wave theory. The coarseness is emphasized by the down wash of the finer material or by the very important action of ants which live on the dry sand rims. In building their nests, the fine grains are left below and the coarse ones are brought to the surface; also wind tends to move the fine sand grains from the rim. If air-shock waves are responsible for the rim formation, one would expect the fine sand particles to be carried farther from the depression than the coarse particles.

(32) The sand in the rim shows little, if any, stratification. The formations beneath the rim appear to be undisturbed. There are no known deep sections across bays at the critical points (deepest area in the bay). A rumor of the presence of a 'pipe' of disturbed ground beneath bays has not so far been verified.

(33) Metallic iron, fragments of basement rock, or fused glass have not been found in association with any of the Carolina Bays. They should not be expected in view of the porous soil and climatic conditions.

(34) All bays were formed on the superficially sandy Pleistocene terraces of the

coastal plain and are younger than any of the well developed beach ridges with which they are associated, as shown by the fact that they cut across these ridges. An exception to this is found in some bays near the coast, where temporary marine flooding has both largely destroyed the sand rims and built faint beach ridges and swales across the bays.

(35) In a few places there is direct evidence that the sea has encroached upon some of these bays since their formation and has again withdrawn, as in Blythe Bay, Wilmington, North Carolina, where peat deposits in the bay have been covered by sediments of probable marine origin. Later elevation and stream erosion has cut through the sediments and into the peat.

(36) A few are known to have lake bottom springs. Most of these springs are near the southeast end of the bay.

(37) Bays are generally largely filled with peat which apparently has a maximum thickness of from 15 to 30 feet. The peat filling reaches an elevation a little below the general level of the surrounding area. This elevation is governed by the height of the water table.

(38) Bottom samples from the deeper part of some of the bays in Bladen County, North Carolina, taken from beneath the peat deposits, show a thickness of several feet of light-colored silt which, according to B.W. Wells is of wind blown character. The deposition of silt over the coarse bottom sand shows that the bays were formed suddenly and were soon filled with water, then followed sedimentation from a wind swept barren area." (R38)

Criticisms of the meteor theory. In the long debate over the origin of the Carolina Bays, long lists of objections to the meteorite theory have been published and, in turn, been refuted point by point. C. Grant, for example, listed 17 objections (R26); all of which were answered by W.F. Prouty (R32). Instead of examining this long list, it seems sufficient to concentrate on only five points made by B. Barringer (R24) and their refutations by W.F. Prouty (R25).

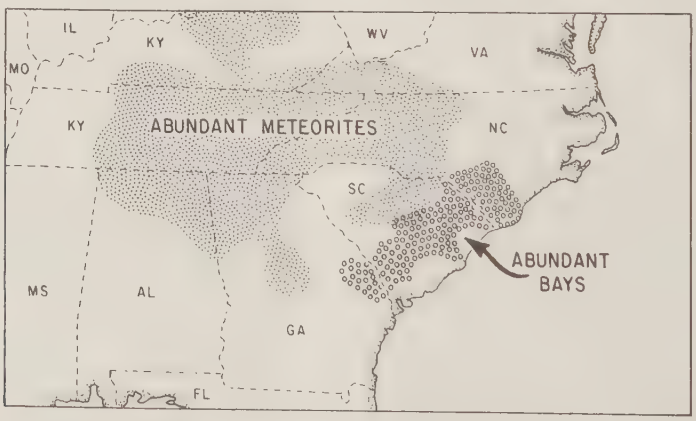
(1) No surface meteorites have been found directly associated with any of the bays. Response: any iron meteorites landing on the coastal plain 20,000 years ago (the assumed age of the bays) would have disintegrated long ago.

(2) The strata beneath the rims of the bays are undisturbed. Response: the bays were excavated by atmospheric shock waves which would not have disturbed the deeper strata.

(3) Small bays would have been filled in more readily in North Carolina than the big bays, as they were at Odessa, Texas. Response: the reverse is actually true!

(4) Aligned bays, such as those near Rains, South Carolina, seemingly would not be formed by a chance distribution of a swarm of meteoric masses. Response: bay alignments are actually not unusual; and they were formed by 'tandem' meteorites hitting the turning earth.

(5) The magnetic highs found at the southeast rims of some of the bays seem too low to be evidence for a meteoric origin. Response: the inconclusive magnetic highs recorded at the rims are not the highs used as evidence. The real highs are at considerable distances south of the southeast ends of the



Map showing areas of abundant Carolina Bays and frequent meteorite finds. However, meteorites are rare in the area of the bays. (X1)

bays.

In addition, critics of the meteoric theory have pointed out that the Carolina Bays do not look anything like bona fide meteor craters, such as the very deep Meteor Crater, in Arizona. The reply is that the Carolina Bays should instead be compared with the largely surficial effects of the 1908 Siberian Meteor. (See ETC3.)

Other Theories of Origin. One estimate has 20 distinct theories on record for the bays. In addition to the meteoric theory, which is currently dominant, several others are worth mentioning.

(1) D. Johnson's hypothesis of complex origin, in which he supposes that artesian springs, rising through moving ground water and operating in part by solution, produced broad shallow basins occupied by lakes, about the margins of which beach ridges were formed by wave action and dune ridges by wind action. (R10, R12, R17) Johnson also wrote a book on the bays entitled The Origin of the Carolina Bays, New York, 1942, and was a main critic of the meteoric hypothesis.

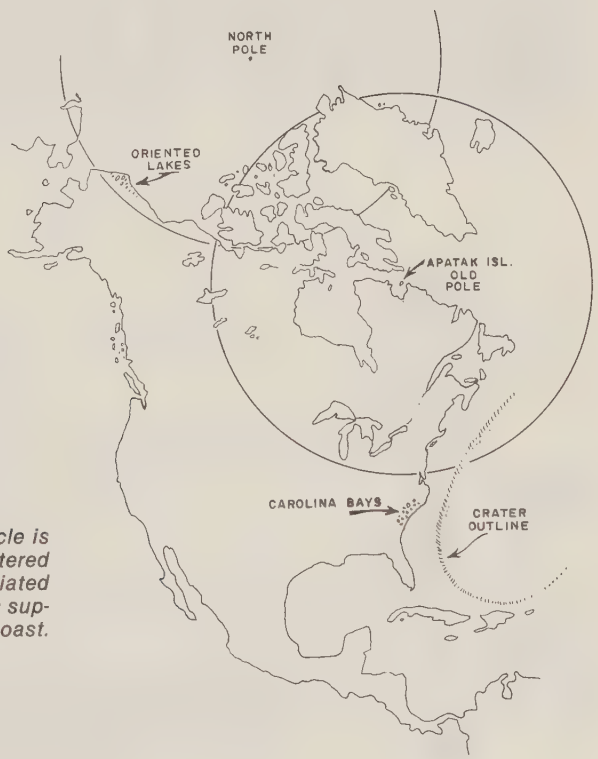
(2) C.W. Cooke's hypothesis of segmented lagoons and crescent-shaped keys, as augmented by gyroscopic action to account for the bays' ellipticity. (R7, R14, R15, R16, R21, R30)

(3) C. Grant's biological explanation of the bays, which entailed excavation by huge shoals of spawning fish. (R20)

(4) A.O. Kelly's theory that the bays were formed by strong tidal currents flowing around fixed objects, namely cakes of stranded sea ice. (R33)

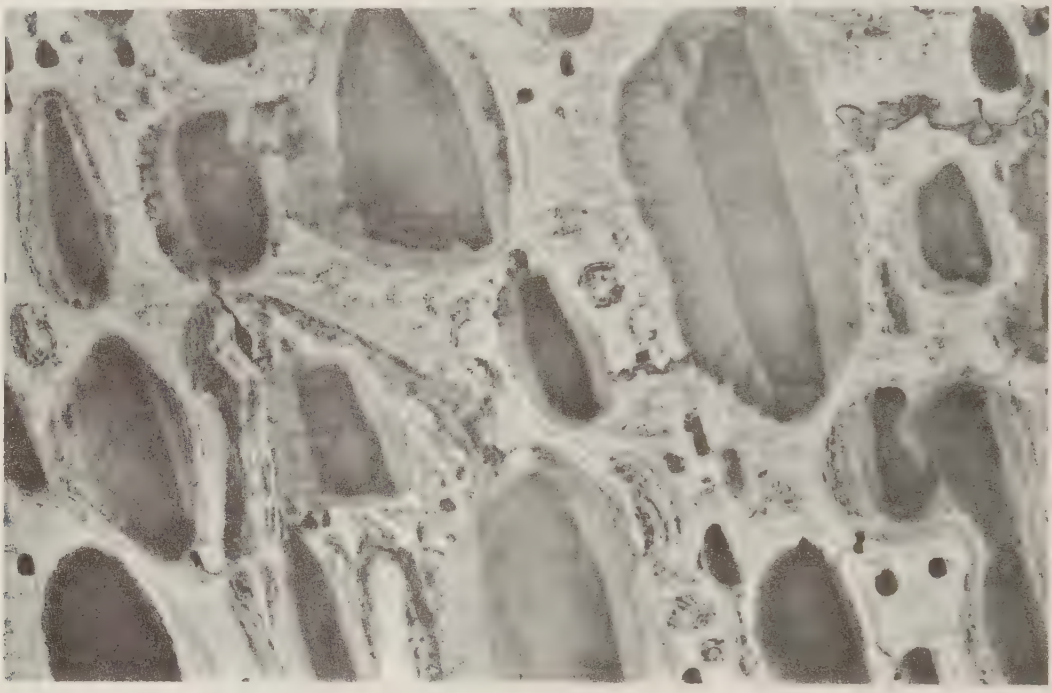
(5) Several authors have proposed wind theories of various sorts. Some theories involve wind-scouring during arid conditions; others utilize wind-driven water as the shaping agent. (R35, R40, R42)

(6) D.J. Bliley and D.E. Pettry, after a study of some 160 Carolina Bays along Virginia's Eastern Shore, concluded that there was more than one period of formation. "Data indicate Carolina Bays were formed by the alteration of poorly drained areas on undissected Coastal Plain interfluves. Wind and waves are suggested as factors in bay formation based on well-sorted sands of elevated rims, 'dune-like' character, and silt content of possible aeolian origin." (R52)

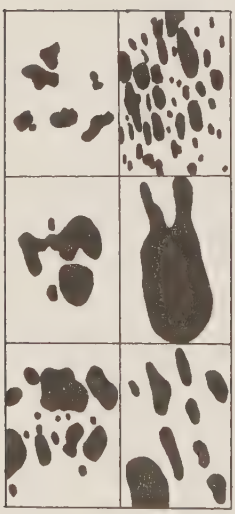


In A.O. Kelly's theory, the current Arctic Circle is intersected by a postulated older circle centered on Apatak Island. The meteor crater associated with pole movement and the Carolina Bays is supposedly located off the U.S. southeastern coast. (X1)

X2. The Alaskan Oriented Lakes. "Abstract. The oriented lakes of northern Alaska occur in an area of more than 25,000 square miles in the Arctic Coastal Plain Province. The topography, drainage, vegetation, climate, geology, and permafrost of the area are briefly described. The average range of orientation of the lakes is 12°---from N. 9°W. to N. 21°W. In any locality the deviation from the average is commonly less than 3° and rarely over 5°. The lakes range in size from small ponds, a few tens of feet in length, to large lakes more than 9 miles long and 3 miles wide. The shapes may be described as elliptical, cigar-shaped, rectangular, ovoid, triangular, irregular,



Alaskan oriented lakes. (X2)



or compound. One group of lakes has a shallow shelf or underwater bench surrounding a deeper central portion. The rest are shallow throughout, and the underwater profile is commonly concave. The major outline of the lakes is smoothly curved, but in detail it is cuspate or jagged. No lacustrine beach ridges were recognized. Former lake basins, now drained, and extensions of the present lakes are evidenced by shore features, lacustrine deposits, the character of polygonal ground, and vegetation. The effect of wind, vegetation, and permafrost are briefly

Representative outlines of Alaskan oriented lakes. The rectangles are about 4 miles wide. North is up. (X2)

described. The lakes are compared with the Carolina Bays and with rectangular lakes in eastern U.S.S.R. Many of the lakes are believed to be the result of thawing of permafrost; others may be produced by the segmentation of uplifted lagoons. The origin of some is not known." (R28) See X9.

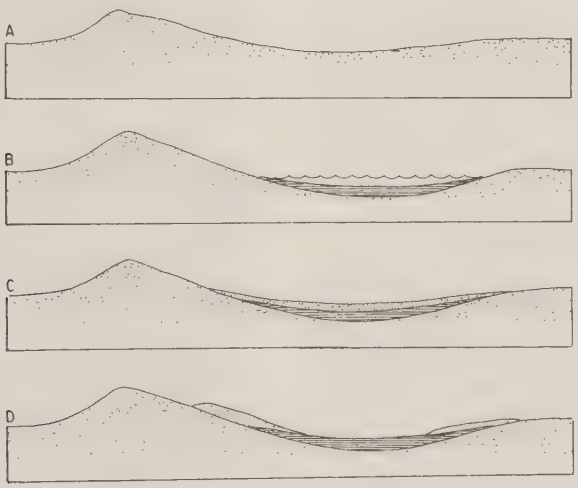
Although the Alaskan oriented lakes are often compared with the Carolina Bays, no one seriously considers a meteoric origin for them. (R42, R45, R51) A.O. Kelly has also applied his stranded iceberg model to the Alaskan lakes. (R33)

X3. The weakly oriented lakes of the Texas Panhandle. "Abstract. The depressions on the surface of the Llano Estacado ("staked plains"), loosely termed 'lakes,' belong to three general classes: (1) Circular or elliptical depressions 10 to 50 feet deep, one eighth to one half mile in diameter; (2) Linear shaped and linear arranged depressions 100 or more feet in depth, one to three miles long; (3) Alkali lakes.

Original irregularities, differential compaction, and slumping due to solution of underlying Permian salt and gypsum strata, may account in part for these depressions, but no one of these causes seems sufficient to account for all of them. An important cause is thought to be the solution of the material immediately underlying the surface such as the 'caliche.' Evidence in support of this is found in the numerous very small depressions forming in the bottom of the lakes at present." (R6)

H. Savage mentions the Texas lakes in his book on the Carolina Bays. (R51) He calls them 'wind-scour' lakes, which "display definite parallelism and, at least at times, a roughly approximate ellipticity."

X4. The salt pans of the Kalahari, South Africa. Abstract. "The pans or small dry or ephemeral lakes, of the southern Kalahari in Botswana are contained in shallow, sub-circular to sub-elliptical, enclosed depressions in the surface sands which mantle the region. The depressions, of probable deflation origin, are concentrated in a well-defined belt along the Okwa, Nosop-Molopo watershed. Two crescentic dunes on the southern side of the pans represent material deflated from the depressions, which are floored by calcareous and saline clays, laid down in the period between the formation of the outer and inner dunes, when the depressions held permanent or seasonal lakes up to three times the area of the present pans. The origins and development of the pans are seen as reflecting the fluctuating climates in the region during the late Quater-



Possible steps in the formation of the Kalahari pans: (1) Deflation forms the outer dune; (2) Clays are deposited; (3) Sands are deposited; and (4) Deflation forms the inner dune. (X4)

nary." (R50)

S. J. Shand has described the Grootpan, near Port Elizabeth, comparing it to the Carolina Bays. This salt pan is 1500 yards long and 1000 yards wide, and is surrounded by a sandy rampart 30 to 50 feet high. Thousands of similar salt pans exist on the South African coastal plain, with many more in the dry interior. (R22) The similarities with the Carolina Bays are particularly strong here. Meteoric origin is not mentioned. (WRC)

X5. The shallow depressions of Eastern New Mexico. The high plains of eastern New Mexico are geographically close to the lakes of the Texas Panhandle and may have been created in the same way. However, in the following discussion by S. Judson, they are not related. "The minor irregularities of the Plains, the depressions, vary in size, shape, and depth. Some are but a few yards wide and less than a foot deep. Others are more than a mile in diameter and over 50 feet deep. These depressions contain ephemeral lakes, some of which are perennial during a series of wet years and dry up only after a series of dry years." (R29) Judson ventures that these depressions are the result of alternate periods of leaching and wind deflation.

X6. Bays in Holland. In connection with the Carolina Bays, C. A. J. von Freitage Drabbe, of the Netherlands Topographic Service, noted "that closely similar formations abound in the Netherlands. There, however, their discovery is difficult because of the overlying civilization, whereas the Carolina Bays are in practically virgin condition. Von Drabbe thinks both groups of oval depressions are glacial phenomena produced by the melting of glacial ice. Some of the ovals may have been formed when already buried glacial ice (ice fossils) melted and the overlying layers of sediment collapsed. Bringing together many geological factors, he presents very convincing evidence in support of his theory. In particular, he calls attention to rocks in the vicinity of the Dutch craters. No natural rock formations of the sort exist in the Netherlands, but similar boulders are found strewn along the Baltic. The origin of such boulders seems to be in the mountains of Finland and Scandinavia, whence glaciers carried them southward." (R39) A glacial origin for the Carolina Bays would be counter to current thinking, because the North American ice sheet is thought to have stopped well north of the Carolinas. However, in a later Catalog volume (ES), this dogma will be challenged. (WRC)

X7. Playa lakes of southwestern Australia. The playa lakes exist by the thousands. Sizes range from 0.004 km^2 to over 100 km^2. Large numbers are elliptical (average ellipticity = 0.33). Many playa lake features are oriented slightly west of north (average orientation = 347°). Studies of the playa lakes suggest that they are the products of contemporary fluvioaeolian processes. (R49) The aerial photograph accompanying the article shows many features in common with the Carolina Bays.

A. O. Kelly, on the other hand, claims anomalous features for these playa lakes. "Scattered over western, southern, and central Australia are tens of thousands of 'salt pans whose origin has long been a matter of debate and conjecture. Most are found on gently rolling landscape at an elevation of about 1,000 feet above sea level. In size, they range from a few hundred feet in diameter to irregular shapes that may be several miles long. In shape, they range from round to oval to linear and irregular, but must are oval in shape and have their longer axis aligned in a general east to west direction. This orientation has been a problem to students of salt pans in Australia---and in the northern hemisphere, students of the orientated lakes of Alaska and the Carolina Bays. Unlike lakes in a glaciated country like Canada, the salt pans may be found on slopes, hilltops, or flat ground, and unlike other lake country where the drainage is from lake-to-lake, the salt pans and oriented lakes drain into channels that wander around among the lakes, never from lake-to-lake." Kelly explains the Australian playa lakes (and the Carolina Bays) as the consequences of icebergs stranded following a marine inundation caused by a large meteor impact. (R54)

X8. The "pits" of central Asia. The following account originated with an 1870 expedition to Yarkand (now Soche, China). "After two days' march (50 miles) we came to a number of limestone ridges, rising from 200 to 500 feet above the plain, with wide valleys between them; and in one of these valleys, between the camps named Luk Zoong and Tarl Dat, I first noticed the circular pits. The valley was about eight miles long, and from half a mile to a mile wide, and had a very gentle slope. The surface of the ground consisted of sand, clay, and gravel (formed mostly of angular fragments), in varying proportions, and for miles was indented with pits, all very regularly circular in shape; they varied in diameter from six to eight feet, and were from two to three feet deep. The sides sloped regularly towards the centre; and some of them were partially filled up with sand, which seemed to have been blown by the wind. The intervals between the pits were about equal to their diameters; and there were no raised ridges round their margins. The soil was quite dry; and there were no signs of water having flowed over it; nor was there any saline efflorescence." More such pits were observed at Tarl Dat; many of which had a mound of dry frothy mud projecting two or three feet from their bottoms. Along the Karakash river, another group of pits was found. These were partially filled with strong brine. (R1)

X9. The rectangular lakes of eastern Siberia. "(S. V.) Obruchev reported that rectangular lakes oriented in a rectangular pattern occur on the recent Arctic Coastal Plain to the southwest of the Iamskaia beach of the Okhotsk Sea, in the valley of the Penzhina River near the village of Penzhino, and in the valley of the Anadyr River. These lakes are reported to vary in diameter from several meters to as much as 5 km. Those on the plain surrounding the Okhotsk Sea are parallel to the coast. Obruchev believes that the origin of the lakes in the valley of the Penzhina and Andyr rivers is connected with the origin of the polygonal ground which occurs in the area, but he does not explain further. He believes that many of the lakes less than 2 meters in depth are the result of thawing of the permafrost. Some lakes deeper than 2 meters are fed by fresh-water springs and others by mineralized waters from taliks, or thawed zones within the permafrost. Seasonal and biennial mounds are reported to rise from the bottoms and from the shores of some of the lakes. It is not known how well the lakes are oriented or how large an area they cover. They are presumed to be Quaternary in age." (R28)

X10. Oriented lakes of the Beni Basin, Bolivia. "Density and distribution. Oriented lakes occur over an area of roughly 45,000 square miles in the Beni basin where the water table is at or near the surface. They extend from the margin of the Brazilian Shield outcrop, westward to within 20 miles of the Sub-Andean zone. In the area of detailed study there are 104 oriented lakes and dry lakes more than 1 km in length, and almost an equal number of lakes less than 1 km in maximum dimension. Lakes constitute 3 per cent of the total area with roughly one lake more than 1 km long per 40 square miles.

In general, lake distribution is similar to that of the lineaments, except that the lakes are restricted to flat terrains with high water tables. As with the lineaments, they are concentrated along the more recently alluviated areas such as the west side of Rio Mamore and the abandoned courses of the Rio Beni and the Rio Grande. In one exceptional instance, a large lake, Lago Rogagua, clearly cuts across an abandoned channel of the ancestral Rio Beni.

Orientation and physical characteristics. Most of the lakes in the Beni basin have axes or long straight segments of shore line that trend within 10^{o} of N. 45^{o}E. or N. 45^{o}W. Lake shore lines in the mapped area either are oriented in one or both of these two directions or are completely unoriented.

The lakes range from about 1000 feet square to 12.4 miles long by 5.4 miles wide." (R46)

X11. The oriented clamshell lakes of southern Chile. These wind scour lakes are located on the windswept plains of Tierra del Fuego, near the Strait of Magellan. (R51)

X12. The lakes on Old Crow Plain, Canada. G. Plafker asserts that the oriented lakes on the Old Crow Plain, in the northern Yukon Territory, are very similar to those he examined in Bolivia (X10). (R46)

References

R1. Henderson, George; "Notes and Sand Pits, Mud-Discharges, and Brine Pits Met with during the Yarkand Expedition of 1870," Geological Society of London, Quarterly Journal, 28:402, 1872. (X8)

R2. Glenn, L.C.; "Some Notes on Darlington (S.C.), 'Bays'," Science, 2:472, 1895. (X1)

R3. Smith, Laurence L.; "Solution Depressions in Sandy Sediments of the Coastal Plain in South Carolina," Journal of Geology, 39:641, 1931. (X1)

R4. Melton, F.A., and Schriever, William; "The Carolina 'Bays'---Are They Meteorite Scars?" Journal of Geology, 41:52, 1933. (X1)

R5. Wylie, C.C.; "Iron Meteorites and the Carolina 'Bays'," Popular Astronomy, 41:410, 1933. (X1)

R6. Patton, Leroy T.; "Some Observations on the So-Called 'Lakes' of the Llano Estacado of Texas," Geological Society of America, Proceedings, p. 451, 1934. (X3)

R7. Cooke, C. Wythe; "Discussion of the Origin of the Supposed Meteorite Scars of South Carolina," Journal of Geology, 42: 88, 1934. (X1)

R8. Prouty, William F.; "'Carolina Bays' and Elliptical Lake Basins," Journal of Geology, 43:200, 1935. (X1)

R9. Watson, Fletcher, Jr.; "Meteor Craters," Popular Astronomy, 44:2, 1936. (X1)

R10. Johnson, Douglas; "Origin of the Supposed Meteorite Scars of Carolina," Science, 84:15, 1936. (X1)

R11. "The Carolina Bays and Their Supposed Meteoric Origin," Royal Astronomical Society of Canada, Journal, 30:57, 1936. (X1)

R12. Johnson, Douglas; "Role of Artesian Waters in Forming the Carolina Bays," Science, 86:255, 1937. (X1)

R13. MacCarthy, Gerald R.; "The Carolina Bays," Geological Society of America, Bulletin, 48:1211, 1937. (X1)

R14. Cooke, C. Wythe; "Elliptical Bays in South Carolina and the Shape of Eddies," Journal of Geology, 48:205, 1940. (X1)

R15. Cooke, C. Wythe; "The Origin of the Carolina Bays," American Journal of Science, 241:583, 1943. (X1)

R16. Cooke, C. Wythe; "Elliptical Bays," Journal of Geology, 51:419, 1943. (X1)

R17. Johnson, Douglas; "Mysterious Craters of the Carolina Coast," American Scientist, 32:1, 1944. (X1)

R18. McCampbell, John C.; "Meteorites and the 'Carolina Bays'," Popular Astronomy, 53:388, 1945. (X1)

R19. McCampbell, John C.; "A Geomagnetic Survey of Some Bladen County, North Carolina, 'Carolina Bays'," Journal of Geology, 53:66, 1945. (X1)

R20. Grant, Chapman; "A Biological Explanation of the Carolina Bays," Scientific Monthly, 61:443, 1945. (X1)

R21. Cooke, C. Wythe; "Neptune's Racetracks," Scientific Monthly, 60:286, 1945. (X1)

R22. Shand, S. James; "Dust-Devils?" Scientific Monthly, 62:95, 1946. (X4)

R23. Buell, Murray F.; "The Age of Jerome Bog, 'A Carolina Bay'," Science, 103: 14, 1946. (X1)

R24. Barringer, Brandon; "Observations of the Carolina 'Craters' or 'Bays'," Popular Astronomy, 55:215, 1947. (X1)

R25. Prouty, William F.; "A Reply to an Article by Mr. Brandon Barringer on the Origin of the 'Carolina Bays'," Popular Astronomy, 56:499, 1948. (X1)

R26. Grant, Chapman; "Meteoric Origin of the 'Carolina Bays' Questioned," Popular Astronomy, 56:511, 1948. (X1)

R27. Prouty, William Frederick; "Heart-Shaped Carolina Bays," Geological Society of America, Bulletin, 59:1345, 1948. (X1)

R28. Black, Robert F., and Barksdale, William L.; "Oriented Lakes of Northern Alaska," Journal of Geology, 57:105, 1949. (X2, X9)

R29. Judson, Sheldon; "Depressions of the Northern Portion of the Southern High Plains of Eastern New Mexico," Geological Society of America, Bulletin, 61:253, 1950. (X5)

R30. Cooke, C. Wythe; "Carolina Bays, Traces of Tidal Eddies," Geological Society of America, Bulletin, 61:1452, 1950. (X1)

R31. Melton, Frank A.; "The Carolina 'Bays'," Journal of Geology, 58:128, 1950. (X1)

R32. Prouty, William F.; "Origin of Carolina Bays," Popular Astronomy, 58:17, 1950. (X1)

R33. Kelly, Allan O.; "The Origin of the Carolina Bays and the Oriented Lakes of Alaska," Popular Astronomy, 59:199, 1951. (X1, X2)

R34. Schriever, William; "On the Origin of the Carolina Bays," American Geophysical Union, Transactions, 32:87, 1951. (X1)

R35. "Winds Caused Pattern," Science News Letter, 60:327, 1951. (X1)

R36. LeGrand, H.E.; "Streamlining of the Carolina Bays," Geological Society of America, Bulletin, 62:1459, 1951. (X1)
R37. "Streamlining of the Carolina Bays," Popular Astronomy, 59:539, 1951. (X1)
R38. Prouty, W.F.; "Carolina Bays and Their Origin," Geological Society of America, Bulletin, 63:167, 1952. (X1)
R39. Hoffleit, Dorrit; "Bays in Holland," Sky and Telescope, 12:8, 1952. (X6)
R40. Odum, Howard T.; "The Carolina Bays and a Pleistocene Weather Map," American Journal of Science, 250:263, 1952. (X1)
R41. Kelly, Allan O., and Dachille, Frank; "The Carolina Bays and Oriented Lakes of Alaska," Target;Earth, Carlsbad, 1953, p. 24. (X1, X2)
R42. Livingston, D.A.; "On the Orientation of Lake Basins," American Journal of Science, 252:547, 1954. (X1, X2, X4)
R43. Schriever, William; "Were the Carolina Bays Oriented by Gyroscopic Action?" Science, 121:806, 1955. (X1)
R44. Rasmussen, William Charles; "Origin of the 'Bays' and Basins of the Atlantic Coastal Plain," Geological Society of America, Bulletin, 70:1660, 1959. (X1)
R45. Carson, Charles E., and Hussey, Keith M.; "The Oriented Lakes of Arctic Alaska," Journal of Geology, 70:417, 1962. (X2)
R46. Plafker, George; "Oriented Lakes and Lineaments of Northeastern Bolivia," Geological Society of America, Bulletin, 75:503, 1964. (X10)
R47. Thom, Bruce G.; "Carolina Bays in Horry and Marion Counties, South Carolina," Geological Society of America, Bulletin, 81:783, 1970. (X1)
R48. Cooke, C. Wythe, and Thom, Bruce G.; "Carolina Bays: Discussion and Reply," Geological Society of America, Bulletin, 81:3171, 1970. (X1)
R49. Killigrew, L.P., and Gilkes, R.J.; "Development of Playa Lakes in South Western Australia," Nature, 247:454, 1974. (X7)
R50. Lancaster, I.N.; "The Pans of the Southern Kalahari, Botswana," Geographical Journal, 144:81, 1978. (X4)
R51. Savage, Henry; The Mysterious Carolina Bays, Columbia, 1982. (X1, X2, X3, X11)
R52. Bliley, D.J., and Pettry, D.E.; "Carolina Bays on the Eastern Shore of Virginia," Soil Science Society of America, Journal, 43:558, 1979. (X1)
R53. "North American Permafrost and Some Related Phenomena," Geographical Review, 40:139, 1950. (X2)
R54. Kelly, Allan O.; Impact Geology, Encinitas, 1985, p. 120. (X7)

ETB2 Anomalous Features of Potholes

Description. The irregular shapes of potholes; wall fluting and other fine structure; unusually large sizes; deviations from the vertical; group organization; apparent absence of water sources, past and present; etc.

Background. Potholes are common in areas that have been glaciated. Superficially, they give every evidence of having been ground out of the solid rock by rushing water, perhaps aided by entrained sand and pebbles. The explanation of these often impressive cavities is perhaps too simplistic---as are the explanations for glacial scratches, drumlins, rock trains, and other signatures of the Ice Ages. Pleistocene glaciations are an integral part of our scientific belief system; but the venerable Ice Ages must be challenged if the facts so dictate. With potholes, however, the challenges are less serious than we find with other purported adjucts of the Ice Ages (see ESD in another volume of the Catalog of Anomalies).

Data Evaluation. Much of the pothole literature found so far is rather old, suggesting perhaps, that pothole research no longer offers scientific challenge. Nevertheless, despite their age, the data at hand are quite good. Thanks to the geologists who have taken them more seriously, the basic facts about potholes are undisputed. Rating: 1.

Anomaly Evaluation. What is in dispute, though, is whether all pothole features can be accounted for by rushing streams and powerful streams of water (moulins) cascading from ice sheets. The cumulative effect of the pothole anomalies (X1-X9) casts doubt on the stream/moulin theory in its simplest form. There is little doubt that potholes are somehow associated with

water and ice in their genesis, but the theory seems to need some fine tuning. Rating: 3.

Possible Explanation. Other factors that might be added to the stream/moulin theory include chemical action (see X8) and freeze-thaw phenomena, as in weather-pit formation (ETB5).

Similar and Related Phenomena. Weather pits (ETB5); plunge pools at waterfall bases; the "other evidence" for the Ice Ages---scratches, polishing, drumlins (ETM4), etc.

Examples

X0. Baseline explanation of potholes. The following quotation from a writer in 1850 presents the still popular description of how potholes were excavated. "The manner in which these excavations are formed at the base of a water-fall is presumed to be generally known. They are produced by the gyration of loose stones resting on the rocks immediately below the falls, the force moving them being the impelling current of falling water, acting in whirlpools. A shallow basin is first formed, which soon gathers a quantity of loose pebbles and sand, and then, by the continued rotation of the

Potholes at Kongshavn, Norway. (X0)

pebbles, the cavity is deepened by attrition of their mullers and sand, until it reaches a considerable depth, and appears like a huge mortar, the bottom and sides of which have been ground and polished by abrasion." (R1) More recent literature speaks of "moulins" or "mills" in describing the rotary grinding action in the potholes. The water source, of course, need not be a waterfall, but could gush from ice formations, either vertically or at an angle.

Today, the moulin theory is being seriously questioned, and the burden of explaining potholes is being shifted to stream action. C. G. Higgins summarizes the situation as follows:

"There is no direct evidence that moulin waterfalls form potholes. Neither is there, as noted above, any indirect evidence that they might have done so. Furthermore, there are grave mechanical difficulties in the moulin hypothesis. In addition to minor objections, 'the main objection to the hypothesis lies in the difficulty of conceiving the moulin as existing long enough in the necessary definite form at the same spot, or as reforming in the same manner and at the same spot often enough to account for the work accomplished'. (R11)

. . . . .

In short, there is neither direct nor indirect evidence that moulin action forms potholes. Furthermore, in the unlikely event that moulin torrents could remain long enough at one spot, they would actually produce potholes quite different from those that have been ascribed to them. On the other hand, all features of potholes ascribed to moulin erosion may readily be explained as natural consequences of erosion by sub-, en-, or latero-glacial streams, as has been so ably demonstrated by Angeby and Alexander. In view of these arguments, continued entertainment of the moulin hypothesis seems a needless extravagance." (R14)

Despite these comments by Higgins, just about everyone still seems wedded to the moulin or glacial mill explanation. However, the following peculiarities of some potholes seem inimical to both moulin and stream action hypotheses. (WRC)

X1. Highly irregular shapes of potholes. Most potholes are nicely circular or elliptical, but a few are decidedly not---a fact

seemingly incompatible with whirlpool origin.

Kongshavn, Norway. Many of the potholes in this region are shaped like footprints, earning them the name "Giants' Kettles". "...the first kettle discovered was on the shore near Kongshavn; it was 16 feet long, $5\frac{1}{2}$ broad, with the renowned footstep-form sharply delineated by the surface of the water with which it was filled." (R3) The anomaly here is the "footprint" or highly irregular form.

X2. Potholes wider at their bottoms. The erosive force of water and its entrained stones and gravel should diminish rapidly with pothole depth, leading one to think, superficially at least, that potholes should be narrower with increasing depth.

Connecticut. "Last November I discovered an interesting group of pot-holes upon the edge of a bluff at Gurleyville, Conn., on the east side of the Fenton River, four miles above its mouth.

Recently, in company with Professor Washburn, I have cleared the one perfect one of its water and stones, and found it to be six feet seven inches in depth, three feet nine inches in its shorter diameter at the top, and four feet three inches in its longer diameter.

About two feet above the bottom the diameter is reduced to about thirty inches, and then widens again below this point, leaving a horizontal ring at the narrow place. When can have been the cause of the forming of the rings at this point is not entirely evident. If the rock were horizontal, it would seem that a hard layer in the rather uniform gneiss would account for it; but since the rock dips at an angle of about 30°, and this projecting ring is horizontal and only a couple of inches thick, I find myself at a loss for an entirely satisfactory answer." (R5)

Norway. The larger of the Giants' Kettles, mentioned in X1, are almost always wider at their bottoms than at their tops. (R4; R3)

Section of a pothole south of Kongshavn showing an enlarged diameter toward the bottom. (X2)

X3. Fine structure of pothole walls. In the maelstrom of an active pothole (assuming the conventional explanation of their origin), one would not expect the development of well-defined structures.

Norway. One of the potholes at Kongshavn. "From the bottom upwards a distinct spiral line is worn into the walls to the height of 6 feet, where it is broken off by a sausage-shaped projection on the east wall of the kettle. Higher up are perceptible marks of a process like turning, with indications of spirals." (R3) In another pothole, the spiral is so well-developed "that the cauldron might be compared to the coiling of a huge snake." (R4)

General observations. "A significant proof that the potholes are not in the process of formation at the present time, and that they are not worn by the abrasion of streams, is due to the presence on the walls of typical examples of little ridges, or flutings. These are often inclined at an angle to the horizontal.

Where potholes are being washed by streams today, these flutings can often be seen above the level of the water, but in the vicinity of the water they are gradually being worn away. They are not formed by the

action of the water, or by pebbles and sand abrading the walls of the hole. Actually such flutings are destroyed by these agents." (R10)

X4. Implications of large potholes for the moulin theory. In regions where no waterfalls seem to have existed, the moulin hypothesis has a stream of water ejected from an ice sheet, say, from a crevasse. But the amount of grinding, extending to great depths, often in extremely hard rock, opposes this theory.

Pennsylvania. At Archbald, a pothole 45 feet deep was discovered when coal miners encountered its lower end! After clearing out the debris, it was found to have an ovoid cross section, 20 feet wide at the maximum. 'It is supposed to be a product of the latter part of the Glacial era, and to have been made by a great water-fall descending through a crevasse in the glacier. This view implies that the glacier of the region did not move as much as ten feet during the centuries in which the excavation to a depth of forty-five feet was going forward; or else that local conditions occasioning the crevasse were such as to keep the crevasse stationary, and without eroded sides from the water-fall, during those centuries, notwithstanding the movement of the glacier. Either supposition seems to be almost incredible." (R6)

X5. Inclined potholes. The great majority of reported potholes are drilled vertically. However, the mechanism of pothole excavation must also account for off-vertical potholes.

California. At an elevation of some 4,500 feet, on the Mokelumne River, a group of about 250 potholes includes some that are inclined to the vertical. (R7)

X6. Unusual characteristics of groups of potholes. Potholes rarely occur singly. Pothole groups possess fascinating, sometimes conflicting, characteristics, which seem to defy simplistic explanations.

Colorado. An analysis of over a thousand potholes found along the Front Range led to these conclusions: "(a) They occur in groups of six to twenty holes; solitary potholes are rare. They are mostly disposed in lines, and groups of them will show a definite alignment and persistent arrangement along a given slope; (b) The individual potholes may be separate, linked together into a compound cuspate channel, or 'double decked.' Down a steep slope, the little ones may lead into the big ones so as to make a definite plunge channel."

.....

"Some of the groups of potholes encircle the slopes of the mountains in contour fashion. It is believed that such an alignment is due to the action of waters which circulated along a trough developed at the contact between rock and ice slopes when the general thickness of ice had lessened so that the peaks emerged as nunataks." (R8)

California. The Mokelumne River potholes exhibit a regular arrangement (not specified in the article) and seldom or never coalesce. (R7)

New York. Pothole "canyons" exist at Watkins Glen, Little Falls, and elsewhere. In such "canyons" a whole series of potholes intersect to form a continuous channel. But intersecting potholes seem inconsistent with the prevailing model of water-induced rotary grinding.

"A series of potholes in a canyon is made up of intersecting holes; and, if they were formed successively, each new hole that intersected a previous one would have to have been formed with one side missing. The water eroding it would have to rotate without any enclosing wall on one side of the pothole. Clearly this goes beyond the bounds of common sense." (R10)

"Common sense" is in the eye of the beholder; and there may be a simple dynamic explanation for intersecting potholes. Until it is found, we will retain this observation. (WRC)

X7. Potholes located far from any discernable source of water, past or present. Ice sheets are invoked to explain potholes in "difficult" places; but is this standard explanation adequate?

Connecticut. The Fenton River, Gurleyville. "The group is all the more interesting from the fact that the pothole highest on the cliff stands ninety-eight feet six inches alove modern flood plain, while the highest ter-

races to be found in the vicinity are only fifty-six feet six inches high." (R5)

New Hampshire. "The potholes of Orange occur in a linear direction corresponding in direction with drift scratches which abound on the recently uncovered surface of the rocks, seeming to indicate that the scratches and deeper excavations owed their origin to a current having the same direction. The course of the current seems to have been from the Connecticut river towards the Merrimack Valley. From the present contour of the country, it is obvious that no stream of water could flow over the high mountain gap, and produce water-falls on the summit ridge." (R1)

Wisconsin. "For such potholes as those on the high quartzite bluff east of Devil's Lake, Wisconsin, it must be assumed either that the bluff was glaciated---which it evidently was not---or that some ancient river flowing hundreds of feet above the present lake level across the then-buried quartzite ridge eroded the holes in rapids coursing down its southern slope." (R11)

Colorado. Along the Front Range. Over 90% of the 1,000-plus potholes studied are located on the summits of round, flat-topped, knob-like outcrops and bosses of granite. The remainder are located on the intermediate slopes. (R8) This concentration on high granite peaks is curious. One immediately remembers the shallower mountain-top depressions of ETB5, which are also restricted to granite. (WRC)

X8. Potholes with internal coatings. Present theory has potholes ground out by violent motions of water and sediment. The existence of extraneous chemical deposits inside potholes indicates at least a radical change of environment.

Vermont. Near Poultney. "The side of the largest pothole has, in some places, a coating of carbonate of lime one-tenth of an inch thick, laid very evenly over the slate, and large lumps of limestone of the nature of stalactites have been found in the same hole." (R2)

X9. Observations of modern pothole erosion. Potholes existing in streams today show little erosion, particularly at their bottoms where they are protected by accumulated debris. Neither is moulin action observed. (R10)

Laboratory experiments have not been able to duplicate the postulated erosion action of vertical or near-vertical moulins or of horizontal stream flow. (R9, R10)

References

R1. Jackson, C.T.; "On Ancient Pot-Holes in Rocks," American Association for the Advancement of Science, Proceedings, 4:188, 1850. (X0, X7)

R2. Nichols, John A.; "Notes of Pot-Holes near Poultney, Vermont," American Journal of Science, 2:40:264, 1865. (X8)

R3. Brogger, W.C., and Reusch, H.H.; "Giants' Kettles at Christiania," Geological Society of London, Quarterly Journal, 30:750, 1874. (X1-X3)

R4. "On Giant Cauldrons near Christiania and Their Origin," English Mechanic, 21: 394, 1875. (X2, X3)

R5. Koons, B.F.; "On Pot-Holes on the Edge of a Bluff at Gurleyville, Connecticut," American Journal of Science, 3:25:471, 1883. (X2, X7)

R6. "A Pot-Hole of Remarkable Size in Archbald, Pa.," American Journal of Science, 3:34:389, 1887. (X4)

R7. Turner, H.W.; "Glacial Pot-Holes in California," American Journal of Science, 3:44:453, 1892. (X5, X6)

R8. Fuller, Margaret Bradley; "The Bearing of Some Remarkable Potholes on the Early Pleistocene Glaciation on the Front Range, Colorado," Journal of Geology, 33:224, 1925. (X6, X7)

R9. Riley, Christopher; "Glacial Potholes on Outpost Islands, Great Slave Lake, Northwest Territories," Journal of Geology, 51:270, 1943. (X9)

R10. Cox, Douglas E.; "On the Interpretation of Potholes," Creation Research Society Quarterly, 12:25, 1975. (X3, X4, X6, X7, X9)

R11. Alexander, H.S.; "Pothole Erosion," Journal of Geology, 40:305, 1932. (X7)

R12. Streiff-Becker, R.; "Pot-Holes and Glacier Mills," Journal of Glaciology, 1:488, 1951.

R13. Faegri, Knut; "On the Origin of Pot-Holes," Journal of Glaciology, 2:24, 1952.

R14. Higgins, C.G.; "Origin of Potholes in Glaciated Regions," Journal of Glaciology, 3:11, 1957. (X0)

ETB3 Fluid-Vent Craters and Fissures

Description. Craters, fissures, funnels, and pockmarks of various sizes and shapes thought to be caused by the expulsion of water, gases, and fluid-entrained solids. Some of these depressions and cavities are terrestrial; some are on the sea floor. Dimensions range up to hundreds of feet in diameter. Many occur in large groups. Sometimes they are oriented. A sampler of synonyms: sandblows, mud craters, gas pits, blowouts, pockmarks.

Data Evaluation. Sea-floor pockmarks and earthquake-generated sandblows have received considerable attention, but examinations of the other types has been cursory. Rating: 2.

Anomaly Evaluation. Curious as the vent-type excavations may be, they very likely have prosaic origins. We may marvel at the large sizes and populous fields of these structures, but there seems to be little that is anomalous. There is some doubt remaining about the precise origin of the sea-floor pockmarks; and our rating is based mainly on this uncertainty. Rating: 3.

Possible Explanations. Fluids in the earth's crust---water, gases, etc.---are naturally expelled by the pressures applied by earthquakes, atmospheric pressure, internal heat generation, etc. The upwelling fluids, sometimes augmented by the ignition of natural gas, do all the excavating.

Similar and Related Phenomena. Shallow depressions, such as the Carolina Bays (ETB1); meteor craters and astroblemes (ETC); the pits and furrows dredged by marine mammals; mud volcanos, ancient mining operations (M); geysers, blowing caves, periodic wells (GHG).

Examples

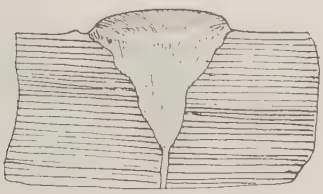
X1. Mud craters. Cataloged here are those formations that are not the consequence of volcanic action.

Pakistan coast. "The mud-craters, which have hitherto been attributed to volcanic action, are, it is believed, peculiar to this coast. They are found over an extent of about 200 miles of coast from Guadur to Ras Kucheri. Probably the most characteristic group is that near the latter place, where there are a number close together, some of which may be termed extinct, others being in action. These craters vary in height from 20 to 300 or 400 feet above the plain.... They rise out of the clay plain many miles from any hills, and are cones of clay of very regular form, with truncated tops, and sides at an angle estimated at about 40°, or whatever the limiting angle of rest of such mud may be.

The largest one ascended by the writer was about 100 feet wide on top, and nearly circular; it resembled a cup filled to the brim with semiliquid mud somewhat thicker than treacle, which slowly and only now and again overflowed, trickling down the outside of the cone, but scarcely sufficient in quantity to reach the base. From time to time an ebullition of gas or air took place from the surface of the pool.... The edge or lip of the cup was very narrow, in parts barely allowing room to walk around it, and being quite soft under foot. A plummet on being thrown in from the side sank rapidly from 50 to 60 feet, when it stopped, apparently from the friction of the line against the side, there being no means at hand of lowering it over the centre. There was no heat accompanying the phenomenon.... There is some evidence of the existence of these curious craters under the sea. Near Jashak I discovered a shoal, three miles off shore, rising suddenly from 13 fathoms to a height of only 10 feet below the surface. It was very small, not a ship's length across, and composed of clay which, on the shoal part, was so tenacious that the lead could hardly be disengaged when let go on it. It is unusual to find so small a shoal unless of rock; and it is suggested that it may probably be of similar origin to the craters on shore." The author suggested that hydrostatic pressure might provide the driving force, especially since the mud discharge is reputed to increase at the time of the spring tides. (R1)

X2. Earthquake sand craters. "Sand blows, mud volcanoes, craterlets, etc. are clearly closely related phenomena and are to be ascribed to the vertical movement of water, gas, sand, etc. along the widened portions of earth fissures. Their connection with larger tectonic movements as the resulting de-

rangement of the ground water system, is only beginning to be appreciated. Perhaps the most striking and significant single characteristic of the mounds thus produced is that they have a composition essentially different from that of the layers of soil underlying their margins, and that the materials are derived from a lower horizon. The report of the Naples Academy of Science upon the great earthquake of Calabria (1783) states that some plains, like that of Rosarno, were covered with circular hollows generally filled with sand but sometimes with a concave surface. At other times, the surface was convex. Upon digging down in them, it was found that they were funnel-shaped pipes, and that the moist, loose, micaceous sand in the center marked the tube up which the water had spouted. At other places in the same district, cones of sand were built up, and the localization of cones and funnels upon fissure lines was recognized." (R5)



Funnel-shaped sand pipe formed during the Calabrian earthquakes of 1783. (X2)

Charleston earthquake. August 31, 1886. "At a distance from ten to fifteen miles from Charleston in the direction of Summerville some of the most curious and interesting effects of the disturbance were to be seen. These were the 'sand craters' and crevices, out of which extensive eruptions of sand and water had taken place on the night of August 31. The craters thus formed varied in size from an irregular oval, twenty-five feet long by fifteen feet wide, to shallow cones not over an inch in diameter and beautifully symmetrical in form. The area surrounding these openings was generally flooded with sand, often acres in extent, to a depth varying from a fraction of an inch to fifteen and eighteen inches. About the larger cavities the average depth was probably not less than six inches, and the area covered often an acre or more. The flow of sand was unquestionably only an incident to the outflowing of vast quantities of water, the greater part of which disappeared within a few hours after its appearance." (R2)

Sketch of some earthquake-generated sand craters. (X2)

Arkansas craterlets. These are some of the largest craters to be associated with earthquakes; in this case, the New Madrid shocks of 1811-1812. "Five of the craterlets occur on the upper surface of one of the low ridges of the Mississippi flood plain. The sixth is a double craterlet, occurring on the slope of the ridge. They apparently bear no relationship to each other except as regards origin and age. With the exception of the double craterlet, they are saucer-shaped, with diameters ranging from 10 to 40 feet, and depths ranging from 2 to 6 feet. One part of the double craterlet is about 15 feet by 10 feet along the diameters of its elliptical outline. The smaller craterlet is about 10 by 8 feet along similar directions. They are separated by a ridge about three feet high. The bottoms of both craterlets lie about 4 to 5 feet below the surrounding surface. These craterlets are all located within a radius of 800 feet." Similar craters farther north are positively associated with the New Madrid quakes. (R6)

X3. Natural gas vents. Releases of natural gases can be devastating, particularly if the gases are flammable and somehow ignited. However, except for the first case mentioned below, the evidence for natural gas venting is mainly circumstantial.

Waldron, Indiana. August 11, 1890. "The explosion occurred about 9 o'clock, on the morning of August 11; it does not appear to have been accompanied by any violent report, for the attention of the people living in the neighborhood was first attracted by a roaring or whizzing sound like the escape

of steam from a boiler, but much louder. Upon looking toward the river, a sheet of flame was seen extending about 250 yards along the east side of the river bend. Regarding the height of the flame, estimates of those in sight at the time varied between 150 and 300 feet or more.

The height and intensity of the flame were sufficient to sear the leaves on the trees standing on the gravel bluff east of the river, and to completely burn off the leaves and small twigs from the trees standing near the fissures through which the gas escaped.

The vegetation around the openings at the west side of the area showed that the gas that escaped from those openings did not burn.

The roaring and flame continued at their height for about fifteen minutes, and then gradually subsided, and the gas burned from only a few of the crevices that had been formed.

The explosion had opened up a great number of crevices in the soil near the river bank. When the ground was visited by the writer, these fissures varied in width from a few inches to four or five feet, with a like variation in depth, the shallowness being caused by the caving in of the soft soil at the sides and from the top.

Some of the fissures had evidently been formed by the upheaval, or depression, of the surface which had been elevated in some places, and in others had sunk down as much as four or five feet. The larger fissures, however, showed that they had been formed by the soil being blown out from below, the blown-out material being piled up at the sides of the fissures." The river bed had been raised several feet in places. Some forest trees had been blown out roots and all. Many standing trees were plastered from top to bottom with fine mud. (R3)

Elk City, Oklahoma. February 1973. "On the 28th February 1973 the Associated Press announced that 30-ton rocks had 'erupted' from a previously smooth field on a farm south of Elk City, Oklahoma, and did so, along with a lot of small rocks, apparently 'overnight'. Allegedly the farmer had pastured his cattle on this field, which lies along a small creek, on the 16th of February...."

"The farm is owned by James Walter who has stated that he first noticed rocks emerging from the earth last fall (probably November 1972) but paid little attention to them since he thought that the Shell Oil Company, which has wells in the area, might be excavating for pipeline construction. The major 'eruption', however, must have been fairly sudden and was due to a gas 'blow-out' (not an explosion) to move some of the chunks of rock. The exact mechanism is, at the time of writing still under investigation.

Quoting in part from the press release from the Oklahoma Geological Survey, 'the center of the site is a shallow cavity paral-

A fissure created during a natural gas explosion at Waldron, Indiana. (X3)

leling the creek bed, 30 to 50 feet across and about 15 feet deep. The rocks around the cavity are composed of red siltstone and shale from the Doxey Shale, which crops out at the surface, and have been raised and tilted from their normal horizontal position to angles ranging from 28° to 78°. The largest rocks are 3 feet thick, up to 20 feet high, and weigh an estimated 30 tons. Trees along the creek have been uprooted and tilted, and smaller chunks and blocks of siltstone have been thrown as far as 75 feet from the cavity. In addition several fissures are evident, generally paralleling the creek. No faulting, however, was visible at the surface of the vicinity of the blowout.'

Some of the fissures were more than a foot in width and as much as 10 to 11 feet deep, and in some cases they are apparently still growing; also, there are indications that the rocks are still emerging. The total area affected measures about 230 feet long and 100 feet wide." (R10)

The Lower Chindwin, Burma. Specific dimensions are not available for these so-called "explosion craters". They are simply said to be large and cover an enormous area. "These indeed would appear to have been formed quite recently---later in fact than the establishment of the existing form of earth surface. The agency at work was most likely steam, acting with extreme violence in one or two or three explosions, divided by considerable intervals of time. There is no evidence that any great heat accompanied the irruptions (sic), and after the relief afforded by the outburst a long period of quiescence might naturally ensue." (R4)

X4. Gas pits in non-marine sediments. Such pits seem well-explained, but they are intriguing enough to include here.

Lake Mead, Nevada. "Abstract. The generation of the natural gas methane during the decomposition of organic debris is responsible for minor phenomena of sedimentation termed gas pits. Some of these are small circular pits with surrounding mud mounds formed by the escape of gas bubbles from the surface of mud bars. Larger crater-like pits are formed in submerged mud and silt bars as the result of erosion in the vicinity of active gas bubble agitation." One large gas pit illustrated in the article is about 3 feet in diameter and over a foot deep. (R8) These gas pits seem closely related to the sea-floor pock marks (X6)

Rich Playa, Terry County, Texas. "Peculiar concentric structures occur locally in the sandy, gypsiferous, bentonitic clay, of Rich playa. Although only 30 of these strutures were found, cross-section of the playa shoreline indicates preservation of previous structures by filling of the low, trough-like areas.

The most probable origin, consistent with present geological knowledge, is escape of entrapped gas, however, the Rich playa structures are significantly different from previously described gas produced features. Consequently these structures are termed gas rings.

.....

The gas rings are confined to a layer of blue-gray, gypsiferous, and sandy bentonitic clay. The majority of the rings are from 15 to 18 inches in diameter; however, one is at least 4 feet across; and faint outlines of like structures some 6-8 feet in diameter appear 200 yards to the south. The shape, when small, tends to be circular, but as the diameter increases the shape becomes oblong." (R20)

X5. Spring pits. Like the gas pits above, these pose no problems in explanation.

Parry Sound, Ontario. "Spring pits have been described (Quirke, 1930) on the shores of Maple Lake near Parry Sound, Ontario. These were formed in a sandy submerged beach by numerous water outlets. They were observed to be usually under 2 feet in diameter and 6 inches in depth. They appear to be more shallow and irregular than gas pits." (R8)

X6. Sea-floor pock marks. These appear to be world-wide phenomena, possibly with more than one explanation.

Scotian Shelf, off eastern Canada. Abstract. "Pockmarks, cone-shaped depressions that occur in unconsolidated fine sediments at the seabed, are generally thought to be formed by gas ascending from underlying sediments. A mosaic of pockmarks in Emerald Basin on the Scotian Shelf was constructed and the problems of mosaic construction are discussed. Within the study area pockmarks have an average depth of

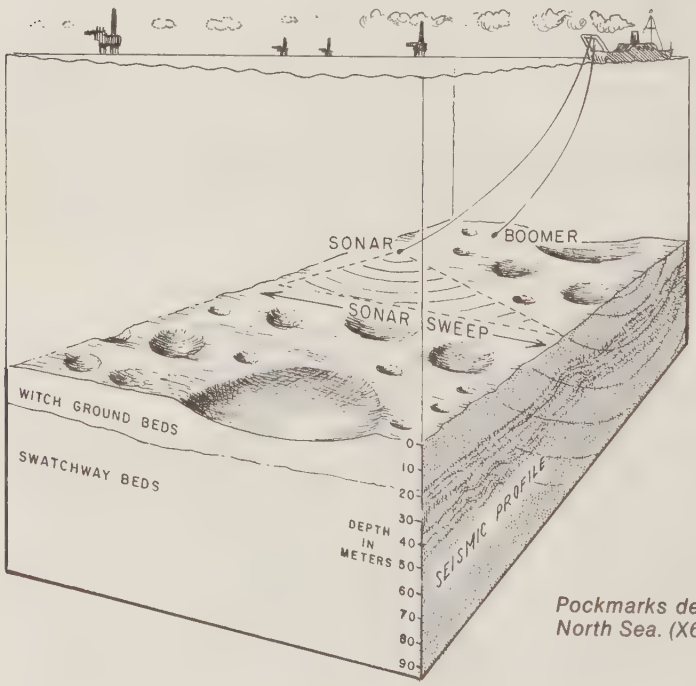
6 m, and average diameter of 85 m and cover up to 18% of the seabed. Pockmarks that occur in thin clay (LaHave clay) are generally < 5 m deep and those in thick clay are up to 15 m deep. Many pockmarks are elongate in shape and show a preferred orientation, both of which may be due to the influence of bottom currents. Within the study area, the process of pockmark formation has displaced 2.5×10^5 m^3 km^{-2} of sediment. Pockmarks on the Scotian Shelf appear to be inactive (relict) and in cases where they are buried they are referred to as ancient." (R13) An earlier study of the Scotian Shelf pockmarks attributed them to gas or subsurface water welling up. (R9)

Off Point Mugu, California. "A number of unexplained craters, three to five feet in diameter and one to two feet deep, have been found in the steep underwater slopes of Point Mugu Submarine Canyon off the southern California coast.....The craters were found every 10 or 15 feet, spread over an observed area about the size of a football field." Three possible causes were listed: collapse of unconsolidated sediments due to earthquake action, the upwelling of gases, and sand-water eruptions. (R12, R11)

The North Sea. "The topography of the seafloor around Britain, like that of its land area, has formed over many thousands of years and results from many well understood geological processes. So it is surprising that recent studies have discovered a wide expanse of seabed in the middle of the North Sea---between 15 000 and 20 000 square kilometers in area---which appears on sonar pictures to have a topography much like a miniature lunar landscape. Geologists by no means fully understand the origin of the principal features---small craters called 'pockmarks'---and are currently hotly debating the subject.

This tract of seafloor, just north of the Forties oilfield, is about 150 metres below sea level. On the broad scale the seabed is flat or gently sloping, but there are many thousands of the shallow crater-like features distributed across it. These pockmarks are defined as cone-shaped depressions normally without a rim, which occur in unconsolidated sediments at seabed level. They were first recognized off Canada where investigators---using echo-sounders, side-scanning sonar and submersibles---found craters that were typically 15-45 m across and 5-10 m deep.

In the North Sea, the Institute of Geological Sciences, supported by the Department of Energy, is making a detailed study of pockmarks in an area of about 80 sq. km where 2500 depressions have been identified; individual pockmarks are between 10 m and 100 m across, and from 2-8 m deep. Thus the larger of them are shallow



Pockmarks detected by sonar on the floor of the North Sea. (X6)

craters about the size of a football pitch the sides of which generally slope between 5^{o} and 10^{o} inwards, though in some of the smaller pockmarks the slopes are up to 17^{o}." Gas eruptions, perhaps in response to storms and earthquakes are the favored explanation. The pockmarks seem to be developing today. (R15; R13, R17)

Bering Shelf, off Alaska. "Abstract. As many as 1,340 small craters per square kilometre cover the sea floor of Norton Sound in the northeastern Bering Sea. The craters are circular pits, 1 to 10 m in diameter and less than 1 m deep, observed on sonographs over 20,000 km^2 of northern Norton Sound sea floor. Craters are typically associated with acoustic anomalies, near-surface peaty mud, and gas-charged sediment." The peaty mud is thick and contains abundant biogenic methane, which may be released by storm action. Some of the craters disrupt modern ice gouges, indicating they are forming today. (R14; R16) The pockmarks are similar to nearby pits and furrows excavated by whales and walruses in their search for food. (R19)

References

R1. Stiffe, A.W.; "On the Mud-Craters and Geological Structure of the Mekran Coast," Geological Society of London, Quarterly Journal, 30:50, 1874. (X1)

R2. Mendenhall, T.C.; "Report on the Charleston Earthquake," Nature, 35:31, 1886. (X2)

R3. Newsom, J.F.; "A Natural Gas Explosion near Waldron, Ind.," Journal of Geology, 10:803, 1902. (X3)

R4. "Crater Pits," English Mechanic, 85: 370, 1907. (X3)

R5. Hobbs, Wm. H.; "Some Topographic Features Formed at the Time of Earthquakes and the Origin of Mounds in the Gulf Plain," American Journal of Science, 4:23:245, 1907. (X2)

R6. Thomas, E.T.; "Craterlets in East-Central Arkansas Probably Due to the New Madrid Earthquake," Science, 56: 20, 1922. (X2)

R7. Sheppard, George; "Small Sand Craters of Seismic Origin," Nature, 132:1006, 1933. (X2)

R8. Maxson, John H.; "Gas Pits in Non-Marine Sediments," Journal of Sedimentary Petrology, 10:142, 1940. (X4, X5)

R9. King, Lewis H., and MacLean, Brian; "Pockmarks on the Scotian Shelf," Geological Society of America, Bulletin, 81:3141, 1970. (X6)

R10. "Erupting Rocks," Pursuit, 6:33, April 1973. (X3)

R11. "Potholes in the Wake of a Quake," New Scientist, 58:663, 1973. (X6)

R12. "Unexplained Craters Pock the Ocean Floor," Science News, 103:240, 1973. (X6)

R13. Josenhans, Heiner W.,et al; "A Side-Scan Sonar Mosaic of Pockmarks on the Scotian Shelf," Canadian Journal of Earth Sciences, 15:831, 1978. (X6)

R14. Nelson, Hans, et al; "Modern Biogenic Gas-Generated Craters (Sea-Floor 'Pockmarks') on the Bering Shelf, Alaska," Geological Society of America, Bulletin, 90:1144, 1979. (X6)

R15. McQuillin, Robert, and Fannin, Nigel; "Explaining the North Sea's Lunar Floor," New Scientist, 83:90, 1979. (X6)

R16. Nelson, Hans, et al; "Modern Biogenic Gas-Generated Craters (Sea-Floor 'Pockmarks') on the Bering Shelf, Alaska," GSA News & Information, 1:190, 1979. (X6)

R17. Fannin, Nigel G.T.; "Pockmarks in the North Sea," Open Earth, no. 13, p. 28, 1981. (X6)

R18. Weisburd, S.; "A Century after the Charleston Quake," Science News, 129: 263, 1986. (X2)

R19. Nelson, C. Hans, and Johnson, Kirk R.; "Whales and Walruses as Tillers of the Sea Floor," Scientific America, 256: 112, February 1987. (X6)

R20. Reeves, C.C., Jr.; "Gas Rings from Terry County, Texas," Journal of Sedimentary Petrology, 34:190, 1964. (X4)

ETB4 Gilgai Topography

Description. Circular and rectangular depressions of modest size found in certain soils in Australia, the Middle East, and Africa, and probably elsewhere. Gilgaies often display regular spacings and, in the case of rectangular varieties, are oriented. Gilgaies vary in depth from about zero to several feet; in maximum dimension, they may reach 40-50 feet. They seem to occur only in certain types of soil, notably calcareous soils, and are thought to be the consequence of soil movement during cycles of wet and dry conditions. Some types of gilgaies occur as stripes and networks, which are very similar to periglacial patterned ground. Such gilgaies are classified thus (ETP1).

Data Evaluation. The Australian scientific literature is the best source of information on gilgaies, but it is difficult to acquire and search. However, several good papers have been found that treat these curious soils. Rating: 1.

Anomaly Evaluation. Although gilgais are observed forming today, the precise mechanism remains obscure. It is also unclear why likely areas of soil are unaffected while surrounded by abundant gilgaies. Despite these uncertainties, no geological laws are at risk here. Rating: 3.

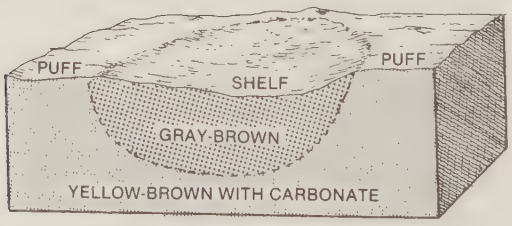
Possible Explanations. Since gilgaies occur where periglacial phenomena and frost action are very unlikely, cycles of drying and wetting are considered the primary cause of gilgaied soils. The soil where gilgaies form develops deep cracks when dry, and these probably contribute to the creation of gilgaies.

Similar and Related Phenomena. Patterned ground (ETP1); large-scale polygonal cracking of soils (ETP3); Mima Mound topography (ETM1); anthropogenic structures, such as ridged fields (South America) and mining operations (Iraq, R3).

Examples

X1. General observations. "The term 'gilgai' was used by Hallsworth et al. (R1), (being the aboriginal word for a small waterhole), to describe soils with two types of surface soil showing (usually) appreciable surface micro-relief. This takes the form of sub-parallel continuous or discontinuous, ridges and valleys, or random mounds and depressions, or a network arrangement of ridges with enclosed depressions. The depressions may fill with water after rain, hence the name 'gilgai.' The ridges are usually referred to as 'puffs' and the valleys as 'shelves,' and the relief difference between the two ranges from nothing to 8 feet. The puff soil is calcareous, containing abundant impure calcareous nodules which are formed as a result of soil processes. The shelf soil is not calcareous on the surface, but has a subsoil similar to that found at the surface of the puffs. These differences are usually reflected by differences in vegetation.

'Gilgai' is synonymous with such terms



A cross section of gilgai soil. (X1)

as 'melon-hole,' 'crab-hole,' 'devil-devil,' 'Bay of Biscay country' and, possibly mima-mound." The genesis of gilgai soils is not well-understood. In most areas where they occur, frost action is very unlikely. (R2)

X2. Australia. Hallsworth et al have described six types of gilgaies found in New South Wales. The lattice, wavy, and stony gilgaies resemble patterned ground and are discussed in Section ETP1 of this Catalog. However, the round, tank, and melon-hole gilgaies are similar in appearance to the other depressions covered in this section.

Round gilgai: "These are the most widespread. The puffs and shelves are subcircular in outline, usually equally well-developed, and show no particular orientation. The shelves are mostly concave and not uncommonly without a sink-hole." The vertical interval or maximum relief may be 8 feet, with wave-lengths up to 40 feet.

Tank gilgai: "In the central west of the State (New South Wales), near Forbes, the development of puffs and shelves has been observed on a large scale and in roughly rectangular form. The vertical interval is 2-4 ft., the puffs about 30 ft. wide, and the

Plan view of Australian tank gilgaies. (X2)

shelves 40-60 ft. long, 20-40 ft. wide, and when filled with water give the appearance of a series of tanks." (These must appear like Alaskan oriented lakes in miniature! WRC)

Melon-hole gilgai: "These occur under high rainfalls on the north coast of New South Wales, extending along the Richmond and Tweed rivers. This complex consists of large mounds and depressions in the centre of which are holes of varying shapes. These holes are from 309 ft. wide, 6-9 in. deep, and the break in the level from the depression to the hole is quite abrupt." (R1) (Here we have terrain similar to that of Mima Mound country (ETM).WRC)

X3. Iraq. S. A. Harris has made a soil survey south of Kirkuk, in northern Iraq, and reports round and tank gilgaies, plus types not fitting Australian classifications. (R3)

X4. Africa. Gilgai soils also occur on the Athi Plains, in Kenya, the Shire Valley, Nyasaland, and in Tanganyika. (R3; R4)

References

R1. Hallsworth, E.G., et al; "Studies in Pedogenesis in New South Wales: VII. The Gilgai Soils," Journal of Soil Science, 6:1, 1955. (X2)

R2. Crook, Keith A.W.; "'Finger-Print' Pattern on Certain Calcareous Soils--- A Suggestion," American Association of Petroleum Geologists, Bulletin, 42:3001, 1958. (X1)

R3. Harris, S.A.; "The Classification of Gilgaied Soils: Some Evidence from Northern Iraq," Journal of Soil Science, 10:27, 1959. (X2-X4)

R4. Stephen, I., et al; "Gilgai Phenomena in Tropical Black Clays of Kenya," Journal of Soil Science, 7:1, 1956. (X4)

ETB5 Mountain-Top Depressions

Description. Circular, elliptical, and trough-like depressions observed on mountain tops. Generally, these depressions occur in solid, exposed rock, usually granite. They range in size from a few inches to over a mile in extent. Mountain-top depressions are a world-wide phenomenon.

Data Evaluation. The smaller depressions in granite, the so-called 'weather pits,' have been studied in some detail, but the much larger circular structures in the same regions are less well-known. Geologists in other countries, particularly those in Europe, seem to have done

much more research on the mountain-top depressions, but we have not yet incorporated this foreign literature. Rating: 2.

Anomaly Evaluation. The small, simple weather pits (X1) seem undeniably to be the result of weathering. However, those weather pits surrounded by 'rock doughnuts' are not so easily explained. The mile-sized coexisting circular structures existing in the same granitic regions (X2) are blamed on large-scale exfoliation, but their extents and circular patterns remain enigmatic to some degree. Moving to the ridge-top troughs (X3), we find reasonable explanations in terms of creep along shear planes. The anomaly rating situation is complicated by the intrusion of two more radical explanations: (1) some rock basins were shaped by ancient man for unknown purposes (especially in the Sierra Nevada); and (2) the large-scale circular structures in the mountains west of the Carolina Bays (ETB1) may somehow be associated with the Bays, say, through a common explanation in terms of meteorite impact! Because of these possible but improbable connections, we assign a low level of anomalousness to these otherwise straightforward geological problems. Rating: 3.

Possible Explanations. As described above.

Similar and Related Phenomena. Rock basins carved by ancient man (M); swallow-hole weathering. The Carolina Bays (ETB1), which are located just east of both small and large mountain-top depressions.

Examples

X1. Weather pits in granite. Although a worldwide phenomenon, weather pits are developed most spectacularly along the tops of the Appalachians.

South Carolina. Abstract. "At two localities in the Piedmont of South Carolina unusual basins occur on the surface of bare dome-like granite masses. These basins have nearly flat floors and are almost symmetrical. The majority range from 10 to 40 feet in diameter, and from 1 to 3 feet in depth. They have been formed by localized weathering. After a miniature pit is started, weathering at that point is accelerated by the action of moisture and vegetation. Microscopic and chemical studies indicate that the granite in the pits weathers largely by alteration along mineral boundaries which results in crumbling of the rock. The fragmental residue is removed largely by the flushing action of rainwater. A portion is carried out in solution, and some may be blown out by wind." (R3; R4)

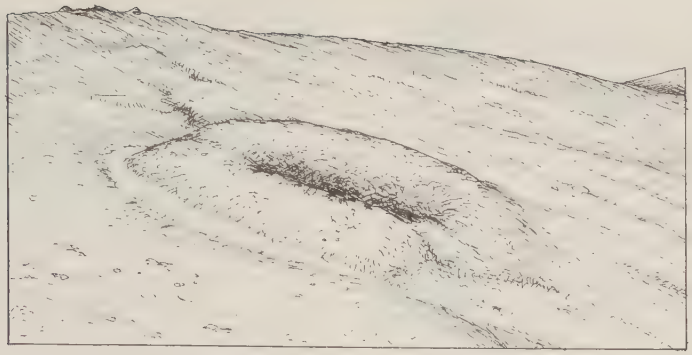
Georgia. Abstract. "Shallow circular weathering pits, 2-6 feet in diameter, are conspicuous on gently sloping granite surfaces at Stone Mountain, Georgia. Many are ring-shaped; the rim is deeply etched, but the center stands up as a mount. The ring pits are too numerous and well-developed to be merely fortuitous.

The ring pits are developed in thinly exfoliating granite, generally where weathering has breached the uppermost, partly detached shell. The next lower shell, bulged up like a blister, forms the central mound. A slight opening beneath the blister is inferred from the hollow sound resulting from a hammer blow. Where weathering has breached some blisters the opening is visible." (R5)

Texas. "The present writer has observed numerous weather pits of various sizes on granite at several localities in central and trans-Pecos Texas. A very few of them are surrounded by raised annular rims, and these are the subject of the present discussion. They may conveniently be called 'rock doughnuts.'.....

The largest doughnut found is located on the west side of the main granite dome at Enchanted Rock, just above the nearly vertical portion of the west face of this dome. A smaller one occurs on the east side of the first large dome to the southwest. Four doughnuts, one of which has been partly destroyed by disintegration, occur on the northwest side of the Flatrock dome, close to the Katemcy-Fredonia road about 6 miles east of Katemcy and 3 miles west of Fredonia. Two more good ones were found on the summit of a granite knob about 1.5 miles south-southeast from Katemcy. A few other less perfect examples were found in the general vicinity.

Most of the doughnuts occur on granite surfaces having a decided slope, although not on the steepest slopes. Two or three, however, were found on sensibly horizontal surfaces, such as the bottom of a large weather pit. Most, but again not all of them, occur along joints, which in such cases pass



A rock doughnut from Enchanted Rock, Texas. (X1)

right through the doughnut. At Flatrock dome three excellent doughnuts occur in line along a joint, but nearby a still more perfect example shows no jointing at all.

Each rock doughnut consists of a nearly circular weather pit, from about 6 inches to about 6 feet in diameter, encircled by a rounded annular ridge up to about 6 inches high and 18 inches wide. In shape each resembles half of a doughnut or an automobile inner tube split in the plane of the wheel. In some examples the annular ridge in turn is surrounded by a shallow annular depression, which shows evidence of scour by running water and connects with shallow channels in the rock above and below."

.....

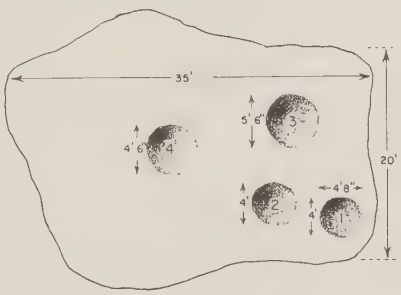
"Possible Origin. The origin of the rock doughnuts is extremely puzzling, and the writer has as yet no satisfactory explanation for them. They are unquestionably connected with the weather pits, but they are rare in comparison with the total number of weather pits, which suggests that they result from some unusual modification or extension of the processes responsible for the pits." (R7)

New York. Incipient weather pits have been detected on the summit of Bear Mountain. (R4)

California. Rock basins occur in Yosemite, where geologists have unhesitatingly called them weather pits. (R4) However, other similar basins in the Sierra Nevada, in and adjacent to Sequoia National Park have been attributed to the labors of ancient man, as the following quotation illustrates.

"In that region there occur numerous smoothly rounded basins artfully hollowed out of the solid granite, the work of a prehistoric race of men of whom the present Indians know nothing. These cavities measure as a rule from four to five feet in diameter and from one to two feet in depth, and are shaped like huge wash bowls with smoothly curving sides and bottoms. To local residents they have been known for many years. But no critical examination of them has been made hitherto. At first they were thought to have been worn by the action of running water, and reports of the occurrence of such basins in locations where streams cannot have existed were given but scant credence.

The basins in question are found in groups at altitudes ranging from 4,000 to 9,000 feet above sea level, and scattered over an area about 35 miles long from northwest to southeast in that part of the Sierra Nevada in Tulare county which is drained by the Kaweah and Tule rivers." (R9)



Ground plan of some California rock basins believed to be human artifacts. (X1)

Great Britain. Numerous rock basins are found atop the granite tors of Cornwall, and in Wales as well. The Cornwall basins average about 2 feet in diameter. Perhaps

not surprisingly, they were originally thought to be the handiwork of the Druids! (R2)

Africa. On the west coast of Africa, large natural rock "cisterns" have been found on huge masses of granite rising from the surrounding plains. (R1)

In South Africa, shallow basins occur on sandstone mountains. (R7)

General observation. Depressions similar to weather pits can also be found in limestone regions, where they are dubbed "tinajitas." (R7)

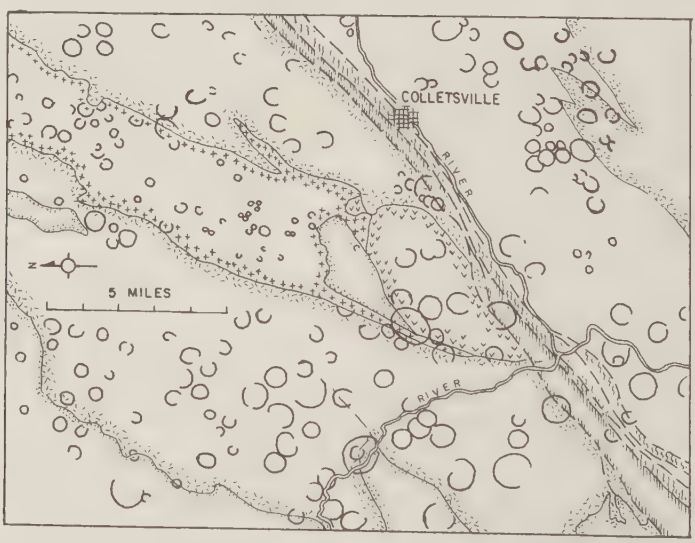
X2. Large-scale circular structures in granite. Aerial photography has discovered much larger circular depressions in granite.

North Carolina. Abstract. "Aerial photographs of areas of crystalline rock in the Piedmont and Blue Ridge of western North Carolina reveal numerous large-scale arcuate, circular, and elliptical patterns with diameters from 1000 to more than 4000 feet. They are commonly defined by curving streams, curving ridges, and curving belts of contrasting vegetation. Geological mapping shows that the circular patterns are not related to primary geologic structures; circumstantial evidence indicates that they are related to exfoliation or sheeting. Rock spalls up to half a mile in diameter may be formed by dilation of the rock as the erosion surface is lowered. The spalls enable tectonic joints to open, forming thin layers of rock of differing permeability and susceptibility to erosion. Exfoliation is probably involved in the erosive process and is probably more important than has been realized, especially in crystalline terrane." (R8)

X3. Ridge-top troughs. These linear strutures parallel the ridge axes.

Washington. "The ridge-top depressions of the Olympic Mountains are shallow swales or V-shaped troughs lying along or near ridge tops. They range in length from about 20 to 1,000 m and in depth from a few meters to 10 meters. Some near timberline form picturesque meadows, here and there with small ponds frequented by elk. They are significant elements of the Olympic scenery and natural routes of travel for the mountain hiker.

Very little has been written in the United States about ridge-top depressions, but they seem to be common in Alpine regions throughout the world; they have been described in Europe, Japan, and New Zealand. Penck referred to them as 'doppel-grat,'



Geological map of the Grandfather Mountain area, in North Carolina, showing the most obvious circular structures seen on aerial photographs. (X2)

that is, twin ridge; a well-developed ridge-top depression splits the ridge into two crests. In this paper, the terms 'ridge-top depression' and 'trough' are used interchangeably." The author thinks that most of the ridge-top depressions are the consequence of large-scale creep along deep-seated shear planes. (R6)

References

R1. "Strange Natural Cisterns," Scientific American, 34:248, 1876. (X1)
R2. Cragor, Thomas; "Rock-Basins on Granite Tors in Cornwall," Geological Magazine, 2:8:480, 1881. (X1)
R3. Smith, Laurence L.; "Weather Pits of the South Carolina Piedmont," Geological Society of America, Bulletin, 50: 2011, 1939. (X1)
R4. Smith, Laurence L.; "Weather Pits of the Southern Piedmont," Journal of Geomorphology, 4:117, 1941. (X1)
R5. Hopson, Clifford A.; "Origin of Ring-Shaped Weathering Pits at Stone Mountain, Georgia," Geological Society of America, Bulletin, 70:1764, 1959. (X1)
R6. Tabor, Rowland W.; "Origin of Ridge-Top Depressions by Large-Scale Creep in the Olympic Mountains, Washington," Geological Society of America, Bulletin, 82:1811, 1971. (X3)
R7. Blank, Horace R.; "'Rock Doughnuts,' A Product of Granite Weathering," American Journal of Science, 249:822, 1951. (X1)
R8. Hack, John T.; "Circular Patterns and Exfoliation in Crystalline Terrane," Geological Society of America, Bulletin, 77:975, 1966. (X2)
R9. Stewart, George W.; "Prehistoric Rock Basins in the Sierra Nevada of California," American Anthropologist, 31:419, 1929. (X1)

ETB6 Horseshoe-Shaped Depressions

Description. Groups of depressions shaped like the imprints of horseshoes or horsehoofs. Common orientation is the rule. Widths vary from a few feet to thousands.

Data Evaluation. Two examples are at hand; they are wildly different in nature and information on both is inadequate, lacking precision and depth. Rating: 3.

Anomaly Evaluation. The Arabian hollows (X1) may be aeolian in origin, for their shape resembles some sand-dune geometry. Without further data, speculation is useless. The North Carolina hoofprints have been ascribed to subsurface solution phenomena---seemingly for lack of any other reasonable explanation. Even though we are reduced to guessing causes, it is likely that well-understood geological processes will account for both types of depressions once more is known about them. Rating: 3.

Possible Explanations. See above.

Similar and Related Phenomena. Fields of sand dunes; Carolina Bay-type depressions (ETB1).

Examples

X1. Large, oriented horseshoe-shaped hollows. Nefud Desert, Central Arabia. "Here he (W.S. Blunt) observed a strange phenomenon, which he describes as the only feature of the tract. The whole surface of the plain is pitted with deep horseshoe hollows, called by the Arabs fulj, which are shown to be permanent in site and conformation by the shrubs and bushes which line their sides, and by the tracks which cross and recross each other in such of them as are frequented by sheep. They are absolutely uniform in shape, differing only in size, and are all set with great regularity toward the same point of the compass. In form they exactly reproduce the print of an unshod horse's hoof, the toe pointing westward and being marked by a steep declivity, while the bottom of the hollow slopes gradually upward to the heel, until it reaches the general level of the plain. The frog of the hoof is roughly represented by a number of shallow watercourses converging to the lowest

point, the toe. Solid ground sometimes occurs at the bottom of the deepest of the pits. They vary in depth from twenty to two hundred and twenty feet, and in width from fifty yards to half a mile; the appearance of depth is often enhanced by a sand-mound at the western edge of the hole. As seen from the tops of the higher rocks, the fuljes 'run in long, sinuous strings with a main direction generally corresponding with their aspect,' which gives them still more the appearance of huge horse-tracks." (R1)

X2. Small, regenerating hoofprints. North Carolina. "Near Bath, N.C., are eight shallow depressions in the ground which legend says originated when a bucking racehorse threw his profane rider against a tree and killed him. The eight marks, conveniently placed to fit the story, indubitably exist and they have persisted for over a century according to records.

Thousands of visitors, at one time or another, have viewed them and efforts to fill them up---and make them stay filled---have failed. Around Bath you can talk with grown men, who as children tried to do this. Temporarily they succeeded but ever the hoofprints reappeared." As for explanation, scientists suggested that subsurface marl dissolves away, perpetuating the depressions. (R2) This 'explanation' hardly explains the shape and regularity of the famous footprints. No apologies will be made for including this delightful item!(WRC)

References

R1. "Features of the Central Arabian Desert," Popular Science Monthly, 17:281, 1880. (X1)

R2. "North Carolina's Legend of Hoofprints Explained," Science News Letter, 34:142. (X2)

ETB7 Cookie-Cutter Holes

Description. Holes left by the mysterious removal of large slabs (divots!) of turf. The intact slabs, weighing tons on occasion, are found nearby and closely match the holes. Human activity does not seem indicated.

Data Evaluation. Two examples are cataloged below. The latter was investigated by geologists and received considerable publicity in the States. Fraud is always possible in such situations but seems unlikely in the examples cited. Rating: 1.

Anomaly Evaluation. Several explanations have been suggested (see below), but they appear weak. The "cookie cutter" phenomenon may well be called "Fortean" (after Charles Fort). The explanation is likely mundane, but the potential exists for wild surmise. In such a climate, anomaly evaluation is risky. Rating: 2.

Possible Explanations. Earthquake action was ventured for the 1984 incident. Since large boulders are ejected from the ground in some quakes, "divots" might be, too, although the precise excision of such large chunks seems improbable. Lightning strikes, which explode ground water into steam, represent another possibility. However, no burning and no fulgerites have been found.

Similar and Related Phenomena. Boulder launching by earthquakes (GQH1).

Examples

X1. January 1887. Penrith, United Kingdom. "A rather unusual occurrence took place a few days ago in a grass field near my house. The facts are these. On a dry hill side a piece of turf (with soil adhering to a depth of 5 inches) was lifted bodily out of its position and placed in exactly its original shape at a distance of 8 feet. It is triangular in shape, and its sides are respectively 3 ft., 3 ft. 2 in., and 2 ft. 11 in. There is a large crack in the soil where it

has been torn out about a yard long. This occurred during hard frost, when the ground was frozen. There is ample proof that no artificial means were employed, for a thick hoar frost prevailed on the morning of its occurrence, and foot marks would have been readily detected. Can any one suggest a cause?" (R1)

X2. October 1984. Grand Coulee, Washington. "No one can figure out how, but a chunk of earth weighing tons was plucked out of a wheat field, as though someone had used 'a giant cookie cutter,' and put down, right side up, 73 feet away.

.....

The displaced slab, mostly soil held together by roots, is about 10 feet long and 7 feet wide. Its thickness varies from 2 feet at one end to about 18 inches at the other.

The shape and thickness of the piece exactly match the hole that was left behind, just like a piece in a jigsaw puzzle, though it was rotated about 20 degrees.

There were no marks to indicate that machines were used, the Seattle Times reported Friday, and the land is fairly flat." (R2; R3, R4)

References

R1. Benn, Thos G.; "Remarkable Displacement of Earth," Symons's Monthly Meteorological Magazine, 22:8, 1887. (X1)

R2. "A Rare Phenomenon Moves Earth," Philadelphia Inquirer, p. 3-A, November 25, 1984. (X2)

R3. Williams, Hill; "Cookie Cutter? Eerie Force Uproots Big Divot," Seattle Times, November 23, 1984. (X2)

R4. Murphy, Cullen; "Earth Cookie," Atlantic, p. 14, April 1985. (X2)

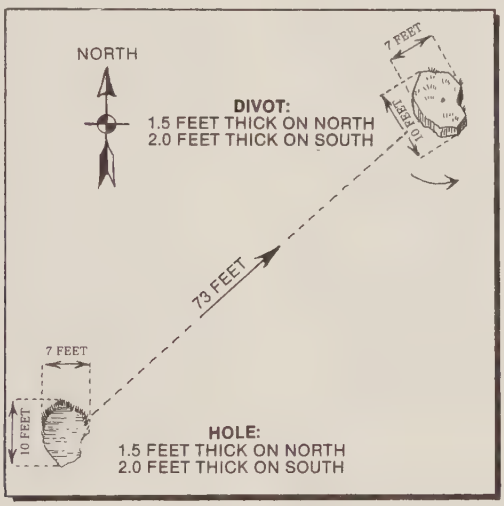


Diagram of the "cookie-cutter event" of 1984, Grand Coulee, Washington. (X2)

ETB8 "Bottomless" Pits

Description. Holes where no bottoms have been found. Such "pits" may be open or water-filled. Of course, bottoms are eventually found.

Data Evaluation. The data smack of sensationalism and must be taken with several grains

of salt. Some basis doubtless exists for each example, but one would have expected that the phenomena would have been clarified by now, particularly the one in New York City. Rating: 3.

Anomaly Evaluation. No geological dogmas preclude the existence of very deep natural holes or difficult-to-fill swampy areas. Rating: 4.

Possible Explanations. None needed.

Similar and Related Phenomena. Ordinary quicksand; the Arabian "dry" quicksand (ES); the "blue holes" of the Bahamas (ETS1).

Examples

X1. Water-filled pits. In these, materials and animals sink out of sight; and no bottom can be plumbed.

New York. "A 'bottomless pit,' which has for more than two centuries defied all attempts to fathom it, exists in New York City. It is located on the west side of Morris-avenue, between One Hundred and Seventy-First and One Hundred and Seventy-Second Streets. At first sight it appears to be a shallow pond, about 60 or 75 yards in diameter; but within the past few years more than 100,000 tons of earth and stone have been dumped into this pond without the slightest apparent effect towards filling it. Recently a horse attached to a heavy waggon backed into this dangerous pool. In a few minutes both had gradually sunk out of sight, and though the owner has searched to a depth of over 100 ft. he has found no trace of his property.

This bottomless pit has been a source of wonder and fear for over two hundred years. The early histories of New York mention it frequently, the first reference appearing in the year 1696. The Indians and the first settlers called it the 'Black Swamp.' The Indians believed it to be the abode of evil spirits.

.....

A year ago the contract was awarded to Mr. D.W. Moran, who confidently expected that a few days work would transform the swamp into solid ground and do away with New York's bottomless pit for ever. To the amazement of the contractor and workmen, load after load sank out of sight without raising the surface of the water in the slightest degree. Sixty thousand cubic yards of earth and stone disappeared in its hungry mouth, and yet the bottomless pit remained as bottomless and as mysterious as ever.

This went on for months. Finally, the endless stream of dirt and stone appeared to take hold. The water drained off and the earth was heaped up to the required level. The workmen hammered it down, and when they left it one night they thought that their task was finished. Next morning, to their surprise, the pit has opened its mouth again and completely swallowed all that had been heaped into it." (R1) If such a pit still existed in the middle of New York City, we should have heard about it by now!

X2. Very deep open pits. Here, no bottoms can be discerned visually and exploration parties have not reached the floors.

Mexico. "Ezequiel Ordonez, dean of Mexican geologists, and Ricardo Mongez, geophysicist and dean of the faculty of the National University of Mexico, will soon explore a mineral-lined pit, believed to be over a mile deep, which is located 80 miles south of Mexico City.

Many legends surround this enormous pit, called Hell's Mouth or Devil's Pit. Tradition says that Indians used the pit to kill enemies and punish criminals. Spaniards threw prisoners into its depths. During Mexico's Independence War and the civil wars which followed, men and women were entombed in the pit.

The rumors are that gangster murders have recently been committed in Hell's Mouth. In hunting for the body of a victim, searchers descended 1,500 feet into the pit. Cold, wind, and lack of air prevented a lower descent. From various measurements taken, it is estimated that the probable depth of the pit is 6,000 feet." (R2)

References

R1. "A Bottomless Pit," English Mechanic, 73:492, 1901. (X1)

R2. Leiva, Agustin Aragon; "Hell's Mouth in Mexico," Science News Letter, 44: 279, 1943. (X2)

ETB9 Large Assemblages of Glacial Kettles

Description. Groups of large crater-like depressions in glacial deposits. Commonly called "kettles", these depressions have depths up to 150 feet, and diameters may attain 8 miles. The Wisconsin Potash Kettles can be traced for 100 miles.

Data Evaluation. The journals examined to date have been rather silent on the matter of kettles, but modern textbooks on glacial geology contain some description. Despite the lack of particulars in our files, kettles represent a well-known phenomenon. Rating: 1.

Anomaly Evaluation. Although early geologists leaned toward glacial flood waters as the cause of kettles, the modern consensus is that the depressions are the consequence of the melting of buried or partially buried glacial ice. The latter explanation seems to fit all the facts. There is little that is anomalous here. Rating: 4.

Possible Explanations. See above.

Similar and Related Phenomena. Swirl pits formed during heavy flooding; the Carolina Bays (ETB1), which according to one theory were formed when stranded icebergs melted; ripples in glaciated regions (ETR1), which also suggest strong glacial flooding.

Examples

X1. General observations. "A kettle is a basin in drift, created by the ablation of a former mass of glacier ice that was wholly or partly buried in the drift. Few kettles exceed 2 km in greatest diameter, although some large ones in Minnesota attain diameters of 13 km. Whereas most kettles are less than 8 m deep, some exceed 45 m. They may have any shape in plan, but most tend to approach circularity, the shape any mass of ice separated from a glacier will tend to assume as ablation progresses. Kettles occur singly, as groups (especially linear groups of coalescent basins), or in such profusion that the body of drift in which they occur appears as a maze of mounds and basins sometimes described as 'kame-and-kettle topography.'" (R2)

X2. Wisconsin. "An important paper was read by Professor Charles Whittlesey, on 'Drift Cavities,' as the 'Potash Kettles' of Wisconsin. Along the summit of the dividing ridge between the waters of Rock River and those of Lake Michigan, there are numberless crater-like depressions, which are called by the people 'Potash Kettles.' They are in the form of cavities sunk below the general surface 10, 15, and even 100 feet, their outline rudely circular, and their sides as steep as the earth will stand. They have been traced about 100 miles. The materials in which they have been found is coarse drift. They seldom contain water; boulders are found in and around them. While exploring the State in 1849 it occurred to the Professor that these cavities cannot be explained by the usual and well-known examples of aqueous deposits. Terraces and oblong ridges of sand and gravel might be formed by currents and eddies acting on the loose material; but these are depressions on an even surface. He stated that in the present state of knowledge it was difficult to account for all the phenomena of western drift, but to his mind the depressions in Wisconsin were most readily and satisfactorily explained on the theory that they were the result of glacial action." (R1)

An encyclopedia describes the Wisconsin kettles as follows: "One of the most spectacular features of glacial origin in Wisconsin is the famous Kettle Interlobate Moraine, which records division of the ice into two lobes, one in the Green Bay lowland, the other in the Basin of Lake Michigan. The Kettle Moraine is the accumulation, chiefly of gravel, in the reentrant angle between these two lobes as their margins melted back." (R3)

X3. New York. Depressions similar to the Wisconsin Potash Kettles also exist in Madison and Oneida counties, New York. (R1)

X4. Minnesota. Very large kettles---up to 13 kilometers in diameter---have been described in this state. (R2)

References

R1. "Wisconsin Potash Kettles," Scientific American, 1:118, 1859. (X1)

R2. Flint, Richard Foster; "Morphology of Glacial Drift," Glacial and Quaternary Geology, New York, 1964, p. 212. (X1, X4)

R3. Thwaites, Frederik T., and Flint, Richard F.; "Glaciated Terrain," McGraw-Hill Encyclopedia of Science and Technology, 6:216, 1977. (X1)

ETB10 Depressions in Chalk Country

Description. Pits, craters, and broad depressions in chalk and its overburden. These depressions vary widely in size and shape.

Background. Sinkhole phenomena are not considered anomalous enough to include in these Catalogs. While the chalk country depressions are closely related to sinkhole phenomena, they possess enough curious features to induce their inclusion.

Data Evaluation. The literature is very skimpy, providing few details. Rating: 2.

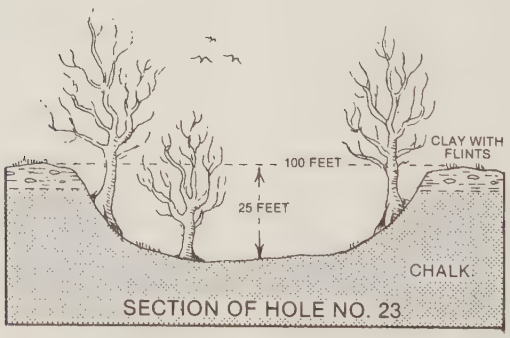
Anomaly Evaluation. Like limestone, chalk is notoriously subject to water erosion and solution. The basic nature of the phenomena is not in doubt. Rating: 4.

Possible Explanations. Solution, spring sapping, slumping, etc.

Similar and Related Phenomena. Sinkholes; the Carolina Bays (ETB1).

Examples

X1. Pits in the chalk overburden. "On Affpuddle Heath and Piddletown Heath, near Dorchester, at an elevation of rather less than 500 feet above the sea, the surface is pitted with circular or oval hollows, like inverted cones, having occasionally a double apex. Their number is very great; and only the



Section of a pit in English chalk country. (X1)

largest are marked in the Map of the Ordnance Survey.

They usually vary from about 60 to 80 yards in circumference; but one measures 130 yards, and another, called 'Culpepper's Dish,' is 290 yards round; in the former the sloping sides are 23 yards high; in the latter 47 yards. After observing that these pits could not have been formed by the washing away of the underlying sand-beds, the author proceeded to show that their formation seemed to be due to the subsidence of the material into 'sand-pipes' in the subjacent chalk, owing to the percolation of rain-water containing carbonic acid, which dissolved the chalk." (R1)

X2. Swallow-Holes in chalk. Hampshire, between Alton and Basingstoke. "The area under consideration is riddled with swallow-holes, 118 being marked on the 6-inch O. S. map, all called 'Old chalk-pits.' These holes are very much alike in form, usually roughly circular or elliptical in plan, with greater diameter from 100 to 200 feet, and the depth from 10 to 30 feet. In section they are shaped like a crater, with steep sides and slightly rounded bottom. Almost without exception they have trees growing in them---generally beeches, which are often of great age and size. A few of the holes have undoubtedly been used as chalk-pits. In such cases a roadway for carts has been made down the side, so that the chalk can be got out. It is quite obvious that the holes existed first, and that the roadways into them were made afterwards." They are found with equal frequency on level and sloping ground; but they are hardly ever found in woods. The swallow-holes seem to have been formed entirely from downward solution. (R2)

X3. The coombes. A 130-kilometer stretch from Beachy Head to the Hampshire border, involving the chalk cliffs of the South Downs. "The embayments in the scarp face of the South Downs are known as coombes. They vary in shape from semi-circular to long and linear, and have steep sides and flat floors. The sides of the coombes provide the steepest slopes found on the chalk and slope angles of up to thirty-five degrees are recorded. Too steep for cultivation, the slopes are traditionally grazed by sheep. Where they are no longer used for grazing, the grassland is reverting to scrub and woodland. The flat sheltered coombe floors are often cultivated, but are also used for rich pasture land for animals." No dimensions are given but the photographs of these embayments suggest that the coombes measure many hundreds of yards. No consensus on their origin exists, but slumping and spring-sapping are suggested frequently. (R3)

References

R1. Fisher, O.; "On Some Natural Pits on the Heaths of Dorsetshire," Geological Society of London, Quarterly Journal, 15: 187, 1858. (X1)

R2. Pitt, W.; "Swallow-Holes in Chalk," Geographical Journal, 33:196, 1909. (X2)

R3. Sheail, Gillian M.; "Coombes of the White Chalk Downs," Geographical Magazine, 43:471, 1971. (X3)

ETC CRATERS, ASTROBLEMES, LARGE CIRCULAR STRUCTURES

Key to Phenomena

ETC0 Introduction

In the preceding section (ETB), we dealt with relatively small depressions that could usually be ascribed to the actions of wind, water, and other terrestrial forces. Now, our attention turns to much larger and deeper depressions, some of which measure many hundreds of kilometers in diameter. Chief among these are the so-called astroblemes or "star wounds", which have generally been accepted as products of astronomical catastrophism, due to the presence of shatter cones, cohesite, and considerable melting and metamorphosis. As anyone who reads the scientific literature knows, large meteor craters are now linked to geophysical and biological events of planet-wide magnitude, notably the extinctions in the fossil record. However, this popular subject must be relegated to a future volume; our purpose here is the compilation of the enigmatic features of astroblemes and other large crater-like structures.

Perhaps the most interesting aspect of this whole business of astronomical catastrophism is its relative recency. In 1950, a scientist risked his reputation by claiming the existence of huge meteor-excavated craters. Even more radical, then, was the concept that craters might have been blasted out periodically and might have profoundly affected the course of life.

Not all astronomers have climbed aboard the meteor-crater bandwagon; and they have good reasons. The now-accepted astroblemes and even the famous 1908 Siberian crater display some unexpected anomalies. In most cases, we do not even know the nature of the supposed impacting body; was it an asteroid, a comet, or something else? The most serious anomalies may reside in those huge circular structures, rings of immense size, that are best appreciated from high-flying aircraft. It has even been suggested by some that some of the ocean basins, like the lunar maria, are really impact structures. "Impact geology" is a new field, and it is in ferment.

ETC1 Probable Astroblemes ("Star Wounds")

Description. Large, generally circular depressions, consisting of a central zone surrounded by ring structures. Considerable melting and metamorphism of the surface rocks is usually evident. Magnetometers may also indicate buried bodies. Shatter cones and cohesite, which are symptomatic of past high-pressure events, are present. Diameters are measured in tens and hundreds of kilometers.

Background. When our compilation of scientific anomalies commenced in 1970, descriptions of meteor craters over 1 kilometer in diameter were considered collectible. During Phase 2, the Handbook phase, the lower size limit was raised to 10 kilometers. Now, in Phase 3, only those craters exceeding 50 kilometers are included. This trend parallels the scientific acceptance of terrestrial craters as meteorite created. It was only a few decades ago when only a small handful of meteor craters, all under 2 kilometers, were "recognized."

Data Evaluation. There is no shortage of scientific reports here. The references at the end of this section could be easily multipled by an order of magnitude with further effort. Rating: 1.

Anomaly Evaluation. Science now acknowledges the existence of very large astroblemes, though not without some dissension. In fact, with impact catastrophism now in fashion, the pendulum may have swung too far in the direction of uncritically accepting any large crater-like structure as being of extraterrestrial origin. In this climate, the only anomalous aspects of the four astroblemes detailed below are some minor features that tend to contradict the accepted meteoritic explanation. Rating: 3.

Possible Explanations. Meteoritic action seems indicated in X1-X4, below, but it must be added that many astrobleme features can also be created by volcanism, magmatic action, and other terrestrial forces.

Similar and Related Phenomena. The much large circular structures discerned on maps and aerial photographs (ETC2); the Carolina Bays (ETB1).

Examples

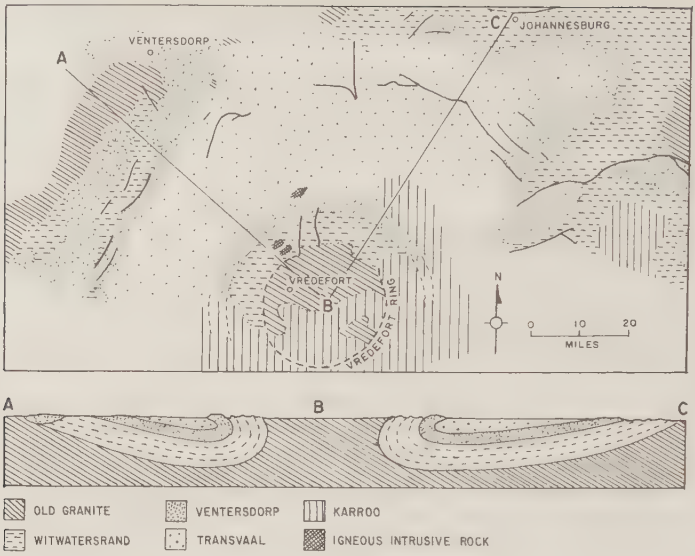
X1. The Vredefort dome and ring structure. Early papers on this complex terrestrial structure rarely mention meteorite impact as a possible cause. (R1) An exception was the 1937 suggestion by J.D. Boon and C.C. Albritton (R26), which was taken up again by R.A. Daly in 1947, when he ventured that "the structure may have been developed by the infall of a speedy meteorite of planetoid or asteroid dimensions..." (R2) In the 1960s, R.S. Dietz carried the meteorite hypothesis further, not only for the Vredefort ring but other possible astroblemes (star wounds), as follows.

"Abstract. The peerless Vredefort Ring structure of South Africa defies rational interpretation by tectonic, volcanic, or magmatic forces. Following the heretical opinion of Boon, Albritton, and Daly, it is suggested to be a meteorite impact structure or 'astrobleme.' Using an impact velocity of 20 km/sec, it was found that an asteroid 2.3 km in diameter would provide the 6 x 10^{28} ergs (1.4 million megatons TNT-equivalent) needed to create the original crater 40 km. across and roughly 16 km deep.

An impact event adequately explains: (1) the apparent impulse direction which was radially outward from the center; (2) the shatter cones as shock-induced; (3) the bilateral symmetry as owing to an oblique impact; (4) the upturned and overtilted 16-km. thick collar as the effect of radial forces spreading out from the explosion focus; (5) the pressure and thermal metamorphism of the sedimentary collar as shock wave-induced; (6) the intensive fracturing and microshearing of rock with relative little displacement as shock wave-induced; (7) the pseudotechylite as a 'shock impactite' produced by overpressures in excess of 10^5 bars; and (8) the granophyre dikes as injected crater-lining 'impactite.'

The uplifted granite plug now filling the original crater was caused by a combination of elastic rebound and isostatic forces. It would seem that, at Vredefort, an impact event transpired equivalent to the formation of Copernicus or Tycho on the moon." (R3)

W.H. Bucher, however, dissented. His primary point being that candidate astroblemes,



The Vredefort Ring in South Africa. The center is a plug of granite surrounded by a collar of up-and overturned strata. (Adapted from Scientific American, *205:56-57, August 1961). (X1)*

such as the Vredefort ring and the Ries Basin in Europe, are not randomly distributed in space and time. More specifically, "the Vredefort Dome is one of a whole string of basic and ultrabasic intrusions, in a part of the continent where such intrusions are widely distributed. " In Bucher's opinion, the Vredefort ring or dome is actually a "geobleme." (R5)

Dietz replied to Bucher, proposing that large intrusive complexes may be created by meteorite impact, as for example the Sudbury complex (X4). In any case, the presence of shatter cones and cohesite at Vredefort constitute very strong evidence for a meteorite impact. (R6)

Although many of today's geologists concur that the Vredefort complex is indeed an astrobleme, some puzzles remain. To illustrate, C.J. Simpson finds that at least some of the shatter cones postdate the overturning of the collar rocks. However, there does not seem to be any way in which tectonic forces could produce the pressures of 20-60 kilobars necessary to form shatter cones. (R17)

X2. The Manicougan impact melt, Quebec. This 210-million-year-old structure is, as the above title implies, generally believed to be the consequence of a meteorite strike. This consensus, like that for the Vredefort complex, evolved rather recently and is by no means totally accepted. The capsule description that follows is by D.L. Orphal and P.H. Schulz.

"The morphology of the preserved Manicouagan structure may be divided into six elements. The central region (1 on the accompanying illustration) is about 25 km in diameter and is dominated by two topographically high regions displaced about 5-7 km north and south of the geometric center of the structure. The northern region includes Mont de Babel, the structure's highest elevation. The inner plateau (2) surrounds this central region with an outer diameter of about 55 km. The inner plateau is marked by a distinct rise in elevation and is overlain by a nearly continuous melt sheet. A circular moat (3) 5-10 km wide bounds the inner plateau. This moat is inferred to be a 65-km diameter graben and is the most prominent feature of the structure. Outside the moat and extending to a radius of about 50 km is the inner fracture zone (4) characterized by a complex and closely spaced joint pattern

The Manicouagan structure, in Canada, is generally thought to be of impact origin. See text for explanation of numbers. (X2)

and drainage towards the center of the structure. Surrounding this zone is the outer fracture zone (5) extending to a radius of about 75 km. The boundary between the inner and outer fracture zones corresponds to an abrupt change in jointing style and drainage direction. The Manicouagan structure is bounded by an outer circumferential depression (not numbered) which has a diameter of about 150 km and is revealed in satellite photographs and detailed topographic maps." Orphal and Schulz remark that there is actually little evidence for a massive flow of impact-melted material to the thick melt sheet outside the transient cavity, as there is for lunar craters. Nor does the lunar crater analogy account for the prominent, ring-like, 2,000-gamma magnetic anomaly over the geometric center of the structure. The magnetic data suggest a shallow causative body. (R14) Additional data may be found in R13.

X3. The Popigay depression, Siberia. This probable astrobleme was investigated by a Soviet expedition. Following is a summary of the expedition's report (R20).

"About five degrees north of the Arctic Circle, near longitude 110° east in the Khatanga river basin, there is a round depression about 45 miles in diameter. The Popigay and other lesser rivers flow through the depressions which has usually been regarded as the result of a collapse some 100 million years ago in the Cretaceous period. But Soviet scientists who explored this feature during the summer of 1970 believe it was formed by the impact of a large extraterrestrial object about 30 million years ago.

.....

Blocks and fragments of rock outline the sunken area and are found as far as 24 miles outside it. The sedimentary rocks around the rim are crushed and crumpled. There is also a circular zone of centrifugal thrust faults, where rocks of many ages are dislocated outward.

Within the depression, exposed cliffs and river valley walls contain impactite (rock fused as glass or slag), which is often noted in meteorite craters. Because the sedimentary rocks containing Cretaceous fossils are generally found in large fragments, not as strata, the Soviet geologists infer that an explosion took place after these sediments became rock. Radioactive dating of fused materials within the depression indicates that they resolidified 30 million years ago." (R24)

X4. The Sudbury complex, Ontario. Faggart et al allow that the Sudbury geological structure "may be the most profitable igneous rock body on this planet." (R21) Such rich mining areas often owe their existence to igneous intrusions from below; and for many years Sudbury was considered as such. A prominent reason for not linking Sudbury to meteorite impact is its highly elongate structure---hardly akin to the nice round craters on the moon, or Vredefort, Popigay, and other similar structures. Nevertheless, in 1964, R.S. Dietz came out strongly for Sudbury as an astrobleme, as summarized next.

"Abstract. The Sudbury structure is interpreted as a 1.7-billion-year-old asteroid impact structure or 'astrobleme' created by a 3×10^{29} erg event. If traveling at 15 km/sec, the asteroid was about 4 km. in diameter. A crater was formed 30 miles across and 2 miles deep. Along with melted country rock, the bolide, possibly a copper-rich nickel-iron meteorite, is still partially preserved, although converted to sulphides, as a marginal sheet along the crater wall and as injections into radial tension cracks. Shock brecciation and rock were heaved up, forming the crater wall. The collar is still

easily recognized along the southern periphery of the Sudbury structure, but it can only be permissibly assumed in the massive granitic rocks around the northern periphery. Because of its great magnitude, the Sudbury event triggered magmatism by offloading the lower crust and mantle and by adding shock heat. Partial fusion of already critically warm rock resulted in a saucer-shaped pool of magma, an extrusive lopolith, formed and differentiated in the crater bottom, also laying down a thick capping of welded tufts (Onaping tufts). A body of water subsequently occupied the basin, in which the Whitewater sediments were deposited. Rebound, isostasy, tectonism (especially the Grenville thrust from the southeast making the lopolith oval), and finally erosion have modified the structure." (R25) The size and age of the Sudbury structure are generally put at 60 x 27 kilometers and 1.6-2.0 billion years, respectively. (R23)

The noncircularity of Sudbury has been attributed to horizontal thrusting action (R23, R25) Initially, isotopic studies suggested that some of the Sudbury rock had welled up from below (R13), but more recent work seems to confirm that it is all surface rock, thus strengthening the case for meteoritic action. (R21)

References

R1. "Structure of the Vredefort 'Dome', Nature, 156:304, 1945. (X1)

R2. Daly, Reginald A.; "The Vredefort Ring-Structure of South Africa," Journal of Geology, 55:125, 1947. (X1)

R3. Dietz, Robert S.; "Vredefort Ring Structure: Meteorite Impact Scar?" Journal of Geology, 69:499, 1961. (X1)

R4. Dietz, Robert S.; "Astroblemes," Scientific American, 205:50, August 1961. (X1)

R5. Bucher, Walter H.; "Cryptoexplosion Structures Caused from Without or from Within the Earth? ('Astroblemes' or 'Geoblemes?');" American Journal of Science, 261:597, 1963. (X1)

R6. Dietz, Robert S.; "Cryptoexplosion Structures: A Discussion," American Journal of Science, 261:650, 1963. (X1)

R7. Kelly, Allan O.; Continental Drift: Is It a Cometary Impact Phenomenon? Carlsbad, 1966, p. 43. (X1)

R8. Dietz, Robert S.; "Vredefort Ring Structure: An Astrobleme (Meteorite Impact Structure)," Geological Society of America, Bulletin, 71:2093, 1960. (X1)

R9. Dent, Brian; "Glacial Exhumation of Impact Craters on the Canadian Shield," Geological Society of America, Bulletin, 84:1667, 1973. (X2)

R10. Robertson, P.B., and Grieve, R.A.F.; "Impact Structures in Canada: Their Recognition and Characteristics," Royal Astronomical Society of Canada, Journal, 69:1, 1975. (X2, X4)

R11. Floran, R.J.; "Petrology and Rb/Sr Systematics of the Manicouagan Impact Melt, Quebec," Eos, 57:275, 1976. (X2)

R12. Hindley, Keith; "Meteoritics at Cambridge," New Scientist, 75:353, 1977. (X3)

R13. Phinney, W.C., et al; "Investigation of the Manicouagan Impact Crater, Quebec: An Introduction," Journal of Geophysical Research, 83:2729, 1978. (X2-X4)

R14. Orphal, D.L., and Schulz, P.H.; "Manicouagan, a Terrestrial Analog of Lunar Floor-Fractured Craters?" Meteoritics, 13:591, 1978. (X2)

R15. Grieve, R.A.F., and Robertson, P.B.; "The Terrestrial Cratering Record," Icarus, 38:212, 1979. (X2-X4)

R16. Dachille, Frank; "Great Meteorite Impacts and Global Geological Responses," The Expanding Earth; A Symposium, S. Warren Carey, ed., Hobart, 1981, p. 267. (X1-X4)

R17. Grieve, Richard A.F.; "The Vredefort Structure Still Not Understood," Nature, 295:644, 1982. (X1)

R18. Dachille, Frank; "Meteorite Impacts of Geological Significance: A Human Perspective," Catastrophism and Ancient History, 5:15, January 1983. (X3, X4)

R19. Shoemaker, Eugene M.; "Asteroid and Comet Bombardment of the Earth," Annual Review of Earth and Planetary Sciences, 11:461, 1983. (X1, X3, X4)

R20. Masaytis, V.L., et al; "The Popigay Meteorite Crater," International Geology Review, 14:327, 1972. (X3)

R21. Faggart, Billy E., Jr., et al; "Origin of the Sudbury Complex by Meteoritic Impact: Neodymium Isotopic Evidence," Science, 230:436, 1985. (X4)

R22. Weisburd, S.; "Meteor Linked to Rich Ores at Sudbury," Science News, 128: 263, 1985. (X4)

R23. "Meteorite Origin of Basin in Canada?" Science News, 106:233, 1974. (X4)

R24. "Popigay Depression: A Siberian Astrobleme?" Sky and Telescope, 43:93, 1972. (X3)

R25. Dietz, Robert S.; "Sudbury Structure

as an Astrobleme," Journal of Geology, 72:412, 1964. (X4)
R26. Boon, J.D., and Albritton, C.C., Jr.; "Meteorite Scars in Ancient Rocks," Field and Laboratory, 5:53, 1937. (X1)

ETC2 Very Large Depressions of Possible Meteoric Origin

Description. Roughly circular depressions, generally over 100 kilometers in diameter, with features that hint at impact origin. Typical "hints" are large-scale melting and metamorphosis, brecciation, correlation with biological extinctions, correlation with tektite events, the presence of large masses of extruded magma, gravitational and magnetic anomalies, and the existence of surrounding rings of geological disturbance.

Data Evaluation. The more soundly founded large meteoritic craters are classified in ETC1. Relegated to this section are suspicious depressions, often of immense size, possessing just a shred or two of evidence inferring a meteoritic origin. In other words, they are controversial and not well-established. Rating: 3.

Anomaly Evaluation. Large meteoritic craters and astroblemes are now generally accepted by science. The spacecraft discovery of widespread cratering throughout the solar system assures us that the earth could hardly have escaped a similar fate. But the craters (?) cataloged here are so large; viz., the ocean basins; that meteoritic origin is not fully accepted. Further, purely geological explanations are available in many instances. Nevertheless, meteors come in all sizes, and if one accepts 50-kilometer craters as impact scars, 1000-kilometer craters are more anomalous only in the sense that they are not yet part of the geological consensus. Rating: 2.

Possible Explanations. Meteoritic cratering; plus such geological phenomena as ring dikes, volcanism, the formation of island arcs by tectonic action, and the opening of ocean basins by tectonic plate motion.

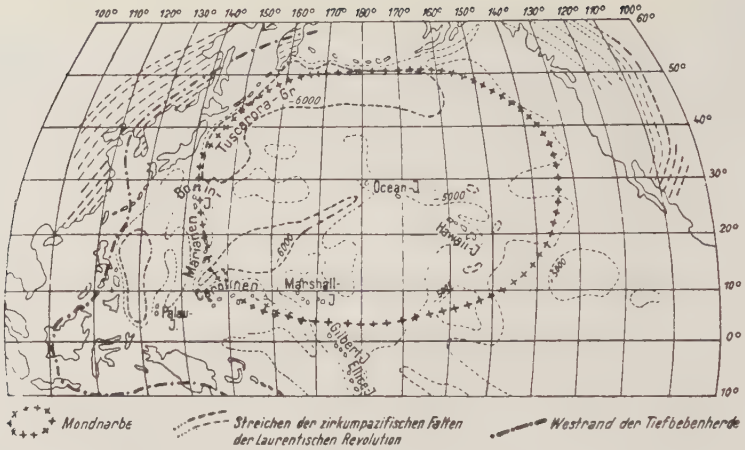
Similar and Related Phenomena. The smaller, better substantiated depressions explained as "astroblemes" (ETC1); the Carolina Bays and similar depressions (ETB); island arcs (ETL2).

X0. Introduction. With meteorite impact geology now so fashionable, just about all large depressions in the earth's surface have received attention from catastrophists. If some relevant geological data are available for a specific depression, it is cataloged as a separate example below. Where data are lacking, as in some speculative surveys, the sites are merely listed in the final entry.

X1. The Pacific Basin. The idea that the Pacific Basin and its surrounding "ring of fire" was the site of ancient catastrophism is well over a century old. George H. Darwin, son of Charles, calculated that the moon was once much closer to the earth and had, perhaps, split off from the earth, leaving behind the Pacific Basin as a scar. O. Fisher, W.H. Pickering, and others later elaborated on this proposal.

If the Pacific Basin is in fact the scar left by the moon, the word "astrobleme" seems inappropriate, because it implies an impact by an extraterrestrial body. Perhaps "geobleme" would be better here. In any case, the first item below presents some geological evidence for a "bleme" of one kind or another. The second, more recent item proposes that a meteoritic origin is preferable to the fission concept.

Kuehn's Moonscar. "The moon's original location is not to be sought for in the entire Pacific area, but rather in a locality bor-



Kuehn's "moonscar" formed the Pacific Basin in his 1949 paper. (X1)

dered by the equator and 50° N. Latitude, extending from 130° E. Longitude to 130° W. Longitude. The North Pacific Depression, thus circumscribed, represents the most extensive and, with its marginal fault zones, the deepest indentation of the earth's crust. Over an area of 13.5 million sq. mi., the sea bottom occurs at a depth of 2.5-3.7 miles, the average being 3.2 miles. If the northern Pacific, which represents less than 1/20 of all the water present on earth, is not included in the calculation, we arrive at an average depth of 2.3 miles below mean sea level for all other oceans, as compared to 3.2 miles for the North Pacific deep. If we calculate the depth of the Pacific Ocean alone, we find the northern part of it to be still 0.9 miles below its average depth.

The North Pacific indentation is further characterized by tectonic fault zones of great depth, occurring at its margins. Deep sea channels, bordering the area, bear witness to the violent shattering of the earth's crust, as in the Marianas, Philippine Islands, Kamchatka, Aleutians, Alaska, and New Pomerania. These fault zones are manifest, even to-day, by earthquakes and volcanism. The world's deepest foci for earthquakes are located in this zone, which is nearly parallel to the 'moonscar'. Among 475 presently active volcanoes, 299 are located at the margin or within the area of the indentation." (R1) This was written in 1949, long before tectonic plates were invented. (WRC)

A Meteorite Impact Hypothesis. "Very little is known about the processes that have fashioned the major features of the Earth's surface. Of the many problems unsolved, perhaps one of the most intriguing of all is that of the origin of the Pacific Basin.

It is known that the lighter crustal layers, which form the continental land masses to a depth of 20-40 km., are relatively thin on ocean floors and in the particular case of the Pacific Basin are almost entirely absent. The Pacific Ocean itself has a mean depth of 5 km. and occupies almost half the Earth's surface; the greater density of its underlying rocks is consistent with the absence in the gravitational potential of any first harmonic terms about the axis of rotation. It was pointed out by Suess in 1888 that an outstanding characteristic of the Pacific is that it is surrounded by a variety of features which lie parallel to its coast lines. Among these features are the island festoons and the multiple arcs of deep-focus earthquakes, gravity anomalies, and ocean deeps. A further impressive characteristic is the seismic passivity of the Pacific Basin itself, which is in direct contrast with the continual tectonic activity in the surrounding regions where dissimilar crustal structures are in close contact and the land masses are folded as if by thrust against the denser and stronger mass of the Pacific Basin.

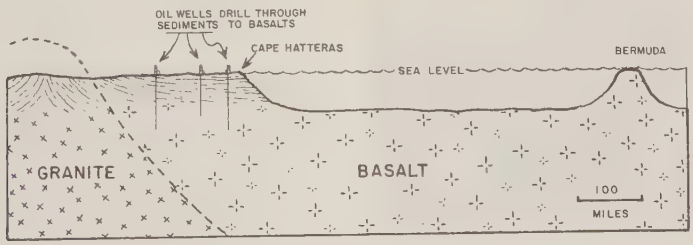
To explain such major surface characteristics it is proposed that the Pacific Basin was the seat of an immense explosion in the

primitive Earth, and that the explosion was possibly due to a collision with a planetesimal or a satellite of approximately 100 km. radius. An attempt will be made to show that the explosion excavated a large crater of several thousand kilometres in radius and some hundreds of kilometres in depth. The great masses of material that were swept back and dropped at the rim of the crater formed the discontinuities of crustal structure and composition which survive to the present day and are responsible for the peripheral features of the Pacific Basin. Following the recovery of hydrostatic equilibrium there remained a shallow and permanent depression (because of the absence of the lighter surface layers) which is the present Pacific Basin." (R4) Once again, continental drift has been omitted from the discussion. (WRC)

X2. The Bermuda impact crater. "This great undersea crater has a rim that stretches for hundreds of miles in a great circle beginning at a point north and east of Puerto Rico and curving past the Bahamas, the Carolina Coast, and north and east along the Atlantic Coast until it loses itself in the deep ocean off the New England Coast. There is a very sudden break, almost a cliff, where the continental shelf (crater rim) breaks off into the deep ocean. The Bahama Islands form the south wall of this crater. They rise only a few feet above sea level but they form an undersea cliff that is nearly 700 miles long. Between the Great Bahama Bank and the islands of Cuba and Haiti, there is a secondary channel that is nearly half as deep as the main crater basin. The islands of Cuba, Haiti, and Puerto Rico are the mountains that form the remains of the outer crater rim, and the Brownson and Bartlett Deeps are the down-warped troughs that are common to many of the other great collision points that we shall mention later.

The floor of this great impact crater is also consistent with what might be expected. It slopes in every direction from the central peak (Bermuda) gradually growing deeper toward the rim although it averages deeper on the south and southwest than it does on the north. It is somewhat ovoid in shape being longer from northeast to southwest; the distance from Bermuda to Cape Hatteras being about 600 miles and from Bermuda to the Bahamas about 750 miles." The crater wall rises 17,000-18,000 feet from the floor in only 15-20 miles---almost three times the height of the Grand Canyon walls and nearly as steep. (R3; R2, R29) A.O. Kelly, author of this bit of speculation, also notes that the Bermuda crater is adjacent to the Carolina Bays. (ETB1).

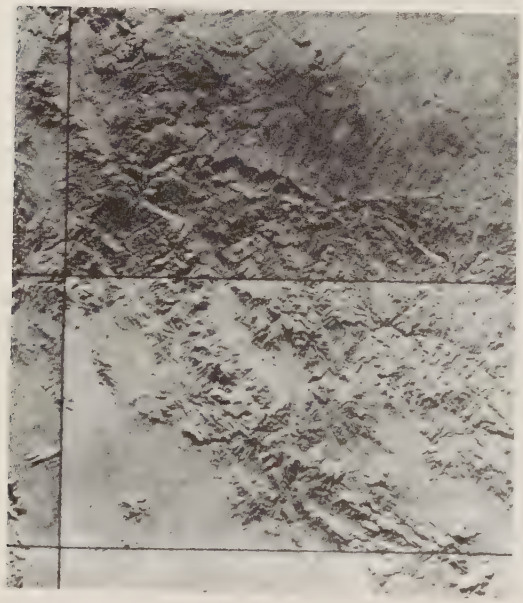
X3. The Aleutian Arc. This chain of mountainous islands curves for over 1500 miles and boasts 80 large volcanos and numerous smaller ones. The water on the Bering Sea side is only about 6500 feet deep, while to the south the ocean averages about 16,000 feet, with the 25,000-foot Aleutian Trench immediately adjacent to the island chain. A.O. Kelly considers the Aleutian chain to be the rim of a large crater made by a projectile impacting from the northwest. The crater to the north was filled with upwelling lava---like the lunar maria. (R3) In modern plate tectonics, the structure is explained by having one plate dive under another at the Aleutian Trench. Even so, this structure remains most interesting.



Section of the Carolina coast, indicating the hypothetical meteor crater of A.O. Kelly. (X2)

X4. Large circular structures in Arizona. As early as 1953, A.O. Kelly noticed immense depressions in Arizona topography. Suggestions of these circles were seen in the first high-altitude photos from the V-2 rockets in 1947. (R3) However, J.M. Saul has gone considerably further, as now described.

"The Earth's surface exhibits faint circular patterns which have not been described before. These circles are characterized by near perfection of outline, by the presence of topographic highs (rims) along parts of their circumferences, by their generally large scale (diameters of from under 7 km up to approximately 700 km in the areas examined), and by their definition in various geological environments, in many rock types, and in rocks of all ages. Many of the circles are intermittent in places along their rims but about 55% of the approximately 1,170 definite circles observed to date can be visually traced around an entire 360^{o} of arc. The circles are further characterized by the presence of fracturing and brecciation along parts of their rims and by the extraordinary control they place on regional geology in general and on ore mineralisation in particular. (R18) Two accompanying illustrations present some of the circular patterns Saul has discovered in Arizona. He believes they were formed by meteoritic bombardment about 4 billion years ago. See X20 for a list of similar circles found elsewhere in the world.



A 70-kilometer ring structure on a relief map of Arizona. This ring is the central ring in the accompanying sketch. (J.M. Saul) (X4)

X5. The Gulf of St. Lawrence. The arcuate arrangement of the coasts of Nova Scotia and New Brunswick partially encloses the Gulf of St. Lawrence. In 1961, J.J. Gilvarry wondered if the Gulf might not be a crater in the 300-kilometer class blasted out by an extraterrestrial projectile. (R5) A.O. Kelly also noticed this structure, opining that Prince Edward Island, which is also arcuate and, in addition, parallel to the Nova Scotia shore, might be an "arc of collision." He attributed the thick, very pure accumulation of rock salt beneath the Gulf to be the consequence of seawater rushing into the magma-filled crater, where it evaporated. (R10, R29) Considerable salt also underlies the Gulf of Mexico (X19).

Large-scale mineral rings in Arizona, as inferred from relief maps. (X4)

X6. Arctic Ocean depressions. "The Arctic contains four depressions of oceanic depth which, unlike other oceans, hold large volumes of sediment. In between the depressions run the 10 000-foot high submarine Lomsonov Ridge discovered by the Russians in 1948-49, the 8000-foot high Alpha Ridge found from a United States drifting ice station in 1957, and this new ridge." The ridges appear to be continental in character. In fact, some scientists think that the Arctic Ocean is not a true ocean but rather a sunken continental mass. (R7)

X7. New Mexico's Mogollon Plateau. This circular structure has a raised rim about 90 miles in diameter. Conventional geological thinking labels it a ring-dike complex. (R8) Obviously, this Plateau may be linked to Arizona's ring structures (X4). If ring dikes are present, they could have been initiated by a meteorite collision. (WRC)

X8. The Hudson Bay arc. The near perfect circularity of the Hudson Bay arc over 150° has led several to propose an impact origin. A.O. Kelly sketched the crater outline in his 1953 book, Target: Earth (coauthored with F. Dachille). In 1965 H.P. Schwarcz introduced some novel evidence for catastrophism in the region. His thought was that the diamonds found in glacial drift in Ohio, Indiana, Michigan, and Wisconsin owed their origin to this impact. In his words, "Following meteorite impact, brecciation extended to a depth of about 150 km., and fragments of this mantle rock breccia, enclosing diamonds, are inferred to have been brought to the surface in a central uplift similar to those found in lunar craters." (R9) But the major evidence for impact still resides in the unique morphology of the region, as expressed by A.O. Kelly.

"The Hudson Bay Arc is a striking feature on any map of North America because of its size and because of its near-perfect half circular outline in a region of angular coast lines. However, the really unique and unusual features of this area are not seen until one studies a large scale map of the islands, rivers, and coast lines in detail.... The Hudson Bay Arc measures 276 miles from point to point across its visible section and 372 miles along the periphery of the arc. Since the visible part of the arc is not a full 180 degrees, a projection of the curve produces a full diameter of 288 miles and a circumference of 905 miles." One of the most remarkable features consists of the long chain of islands that parallels of eastern shore (not shown in the figure), with a deep channel between the chain and shore. (R10)

Occurrences of diamonds in the glacial drift seem to lead back to Hudson Bay. (X8)

In 1972, R.S. Dietz and J.P. Barringer searched this wild area for shatter cones, evidence of melting, and crater ejecta. They found nothing to support the meteoritic hypothesis. (R12)

Nevertheless, the morphology seems to require some special explanation. More recently, gravity measurements have revealed strange circular ripples surrounding a point near Hudson Bay. These density variations in the earth's crust have led to the hypothesis that a 60-90 kilometer projectile impacted there some 4 billion years ago. (R27)

Gravimetrically measured ripples surround a possible impact structure near Hudson Bay. (X8)

X9. The Sunda Arc. Enclosing all of the islands of the East Indies in a near semicircle and extending around the islands of Timor, Java, Sumatra, and all the way to Rangoon, Burma, this is the largest arcuate structure on earth. The deep Sunda Trench associated with the Arc measures 6,000 miles. A.O. Kelly claims that the arc is part of an impact crater with a diameter of over 3,000 miles. The postulated crater's basin is the shallow South China Sea. Kelly dates the crater at 200 million years, suggesting that the havoc wrought at its formation brought an end to the Permian. (R29) A.O. Kelly, as this section amply demonstrates, is an ardent member of the impact school. At this point, it seems wise to reiterate that we are cataloging land forms and not the theories proposed to explain them. Meteoritic impacts represent just one way to form a large depression. (WRC)

X10. The Ishim depression. "According to reports from the Soviet Union, geologists have found evidence that the large depression surrounding Tengiz Lake in West Siberia is an ancient meteorite crater. It is located in latitude 51° north, longitude 69° east, near the city of Tselinograd in Kazakhstan. This depression has a diameter of 350 kilometers (217 miles) and a depth of 10 to 12 kilometers (six to seven miles). (R13) F. Dachille gives the same diameter but notes that radial and arcuate fractures double the given figure. Crater age: 435 million years. (R26)

X11. The Wilkes Land Crater. In 1961, J.G. Weihaupt reported an immense gravitational anomaly in Wilkes Land, Antarctica. R.A. Schmidt suggested a year later that this anomaly could be explained by the existence of a large meteorite crater under the ice. In 1976, Weihaupt elaborated on this hypothesis.

"An unusual assemblage of geological and geophysical anomalies in Wilkes Land, Antarctica, suggests that these features may owe their origin to hypervelocity impact by an extraterrestrial body. The evidence which supports this conclusion includes a 158.3-mGal negative free air gravity anomaly, apparent structural deformation, basin-shaped profiles in the ice sheet and in the subglacial topography, australite distribution, the probable geologic recency of the features, the presence of rim structures similar to terrestrial, lunar, Martian, and Mercurian impact crater rims, lack of isostatic equilibrium, and the excellent agreement between the morphological dimensions of observed features and the morphological dimensions of terrestrial, lunar, Martian, and Mercurian impact craters, namely, crater rim widths, crater rim heights, crater depths, and crater diameters. This evidence reveals a subglacial topography with a depression which is a minimum of 848 m deep and 243 km across." (R14)

But, in 1979, C.R. Bentley announced that extensive investigations in Wilkes Land, including radio-echo sounding, do not support the notion that a large crater exists under the ice. (R21) This example is thus highly questionable. (WRC)

X12. The West African bulge. J. Norman and his colleagues define an "astron" as a large disk of welded rock surrounded by a circumferential fracture zone. An "astron" is, in a sense, a large form of astrobleme. A world map of "astrons" is presented in X20; here and in X13, two are singled out for better description.

"...we suggest that the almost circular bulge of the West African coast marks the graben-defined boundary of one of the Earth's major astrons. Work with satellite images has shown us that a large arcuate graben full of sediments continues this circle along the line of the Benue River, and that further sedimentary basins align themselves with the circle through Chad, Libya, Mauretania and Morocco. There are interruptions in this circle, but that is not surprising when you bear in mind the complex pattern of overlapping craters seen on the Moon." (R16)

X13. The Peruvian Andes. In this part of South America, the coastline has a shape similar to that of West Africa. This may also be the site of an astron. (R16)

X14. The inferred Iceland crater. Scientists have been searching for a crater in northern latitudes that might account for the high iridium levels at the Cretaceous-Tertiary boundary. These iridium concentrations become

higher and higher at more northern latitudes, being especially high in Denmark. Suspicion has fallen on Iceland, which is "a unique example of a land mass lying astride one of the spreading ridges from which oceanic crust grows and pushes outwards. It is built almost entirely of volcanic rock, none older than the early Tertiary, and clearly began to grow just after the Cretaceous-Tertiary boundary." The scenario proposed by F. Whipple has a 10-kilometer meteor blasting a 100-kilometer crater in the thin crust of the spreading ridge in the North Atlantic. Magma welled up through the crater to form today's Iceland. (R22) See also ETC3 for other candidates for the missing Cretaceous-Tertiary crater.

X15. The buried Yucatan crater. As in X14, the worldwide iridium anomaly has stimulated a search for possible crater sites. One of these is beneath the rocks of the Yucatan Peninsula. The physical evidence for this crater comes from magnetic surveys rather than surface indications. G. Penfield and A. Camargo reported on these indications, as uncovered by a 1978 survey. "The survey revealed in buried marine deposits a circular pattern of anomalous magnetic signatures 60 km across, surrounded by a second ring 180 km wide. The feature is centered on the town of Progreso ($21^{\circ}.2$ north latitude, $89^{\circ}.4$ west longitude)." The postulated buried crater is thought to be in Late Cretaceous strata, and the consequence of the impact of a 10-kilometer asteroid. (R25)

X16. The Everglades impact scar. E.J. Petuch has proposed that the Everglades region received a direct hit from an asteroid about 36 million years ago. The Everglades region is a swampy, forested area surrounded by an oval-shaped system of ridges. Geologists usually maintain that the Everglades represent a collapse feature caused by groundwater dissolving away the limestone. Petuch disagrees with the collapse theory and points to the following evidence for an impact origin: (1) The presence of a strong positive magnetic anomaly; (2) Eocene formations, 40 million years old, are missing over the southern Everglades; (3) A network of fractures pervades rock layers older than the Eocene; (4) High iridium concentrations, probably of extraterrestrial origin, exist at the Eocene-Oligocene boundary on nearby Barbados; and (5) The oval reef structure that seems to have grown around the impact area as sealevels rose. (R28)

X17. The Seistan depression. Northeast of the Persian Gulf exists a great basin surrounded on all sides by curved ranges of mountains. The depression's bottom is only a few hundred feet above sealevel, and it possesses an area of about 7,000 square miles. A.O. Kelly opines that a cosmic collision in this region created the great folds ("whalebacks") of the Persian Gulf area, under which the great petroleum deposits reside. (R3)

X18. The Amazon basin. A.O. Kelly sees the huge Amazon basin as a meteor crater. "The Amazon Valley is roughly circular and nearly surrounded by mountains or old plateaus and is so nearly level that elevations of only 650 feet are found at the foot of the Andes 2000 miles from the river mouth. The probabilities are that the Amazon Crater was left as an island sea much like the Gulf of Mexico and that later collisions at some distance filled it with sedimentary deposits. The curvature of the Andes around this old basin seems to indicate this supposition...." (R3)

X19. The Gulf of Mexico. Looking at a map, the coasts of Florida, Texas, and Mexico certainly give the appearance of surrounding an immense crater. Not unexpectedly, A.O. Kelly believes the Gulf is an impact crater. The Gulf is not a simple downwarping of the crust to form a shallow depression. Rather, a sharp continental shelf exists. At the center, where the deepest water is, the depth is well over 12,000 feet. As with the Seistan depression in the Middle East (X17), the Gulf of Mexico, as a meteor crater, is associated with the great oil deposits in the region. (R3) We now have suspected craters in the Everglades (X16), Yucatan (X15), and the intervening Gulf of Mexico. It is unlikely that all three sites are ancient craters. (WRC)

X20. Broad surveys of possible impact-forged depressions. Several authors have identified additional large depressions that may have been created by meteoritic collisions. Since few supportive data are available, we treat these candidates briefly.

The ocean basins. The North Pacific Basin was covered in X1, but all of the ocean basins have been attributed to meteor/asteroid collisions, at least by some bold hypothesizers. Generally, the Atlantic and Pacific are divided into north and south basins, each excavated separately. (R5, R6, R15, R20)

The "astrons." The west African and Peruvian astrons, defined and described in X12 and X13, exemplify a whole family of suspicious structures believed by J. Norman et al to have a meteoritic origin. The accompanying map locates the remainder of the family. (R16)

O. Shields listed many sites not mentioned above. Some of these have not been investigated; others are based on indirect evidence. Here are some of the more interesting:

Tibesti, Africa, 1100 km diameter
Manchuria basin, 650 km
Ordos basin, 600 km
Szechwan basin, 950 km
Thailand basin, 425 km
Dasht-i-Margo basin, Afganistan, 475 km
Washington-Oregon crater (now hidden under Cenozoic basalts) 400 km
Lake Victoria basin, 650 km
Gulf of St. Vincent and Spencer Gulf near Adelaide, 325 km
Mekong River valley and delta (now hidden under sediments), 400 km. (R23)

The continents themselves. Obviously, the continents are not craters at the present time, but J.W. Salisbury and L.B. Ronca

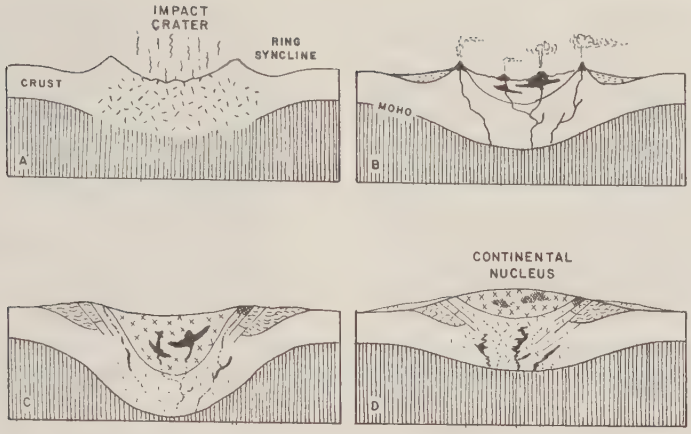
Locations of possible astrons as inferred from topographical maps. (X20)

Large circular structures on aerial photographs. In addition to the Arizona examples (X4), J. Saul has detected similar circles in other western states, in northernmost Mexico, the Appalachians, Alaska, the Yukon, Madagascar, and Corsica. Since only a small part of the planet has been examined, and the circular structures are common there, we are probably dealing with a worldwide phenomenon. (R18) A year before Saul's paper, G.A. Kellaway remarked on the existence of similar circles in Great Britain and Mauritania. He dubbed them "cycloliths." (R19)

Inferred impact basins. In a lengthy table entitled "Asteroid impacts that weakened the earth's crust and formed the oceans," have suggested that they may have begun as impact craters. The caption with the accompanying diagram provides their scenario. A similar proposal was made by W.L. Donn el al in 1965. (R11)

References

R1. Kuehn, Harald; "The Moonscar upon the Earth," Earth Science Digest, 3:3, February 1949, and 3:3, March 1949. (X1)
R2. Kelly, Allan O.; "The Origin of the Carolina Bays and the Oriented Lakes of Alaska," Popular Astronomy, 59:199, 1951. (X2)



Proposed scenario for forming a continental nucleus: (1) The situation immediately after meteor impact; (2) Shortly after a new Mohorovicic discontinuity has formed; (3) Down flow causes sinking and compression; and (4) Heat loss ends, downflow stops, and the continental nucleus rises. (X20)

R3. Kelly, Allan O., and Dachille, Frank; Target: Earth, Carlsbad, 1953. (X2-X4, X17-X19, X8)
R4. Harrison, E.R.; "Origin of the Pacific Basin: A Meteorite Impact Hypothesis," Nature, 188:1064, 1960. (X1)
R5. Gilvarry, J.J.; "The Origin of Ocean Basins and Continents," Nature, 190: 1048, 1961. (X5, X20)
R6. Gallant, R.L.C., and Dietz, Robert S.; "Meteorite Impacts, Lunar Maria, Lopoliths and Ocean Basins, Nature, 197:38, 1963. (X20)
R7. "The Four Oceans at the 'Top' of the World," New Scientist, 21:7, 1964. (X6)
R8. Elston, Wolfgang E.; "Rhyolite Ash-Flow Plateaus, Ring-Dike Complexes, Calderas, Lopoliths, and Moon Craters," New York Academy of Sciences, Annals, 123:817, 1965. (X7)
R9. Schwarcz, H.P.; "The Origin of Diamonds in Drift of the North Central United States," Journal of Geology, 73:657, 1965. (X8)
R10. Kelly, Allan O.; Continental Drift: Is It a Cometary Impact Phenomenon? Carlsbad, 1966. (X5, X8)
R11. Salisbury, J.W., and Ronca, L.B.; "The Origin of Continents," Nature, 210: 669, 1966. (X20)
R12. Dietz, Robert S., and Barringer, J. Paul; "Hudson Bay Arc as an Astrobleme: A Negative Search," Meteoritics, 8:28, 1973. (X8)
R13. "Another Giant Meteorite Crater Identified," Sky and Telescope, 50:156, 1975. (X10)
R14. Weihaupt, John G.; "The Wilkes Land Anomaly: Evidence for a Possible Hypervelocity Impact Crater," Journal of Geophysical Research, 81:5651, 1976. (X11)
R15. Frey, Herbert; "Origin of the Earth's Ocean Basins," Icarus, 32:235, 1977. (X20)
R16. Norman, John, et al; "Astrons---the Earth's Oldest Scars?" New Scientist, 73:689, 1977. (X12, X13, X20)
R17. Classen, J.; "Catalogue of 230 Certain, Probable, Possible, and Doubtful Impact Structures," Meteoritics, 12:61, 1977.
R18. Saul, John M.; "Circular Structures of Large Scale and Great Age on the Earth's Surface," Nature, 271:345, 1978. (X4, X20)
R19. Kellaway, Geoffrey A., et al; "Circular Structures of Large Scale and Great Age on the Earth's Surface," Nature, 273:75, 1978. (X20)
R20. Hindley, Keith; "Did Asteroid Impacts Father the Earth's Ocean Basins?" New Scientist, 77:159, 1978. (X20)
R21. Bentley, Charles R.; "No Giant Meteorite Crater in Wilkes Land, Antarctica," Journal of Geophysical Research, 84:

5681, 1979. (X11)
R22. "The Blow That Gave Birth to Iceland," New Scientist, 89:740, 1981. (X14)
R23. Shields, Oakley; "The Role of Gravity and Asteroid Impacts in Earth Expansion," The Expanding Earth: A Symposium, University of Tasmania, 1981, p. 277. (X20)
R24. Dachille, Frank; "Great Meteorite Impacts and Global Geological Responses," The Expanding Earth: A Symposium, University of Tasmania, 1981, p. 267, (X10)
R25. "Possible Yucatan Impact Basin," Sky and Telescope, 63:249, 1982. (X15)
R26. Dachille, Frank; "Meteorite Impacts of Geological Significance: A Human Perspective," Catastrophism and Ancient History, 5:15, January 1983. (X10)
R27. Simon C.; "Deep Crust Hints at Meteoric Impact," Science News, 121:69, 1982. (X8)
R28. Weisburd, S.; "Asteroid Origin of the Everglades," Science News, 128:294, 1985. (X16)
R29. Kelly, Allan O.; Impact Geology, 1985. (X2, X5, X9)
R30. "Soviets Find Meteor Crater," Astronomy, 5:60, February 1977. (X10)
R31. Schmidt, Richard A.; "Australites and Antarctica," Science, 138:443, 1962. (X11)

ETC3 Hypothetical Craters Inferred from Terrestrial Events

Description. Craters whose existences are inferred from geological and geophysical evidence, but which either have not been definitely located or are anomalous in character.

Data Evaluation. The data pinpointing and describing the Tunguska Event "crater" are good. However, the data from the other events (the Australasian tektites and Cretaceous-Tertiary boundary layer) are still insufficient to locate the inferred craters with any precision. Rating: 2.

Anomaly Evaluation. Scientists are perhaps too confident that all of the events delineated below are impact-caused. In the cases of the Australasian tektite strewn field and the Creaceous-Tertiary iridium layer, several candidates have been proposed, but all are controversial. In fact, volcanism and other forms of terrestrial catastrophism may be involved instead. The Tunguska Event is definitely linked to a depression containing about 200 conical craters of small size. Here, the characteristics of the impact site are so unusual that the nature of the impacting body has not been decided. Taking all these events together, the challenge to the prevailing impact-origin dogma is not serious, but doubts still remain. Rating: 2.

Possible Explanations. Astronomical catastrophism (cometary, asteroidal, meteoritic); terrestrial catastrophism (volcanic).

Similar and Related Phenomena. Astroblemes (ETC1); very large crater-like structures (ETC2).

Examples

X1. The Tunguska Event crater. June 30, 1908. Siberia. On this date, one of the most energetic natural events in historical times shook and burned the taiga of remote Siberia. However, the history of this event was not pieced together for nearly two decades due to the inaccessibility of the region. Only in the late 1920s, when a Russian scientific expedition was dispatched to the site and sent back word of a devastated region 120 kilometers wide, were some geophysical phenomena observed in 1908 connected with the blasted area in Siberia. In the geophysical volumes of the Catalog of Anomalies, there are recorded precursory luminous phenomena in Europe (GLA15-X2), the passage of an atmospheric pressure wave (GSW3-X2), and a geomagnetic disturbance (GEZ5-X6). In this present volume, the

unusual geological and other natural features of the Tunguska site will be described.

The Tunguska Event is widely refered to as a meteorite impact phenomenon. If this were so, we would expect to find a fair-sized crater at Ground Zero, especially in light of the visual, thermal, and pressure-wave effects recalled by the natives interviewed some two decades after the event. There is, in fact, no well-defined central crater resembling, say, Arizona's Meteor Crater. A slightly depressed region exists, and it is pocked with about 200 curious funnel-shaped pits. We are left, then, with two questions: (1) Why is there no conventional meteor crater?; and (2) What was the real nature of the Tunguska Event?

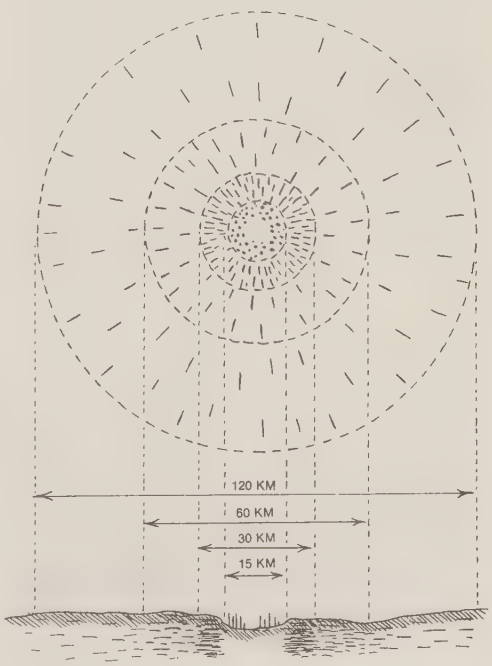
Related testimony from inhabitants of the Tunguska region. "The appearance at 7 o'clock in the morning on June 30, 1908, of a 'fiery body' of unusual brightness, rolling across the sky out of the northeast and falling down in the 'taiga' between the Yenissei and Lena Rivers, north of the Railroad line, was observed by a great number of people, mostly the native inhabitants, living in the basins of these rivers.

The fall of the meteorite was instantly followed by a column of fire rising skyward, by the formation of the heavy black clouds, and by a most deafening, resounding noise far surpassing in its magnitude, any thunderstorm, or artillery cannonade. This was heard for hundreds of kilometers within a radius of the cities of Yenisseisk, Krasnoyarsk, Kansk, Nijneudinsk, and Kirensk on Lena.

A terrific air-wave was formed which pushed ahead everything that it met in its way. The water in all rivers, lakes and streams was raised up; people and animals were lifted up by it and carried along.

The vibrations produced by the fall of the meteorite were detected and registered by the seismographs of the Physical Observatory at Irkutsk, where Mr. A.V. Vesnesenski, who was in charge of the observatory, calculated the epicenter of the 'earthquake' to be located in the upper part of the Podkamennaya Tunguska." Several searches for the meteorite were made without success in 1908, primarily because they were in the wrong area. Interest in the event soon died. (R1)

Descriptions from the 1927 Kulik expedition. After great difficulties, not the least of which involved misquitoes, the second expedition of L. Kulik reached Ground Zero. Here, the scientists found a very shallow depression about 2 miles wide, in which there were about 200 "pits." "These proved to be from 30 to 150 feet in diameter and about 12 feet deep. The bottom was covered with swamp moss. Around the craters the earth was crinkled in a direction at right angles to the southwest and northeast line. Round about the craters the ground had been entirely blasted and at the time the meteorite fell every living thing must have been quite consumed. Professor Kulik told me of one remarkable feature: within the central blasted area was a ring of upright trees. The trunks are seen to be stripped or singed of foliage. The fact that they remained upright while all vegetation inside and for some distance outside the ring was destroyed seems to suggest that they mark some kind of node or region of rest due to interference of air waves coming from the craters.... From a pencil diagram Professor Kulik drew for me, one sees that the central area which was devastated except for the ring of upright trees, was about fifteen to twenty kilometers (roughly 10 or 15 miles) in diameter. Beyond this circle was a ring of felled trees extending up to a diameter of 30 or 40 kilometers, as shown in the diagram. The next zone extended to about 60 kilometers diameter and contained a considerable number of felled trees, while occasional trees were found felled within a diameter of 120 kilometers or about 75 miles. Throughout the circle the trees were felled radially." (R2) For English translations of Kulik's reports, see R3-R5.



Additional data from a 1929 expedition. This expedition carried in a small drilling rig. Crushed and pulverized rock was found beneath the surface. However, no fragments of the meteorite were found. Interestingly enough, some of the natives in the area said they had picked up "chunks of shiny, white metal as big as one's fist." The scientists never saw any of these bits of metal. (R7)

The radioactivity flap. Another Russian visit to the site, circa 1959, led to the discovery of enhanced radioactivity in the area. This helped engender and promote the theory that an alien spaceship using nuclear power had blown up accidentally over Siberia. (R8) Later, this radioactivity was attributed to fallout from nuclear weapons tests. (R12)

Speculation about the nature of the Tunguska Event. Originally, the scientific community was almost unanimous in ascribing the Siberian devastation to the impact of a large meteorite, even though no typical meteorite crater and no meteorite fragments exist. An incoming meteorite, the thinking went, might have exploded before it hit the surface. The blast wave felled the trees and the resulting fragments dug the conical pits. In recent years, it has become more common to propose a cometary impact. Such would account for the lack of meteorite fragments. (R12) Z. Sekanina, however, gives several reasons why a comet is not indicated. He considers it "inconceivable that cometary material known for its extreme fragility could survive a load of this magnitude." He refers, of course, to the aerodynamic loading on the object as it penetrated deep into the earth's atmosphere. Sekanina thinks the object was an Apollo-type asteroid 90-190 meters in diameter, which flared up at the end of its flight. (R22) Obviously, both the meteorite and comet hypotheses leave something to be desired.

X2. The Australasian tektite crater. The huge Australasian tektite strewn field should, if tektites are truly created by terrestrial impacts, be unequivocally linked to a specific meteorite crater. Since the Australasian tektites are only about 700,000 years old, their crater-of-birth can hardly have been completely erased by erosion. This embarrassing lack of a suitable crater has only encouraged those who still believe that tektites were born from meteorite impacts on the moon. (For more on this often bitter controversy and the tektites themselves, see a later volume in this series.)

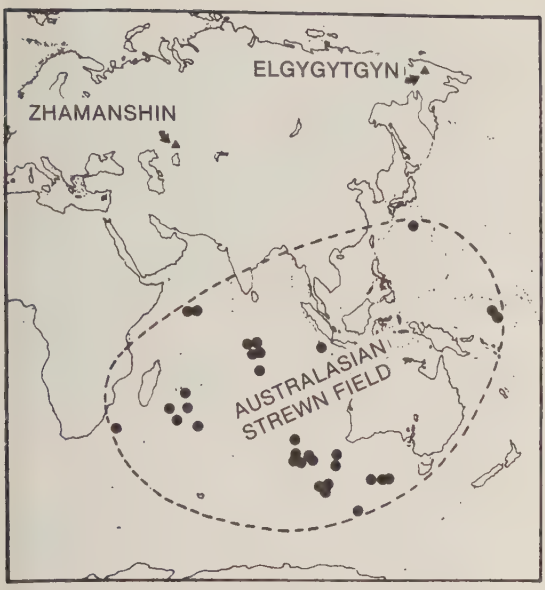
At least five candidates have been considered as craters-of-origin for the Australasian tektites. As the following items will demonstrate, a scientific consensus is not yet at hand.

Lake Toba, Indonesia. Lake Toba is usually thought of as a volcanic phenomenon. But since the distribution of Australian tektites seems to consist of two lobes, which have axes intersecting at Lake Toba, some have claimed that Lake Toba is really an impact phenomenon and the source of the Australasian tektites. (R10)

The possible Wilkes Land crater. The distance of the putative Wilkes Land, Antarctica, crater from the Australasian tektite strewn field is in good agreement with the trajectory expected for the Australites. (R13). Other investigators, however, deny the existence of such a crater under Antarctica's ice. (R17)

The Elgygytgyn crater, Siberia. "There is now a consensus that tektites are derived from giant meteoroid impact splashes on earth, but the crater sources for the australasian and bediasite strewnfields remain to be identified. The following points implicate Elgygytgyn Crater (67°30'N, 172°00'E) in Siberia for australasites: (1) Morphology from Landsat imagery suggest Elgygytgyn is a very likely impact crater and of sufficient size (18 km dia.) to generate a downrange tektites splash; (2) The geomorphic age of the crater appears to be about 700,000 yrs such as is needed to be synchronous with the tektites; (3) An apex of the strewnfield points toward the crater and the compositional and specific gravity lineations of Chapman et al. (1964) are in part directed toward it; (4) The regolith and bedrock is Mesozoic fitting the age of the tektite parental material from Sr/Rb data while the loess cover and mixed acid/basic rocks of the impact site provide a suitable subgraywacke-type source material of appropriate chemical compositions; (5) With respect to Elgygytgyn the high velocity, twice-melted australites are distal with the low velocity tektites (splash-forms and Muong Nong impactites) are proximal---a relationship which incidently rules out Antarctica as a source." (R15; R14)

The Zhamanshin crater, Siberia. "Tektite-like glass objects called irghizites have been found associated with the Zhamanshin crater in southern Siberia. The irghizites are similar to the Australasian tektites in



Geographical limits of the Australasian tektite strewn field and the locations of Zhamanshin and Elgygytgyn craters. (X2)

composition, and the Zhamanshin crater appears to be about the same age as the Australasian tektites. Variations in size, structure, form, petrography, and chemical composition of tektites within the Australasian strewnfield suggest that the source of the Australasian tektites lies to the northwest, in the direction of the Zhamanshin crater. It is hypothesized that both the irghizites and the Australasian tektites may have been produced by impact melting of loesslike deposits that covered the area at the Zhamanshin crater site prior to the impact." The author of this paper, B. P. Glass, claims that new additions to the Australasian strewn field shifts its axis away from Elgygytgyn (R15) in the direction of Zhamanshin. Further, Elgygytgyn has not been shown to be an impact feature. (R16)

The Mekong River valley crater. O. Shields simply lists this crater as the probable cause of the Pleistocene Ice Age and the source of the Australasian tektites. As mentioned in ETC2, this crater, if such there is, is supposed to be located beneath the valley and delta sediments. (R19)

X3. The Cretaceous-Tertiary Event crater. The Cretaceous-Tertiary boundary is marked by massive biological extinctions and a widespread deposit enhanced in iridium. Iridium is rare on earth but more abundant in meteoritic and asteroidal materials. This fact encourages the theory that the Cretaceous-Tertiary transition was precipitated by astronomical catastrophism. The Cretaceous-Tertiary Event, which must have shaken the entire planet, is postulated to have occurred about 65 million years ago. But scientists have not yet found an acceptable crater that would confirm that impact (rather than, say, volcanism) was the true cause of this geological milestone. Proposed, potential craters abound, as the following examples will demonstrate.

Iceland. The increasing amounts of iridium at higher latitudes favors a northerly site. See discussion in ETC2-X14. (R18)

Devil's Hole, North Sea. A perfectly circular hole 80 kilometers in diameter, 250 meters deep, 325 kilometers east of Dundee, Scotland. Selection based on the increasing concentration of iridium in the North Sea direction. (R20)

Yucatan, Mexico. A potential buried crater that has been detected magnetically. (ETC2-X15) A candidate because it is believed to be located in strata of the proper age. (R21)

The Sierra Madera structure, Texas. More than 10 kilometers in diameter with shock-metamorphized rocks, this crater is younger than the Lower Cretaceous. (R23)

Manson structure, Iowa. About the same characteristics as the Sierra Madera structure. (R23) Another reference puts its diameter at 35 kilometers. It lies under the town of Manson, Iowa. (R24)

Amirante Basin, Indian Ocean. A 300-kilometer circular depression, located 500 kilometers northeast of Madagascar. Dated at 65 million years, it must also be considered a candidate. (R24, R27)

References

R1. Merrill, George P.; "The Siberian Meteorite," Science, 67:489, 1928. (X1)
R2. Crowther, J.G.; "More about the Great Siberian Meteorite," Scientific American, 144:314, 1931. (X1)
R3. Kulik, L.; "On the Fall of the Podkamennaya Tunguska Meteorite in 1908," Popu-

lar Astronomy, 43:596, 1935. (X1)
R4. Kulik, L.; "Preliminary Results of the Meteoric Expeditions Made in the Decade 1921-1931," Popular Astronomy, 44:215, 1936. (X1)
R5. Kulik, L.A.; "The Question of the Meteorite of June 30, 1908, in Central Siberia," Popular Astronomy, 45:559, 1937. (X1)
R6. Astapowitsch, I.S.; "On the Fall of the Great Siberian Meteorite, June 30, 1908," Popular Astronomy, 46:310, 1938. (X1)
R7. Christie, William H.; "The Great Siberian Meteorite of 1908," Griffith Observer, 6:38, 1942. (X1)
R8. Klass, Gerald; "The Great Siberian Explosion," Science Digest, 47:6, February 1960. (X1)
R9. Florensky, Kirill P.; "Did a Comet Collide with the Earth in 1908?" Sky and Telescope, 26:268, 1963. (X1)
R10. Taylor, S.R.; "Lake Toba, Sumatra, and the Origin of Tektites," Nature, 227: 1125, 1970. (X2)
R11. Wick, Gerald L., and Isaacs, John D.; "Tungus Event Revisited," Nature, 247: 139, 1974. (X1)
R12. Ridpath, Ian; "Tunguska: The Final Answer," New Scientist, 75:346, 1977. (X1)
R13. Weihaupt, John G.; "The Wilkes Land Anomaly: Evidence for a Possible Hypervelocity Impact Crater," Journal of Geophysical Research, 81:5651, 1976. (X2)
R14. Dietz, Robert S.; "Elgygytgyn Crater, Siberia: Probable Source of Australasian Tektite Field," Meteoritics, 12:145, 1977. (X2)
R15. Dietz, Robert S.; "Elgygytgyn Crater: Source of Australasian Tektites (and Bediasites from Popigai)," Meteoritics, 12:205, 1977. (X2)
R16. Glass, B.P.; "Zhamanshin Crater, a Possible Source of Australasian Tektites," Geology, 7:351, 1979. (X2)
R17. Bentley, Charles R.; "No Giant Meteorite Crater in Wilkes Land, Antarctica," Journal of Geophysical Research, 84:5681, 1979. (X2)
R18. "The Blow that Gave Birth to Iceland?" New Scientist, 89:740, 1981. (X3)
R19. Shields, Oakley; "The Role of Gravity and Asteroid Impacts in Earth Expansion," The Expanding Earth: A Symposium, S. Warren Carey, ed., University of Tasmania, 1981, p. 279. (X2, X3)
R20. Pellegrino, Charles; "The Fallen Sky," Astronomy, 9:68, April 1981. (X3)
R21. "Possible Yucatan Impact Basin," Sky and Telescope, 63:249, 1982. (X3)
R22. Sekanina, Z.; "The Tunguska Event: No Cometary Signature in Evidence," Astronomical Journal, 88:1382, 1983. (X1)
R23. French, Bevan M.; "Impact Event at the Cretaceous-Tertiary Boundary: A Possible Site," Science, 226:353, 1984. (X3)
R24. Murray, M.; "Point of Impact: The Indian Ocean?" Science News, 129:356, 1986. (X3)
R25. "Counterpoint in Impact Debate," Science News, 129:394, 1986. (X3)
R26. Kleist, T.; "Crater and Debris Linked for First Time," Science News, 130:38, 1986.
R27. Hartnady, C.J.H.; "Amirante Basin, Western Indian Ocean: Possible Impact Site of the Cretaceous/Tertiary Extinction Bolide?" Geology, 14:423, 1986. (X3)

ETC4 Periodicity of Crater Ages

Description. The tendency of the ages of large meteoric craters to cluster around dates that are separated by a fixed span of years---typically 25-30 million years. Periodic bombardment of the earth is thus suggested.

Background. The idea of regularly occurring terrestrial convulsions is not new to geology. Until recently, though, any periodic upheavals were attributed to internal forces. In fact, the existence of many, large meteoric craters was not widely admitted until the 1960s. The debate in the early 1980s over crater periodicity and its possible link to possible periodicity in the fossil record seems to stem largely from the discovery of the iridium anomaly at the Cretaceous-Tertiary boundary (ES). This iridium anomaly was first taken to be proof of astronomical catastrophism, although this is now challenged.

Data Evaluation. Only about 100 craters larger than 1 kilometer have been dated, and most of these come from a small region of the earth's surface (mainly Canada and the USSR). Thus,

the data sample is small and geographically and temporally narrow. Neither are the ages known with good precision. Further complicating the picture is the probability that some of the craters are asteroidal in origin, while others may be cometary. Rating: 3.

Anomaly Evaluation. Crater-age periodicity implies a repeating astronomical phenomenon, such as the periodic perturbation of the Oort Cloud of comets or the encounter of the earth with a stream of large meteors. Admittedly, there has been much controversy about crater periodicity, but in reality the suggested astronomical mechanisms are quite plausible. This means that the basic phenomenon is not highly anomalous. Rating: 3.

Possible Explanations. Regular perturbation of the Oort Cloud by an unseen solar companion or the solar system's passage through regularly spaced structures in the galaxy. Another possibility is the periodic encounter of the earth with a so far uncharted stream of large meteors.

Similar and Related Phenomena. The alleged periodicity of the fossil record (B); the possible periodicity of magnetic field reversals (EM); the possible periodicity of tectonic activity (ES).

Examples

X0. Crater dating fundamentals. "Geologists can assign fairly accurate dates to most of these craters by examining the rocks at the site that were melted by the impact, using the radioactive decay of potassium isotopes into argon isotopes as a 'clock' for dating once-molten rocks. The melting through impact in effect restarted the clock, because it allowed the gaseous argon previously formed by decay and trapped within the rocks to escape. Measurement of the amount of 'daughter' argon formed through radioactive decay then dates the rock to the time it was last in a molten state." (R7)

X1. Crater-age data. Despite the application of radioisotope dating, the basic data are rather unsatisfactory. The ages of only about one hundred craters have been estimated, and for some of these only upper limits can be assigned. Precision is wanting in many instances. Most scientists studying the problem agree that some crater ages must be excluded from any analysis, but controversy exists over which ones to omit. In statistical analysis, one can prove almost anything with astute selection of data.

Overview. "With regard to the question of periodicity of impacts, the record of terrestrial cratering is incomplete. Known impact structures are confined to land areas. The best data are from the North American and European cratons, which have provided relatively stable surfaces over geologically significant periods of time. Furthermore, the estimates of crater ages are of variable accuracy and precision. Within these restrictions it is not obvious that there is a periodicity in the cratering record. It is possible to define by time series analyses a number of periods ranging from 13.5 to 29.5 million years, depending on which craters are considered the most representative sample of the record over the past 250 million years." (R12)

Specific Data. The most widely used crater age data were compiled by R. A. F. Grieve. His 1982 survey included 88 craters.(R13) It is impractical to reproduce the entire list, but to give the reader a taste for the data we tabulate the recent, well-defined-agewise, larger craters below.

X2. The major claims of periodicity. Two groups of researchers have found sharply different periods in the data.

The 28.4-million-year cycle. W. Alvarez and R. A. Muller analyzed only those craters larger than 10 kilometers and older than 5 million years. Their purpose was to eliminate any bias introduced by missing, older, smaller craters. Their conclusion: "We report here that most of the craters occur in a 28.4-Myr cycle. Within measurement errors, this period and its phase are the same as those found in the fossil mass extinctions. The probability that such agreement is accidental is 1 in 10^3." (R4)

Critics of the Alvarez-Muller study point out that only 13 out of the list of 88 craters compiled by Grieve were used, and that the biological extinctions in the fossil record actually show a periodicity of 26 million years. Alvarez and Muller repeated their analysis employing smaller craters. They found the same 28.4-million-year period,

Terrestrial Impact Craters with Diameters Greater Than 5 Kilometers and Well-Constrained Ages for the Past 80 Million Years (R12)

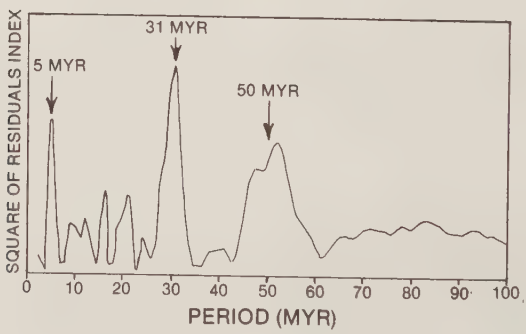
Structure	Diameter (km)	Age (10^6 yrs)
Zhamanshin,USSR	13	0.77 ± 0.8
Bosumtwi, Ghana	10.5	1.3 ± 0.2
El'gygytgyn, USSR	19	3.5 ± 0.5
Karla, USSR	10	7.3 ± 3.9
Ries, Germany	24	14.8 ± 0.7
Haughton, Canada	20.5	20 ± 5
Wanapitei, Canada	8.5	37 ± 2
Mistasin, Canada	28	38 ± 4
Popigai, USSR	100	39 ± 9
Beyenchime-Salaatin, USSR	8	40 ± 20
Kara, USSR	50	60 ± 5
Usi-Kara, USSR	25	60 ± 5
Kamensk, USSR	25	71 ± 2
Lappajarvi, Finland	14	77 ± 4

although it was less significant statistically. They also maintain that when error limits are considered, their crater period is close enough to the extinction period. (R7)

The 31 or 32-million-year cycle. M.R. Rampino and R.B. Stothers also used Grieve's compilation of 88 craters but included many younger craters, for a total of 65. Their conclusion: "We find a dominant cyclicity of 31 ± 1 Myr in the observed age distribution of impact craters on Earth, the phase of this cycle agreeing with that shown by the major biological crises." (R3) E. Shoemaker also analyzed the same data employed by Rampino and Stothers and arrived at a period of 32 million years. (R7)

X3. General observations. In concluding his discussion of the conflicting periods obtained by different groups, D. Goldsmith stated: "Each approach to rejecting some of the craters on the list has merit---and flaws. Unfortunately, the record of impact craters on Earth is just not good enough to enable us to discriminate between a 28.4-million-year period, on one hand, and a 31- or 32-million-year period on the other." (R7)

In fact, the whole business of crater age analysis has been challenged by R. Grieve and his colleagues. They considered the incompleteness of the cratering record and



Periodicity of terrestrial impact crater ages. The 5- and 50-million-year peaks are analytical artefacts. (X2)

the uncertainties in ages. "They found that various statistical periods could be extracted from the data depending on assumptions about the impact data, and that variations in assigned ages of a few craters could significantly alter the derived periodicities. Thus, more data are required before categorical statements on periodic impact-extinction episodes can be made." (R8; R15, R16)

A somewhat different tack was taken by P.R. Weissman, when he examined the meteoritical material in the impact melts of various craters. His study suggests that both comets and asteroids contribute to the cratering record. And while an astronomical mechanism exists for creating cycles of cometary impacts, there is no known source of asteroidal impactors with a period around 28 million years. He concludes that there is no simple, one-to-one relationship between asteroid and/or comet impacts and biological extinctions. Further, other types of events may trigger biological extinctions. (R9)

References

R1. Rampino, Michael R., and Stothers, Richard B.; "Geological Rhythms and Cometary Impacts," Science, 226:1427, 1984. (X2)

R2. "A Star Named George," Scientific American, 250:66, April 1984. (X2)

R3. Rampino, Michael R., and Stothers, Richard B.; "Terrestrial Mass Extinctions, Cometary Impacts and the Sun's Motion Perpendicular to the Galactic Plane," Nature, 308:709, 1984. (X2)

R4. Alvarez, Walter, and Muller, Richard A.; "Evidence from Crater Ages for Periodic Impacts on the Earth," Nature, 308:718, 1984. (X2)

R5. Shoemaker, E.M., and Wolfe, R.F.; "Crater Ages, Comet Showers, and the Putative 'Death Star,' Meteoritics, 19: 313, 1984.

R6. Weissman, Paul R., et al; "Cometary Showers and Unseen Solar Companions," Nature, 216:380, 1984.

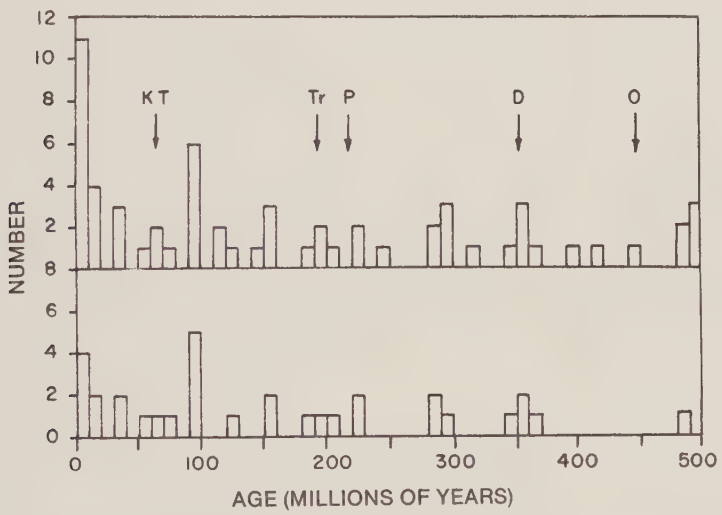
R7. Goldsmith, Donald; "Do Extinctions and Impacts Come in Cycles?" Nemesis, New York, 1985, p. 47. (X0-X3)

R8. Croft, Steven K.; "Impacts: Earth, Mars & the Geologic Record," Geotimes, 30: 22, June 1985. (X3)

R9. Weissman, Paul R.; "Terrestrial Impactors at Geological Boundary Events: Comets or Asteroids?" Nature, 314:517, 1985. (X3)

R10. Morrison, Nancy D., and Gregory, Stephen; "Astronomical Origins for Periodicities in the Geologic Record?" Mercury, 14:55, 1985. (X2)

R11. Pal, Poorna C., and Creer, Kenneth M.;



Distribution of ages for dated terrestrial impact craters. The upper histogram includes all dated craters; the lower one excludes craters smaller than 10 kilometers. Arrows indicate dates of biological extinctions. (X3)

"Geomagnetic Reversal Spurts and Episodes of Extraterrestrial Catastrophism," Nature, 320:148, 1986.

R12. Officer, Charles B., and Grieve, Richard A. F.; "The Impact of Impacts and the Nature of Nature," Eos, 67:633, 1986. (X1-X3)

R13. Grieve, R. A. F.; Geological Society of America, Specialist Paper 190, 1982. (X1)

R14. Grieve, R. A. F., and Robertson, P. B.; "The Terrestrial Cratering Record," Icarus, 38:212, 1979. (X1)

R15. Sharpton, V. L., et al; "Periodicity in the Earth's Cratering Record?" Eos, 68: 344, 1987. (X3)

R16. Kerr, Richard A.; "Geophysics Smorgasbord Was Spread in Baltimore," Science, 236:1425, 1987. (X3)

ETE RAISED BEACHES, FOSSIL CORAL REEFS, INLAND TERRACES

Key to Phenomena

ETE0 Introduction

Beaches, fossil reefs, and terraces are good markers of former shorelines and, thus, are indicators of ancient sea- and lake-levels. The great majority of these water-level markers lie within a few hundred feet of present water levels. Geologists have few explanatory problems here. Generally, local crustal up- and down-warping and sealevel changes due to climatic variations suffice. But when beaches, reefs, and terraces of recent vintage are greatly elevated or submerged---say, over 500 feet---over wide geographical regions, the usual explanations become inadequate, or at least are sorely tried. In fact, raised beaches do occur at concordant altitudes in many areas. In particular, a 1200-foot set of raised beaches may be worldwide in extent. Below the waters, significant drops in sealevel in past epochs may be indicated by terraces along submarine canyons and seafloor channels.

Inland, widespread systems of terraces draped around hills and mountains led some earlier geologists to postulate either great marine inundations or, equivalently, the very recent, rapid risings of such mountain chains as the Andes and Alps. Modern earth scientists do not countenance such suggestions, but the evidence is nonetheless fascinating.

ETE1 Greatly Raised and Submerged Beaches

Description. Wave-cut beaches located hundreds of feet above or below present sealevel. The key feature of this phenomenon is the concordance of altitudes and depths over wide geographical areas. Another feature, probably less anomalous, are the very great altitudes of some of these exposed marine terraces; some approach altitudes of a mile.

Background. In raised and submerged marine beaches we have a phenomenon which is well-accepted by science but which is inevitably explained in conventional terms, even though there are strong indications that such is dangerous policy. It is very convenient to interpret a raised beach as the consequence of local uplift---an explanation that is often correct. But can all raised and submerged beaches be explained in this way? Only a few geologists have remarked on the world concordance of raised beaches and rejected the "emergence hypothesis" as a blanket explanation. They maintain that the whole planet; that is, all the land masses; could not have simultaneously risen, say, 1200 feet. Rather, ocean levels must have subsided everywhere by 1200 feet. Unfortunately, it is hard to explain how this might have happened.

Data Evaluation. Many raised beaches and a lesser number of submerged beaches have been measured on all continents and a large number of islands. These data are of fair quality but largely scattered in the geological literature. There has been little effort to collect them all and analyze them for concordances. In other words, the measurements are available but their analysis is inadequate to determine the reality of this phenomenon. Rating: 2.

Anomaly Evaluation. The major implication of worldwide raised beach concordances is that very large changes of sealevel have occurred---changes of thousands of feet. This is contrary to current geological thinking. Furthermore, some of the raised beaches are so high (a mile or more) that even the local emergence theory is sorely tried. Rating: 1.

Possible Explanations. Large changes in sealevel could have taken place if either the volume of the ocean basins changed or the volume of available seawater changed. Ocean basin volumes might change because of an expanding earth (a subject covered later, in ETL5) or because or large-scale downwarping or upwarping of portions of the crust. These are obviously extrapolations of the local emergence hypothesis. Changes in the volume of water might come through the expulsion from or withdrawal of water into the crust. (Note that all Martian water is now thought to reside in crustal reservoirs.) Extraterrestrial water might be added in the form of a flux of icy meteors---a subject currently under debate.

Similar and Related Phenomena. All other phenomena in this section, especially the elevated and submerged fossil coral reefs (ETE2). Other phenomena that might involve great changes in sealevels are guyots (ETH1), submarine canyons (ETV1), and evaporites (ES).

Examples

X1. Worldwide surveys and general observations. Quoted here are the opinions of investigators who have concluded that very large, worldwide fluctuations in sealevel did indeed occur. Most geologists do not agree with this position.

C. Johns and Quaternary sealevel changes. "In a preliminary article dealing with the British Quaternary strand-line oscillations it was shown that unexpected correlations had emerged as a result of the methods employed. Of the possible assumptions the only one to prove workable was that there had been, during Quaternary time, a temporary lowering of ocean level of 1,000 metres or more. The graphs left no reasonable doubt that if the ocean level had moved in the way assumed the Mindel-Riss interval of Penck's Alpine sequence must be equated with the major glaciation of North-West Europe and the British Isles. In order to test this, the only assumption made, it was applied to the coral reef problem and there it was successful in offering what should be an acceptable solution. It was surprising to find that Darwin had actually used an apparent rise of ocean level, of the same order of magnitude, to illustrate his own theory of subsiding islands. The success of the postulate when faced with the coral reef problem was held to have invested it with a high degree of probability. It was pointed out, however, that changes of ocean level of that magnitude could best

be explained by the sinking of the ocean floor, and the North Pacific Ocean was indicated as the probable position." (R14)

Geyl's investigations of stepped erosion surfaces. "Abstract. A brief account of opposed schools of thought regarding erosion surfaces is given. It is suggested that the convex break of slope between the flatter part of one erosion surface and the marginal slope of the next lower surface is the main criterion for recognition, on contoured maps, of erosion surfaces. A method of altimetric (morophometric) analysis is described, and graphs for a number of Australian and other maps are presented. A recurring pattern, with some variations, is noted on the graphs. In some cases correspondence exists with levels mentioned in the literature of the area. It is suggested that stepped erosion surfaces, to perhaps 2,000 ft. and over, may be a world-wide feature in stable regions, despite the difficulty of explaining their apparent non-deformation." (R21) See X6 for Geyl's study of Australian stepped erosion surfaces.

An astronomical cause for differential sea-level changes. "Study of submerged and emerged shorelines, and of the depths of continental shelves, suggests that sea level has risen in the Arctic and fallen in the equatorial regions. The amount seems to be in the range of 600 ft. This is a measurable effect since the Cretaceous.

The cause is thought to be a slowing down of the earth's rotation, due to the drag of lunar tides. The equatorial bulge of the solid mantle and crust has lagged in adjustment to the slower rate of rotation, but the ocean waters have adjusted immediately." (R28) In contrast, Johns and Weyl visualized uniform worldwide changes in sealevel, due, perhaps, to ocean basin volume changes.

R. Daly's synthesis and speculations. "G. H. Dury gives an extensive listing. 'The highest Welsh platform lies at 1700 to 2000 feet and its shoreline at 1650 feet.... On the flanks of Exmoor, old shorelines at 1225, 925, 825, 675, 425, and 280 feet above sea level.' ...G. H. Drury points out that some of these beaches can be correlated with beaches in the farthest parts of the world at the same height, showing that the fall in sea level is a world-wide and not a local phenomenon. For instance, there are 100-foot-level, raised beaches, all at the same level, in Kamchatka, Australia and Tasmania, in Virginia, in the Mediterranean and in the Thames Valley....

It is derived from the theory that these beaches, all over the world, have been raised by forces shoving up from below. At each place the receding waters left an abandoned beach line, the raised-beach theory postulates a local uplift. This theory requires uplifts, not only around all of the world's oceans, but around all of the world's lakes, and also along the banks of all (or almost all) of the world's rivers; for there are raised terraces along the banks of all major rivers and abandoned shorelines around the world's lakes....'Often the highest terraces of such rivers as the Seine or the Elbe, when followed down to the mouth, are seen to blend with old shorelines which border the oceans at levels considerably higher than the present beaches.' This blending of the river terraces with ocean shorelines establishes the fact that the general recession of water levels is a world-wide phenomenon common to both rivers and oceans which cannot be reasonably attributed to a multiplicity of local uplifts." (R34)

P. D. Nunn's invocation of migrating geoid anomalies. Nunn's thoughts are provided in more detail in ETE2-X4. Briefly, he thinks that moving geoid anomalies must be added to tectonic uplifting and glacio-eustatic changes to explain coral reefs at high elevations.

X2. North America and the Caribbean.

Labrador. "Labrador's recent geological history has been recorded on the bleak and barren cliffs of the eastern coast in bold and legible characters. No fisherman can fail to recognize the autograph of the sea in the elevated boulder beaches and terraces of sand, which may be seen in many places 200 feet or more above the present sea level and which at scores of localities look almost as fresh and perfectly preserved as those now being built by the sea. Beaches of glacial boulders such as justify Packard's characterization of 'a truly noble beach' occur all the way from Hamilton Inlet to the western end of the Strait of Belle Isle, where Twenhofel observed at one locality eight beaches, the highest of which was 350 feet above high tide. Terraces, however, are seen in their best development along the interior waterways. In the Hamilton Inlet and Lake Melville region they run inland more than 200 miles from the coast along the fiordlike valleys and rivers." (R10) See X3 for more on river terraces.

Northwest Canada. "In the Canadian Northwest Territories west of Hudson Bay, the postglacial marine transgression was more extensive than in any other part of North America. Although there are numerous isolated observations of strand lines and other raised marine features, there has been no systematic study of the maximum depth of this sea and the form of the subsequent emergence of the land.

Measurements made during 3 summer's field work in the area show that on the mainland the sea reached a depth of 360-400 feet. On the islands in the north of Hudson Bay the depth was 550-650 feet. The difference is explained by unequal waning of the ice sheet. In the western part of the Thelon and Dubawnt basins a large proglacial lake preceded the invasion of the sea. The lake fell by clearly defined stages. Subsequent emergence from the sea was continuous until the final 100 feet when there were two periods of temporary stability. There is widespread evidence that the land is still rising." (R18)

Hudson Bay, Canada. R. Bell contributed a more extreme example. "In my Geological Survey Report for 1884, I have mentioned ancient beaches at Nachvak, 140 miles south of Hudson Strait, which have an estimated altitude of 1500 feet above the sea." (R39)

Alaska. Pleistocene beaches in Alaska are found as high as 1,700 feet above sea level. (R29)

The Atlantic Continental Shelf. "Abstract. Teeth of mastadons and mammoths have been recovered by fishermen from at least 40 sites on the continental shelf as deep as 120 meters. Also present are submerged shorelines, peat deposits, lagoonal shells, and relict sands. Evidently elephants and other large mammals ranged this region during the glacial stage of low sea level of the last 25,000 years." (R30)

Near the New England Seamounts. This research was conducted from the submersible Alvin. "Coming up from a depth of 1,800 m the first major cliff was encountered. It was 260 m high and had several small benches covered with sediment that showed ripple marks caused by persistent ocean currents. This rugged cliff, which was characteristic of almost all seamounts visited on the cruise, was made up of steps that appeared to be small faults." (R35) This "cliff" could well be of tectonic origin and not wavecut. (WRC)

Caribbean stepped erosion surfaces. "Altimetric analysis of a series of topographic maps covering the main Cordillera of Puerto Rico indicates the existence of erosion surfaces, represented largely by concordant summit levels, at the following average elevations: 760, 620, 470, 330 and 160 m. above present sea-level. Field work at present in progress suggests that these elevations in fact represent mean elevations of groups of stepped surfaces, in some instances bearing sedimentary deposits which have been described previously as redidual soils.

At the present time it is not possible to reach any firm conclusion as to the mode of origin of these surfaces; but their distribution, at least in western Puerto Rico, suggest that they probably originated as marine cut surfaces, later modified by sub-aerial processes as they successively emerged from the sea. Whatever conclusion is eventually reached as to their origin, it seems fairly certain that they are related to changing sea-levels, the more widespread surfaces---particularly the 330 and 160 m. ---presumably representing periods of relative standstill." The author compares the Puerto Rico erosion surfaces to those in French Guiana at 600+, 500, 330, 235, and 160 meters. In the Lesser Antilles, too, a 330-meter surface is suggested by a conspicuous concordance of summits. (R23)

Florida Keys. A sunken terrace, covering some 1300 square miles, has been located at a depth of 1500 feet just south of the Florida Keys. It is "dotted with many valleys and sinkholes." One sinkhole is a half mile in diameter. (R27) This formation may only be a piece of foundered crust and not a true erosion surface. (WRC)

Cuba. "At the eastern end of the island of Cuba, on and in the vicinity of the promontory known as Cape Maysi, is the most magnificent example of raised shore lines as seen from the ocean that I know of. They are in the form of large wave-cut benches extending with perfect regularity and practical horizontality along the face of a long moderate slope and around several promontories. When a profile of the latter is seen from a passing ship the sharp-cut, step-like form readily attracts the attention even of the unscientific observer. The terraces are found one above the other at somewhat irregular intervals, are of different degrees of development, possibly as much as a dozen in number, and seem to extend to an altitude of about 1,000 feet above the sea. Above the last terrace visible the land has a topography indicative of sub-aerial erosion." (R5)
See also ETE2-X1.

Bermuda. In 1931, W. Beebe reported the discovery of a submerged beach off Bermuda during his dredging explorations. "The discovery of a submerged sea-beach of great extent, in situ, at a depth of 1,500 fathoms, was quite unexpected in this part of the Atlantic." (R12)

X3. South America. A. Geike summarized C. Darwin's descriptions of South American terraces: "On the west coast of South America, lines of raised terraces containing recent shells have been traced by Darwin as proofs of a great upheaval of that part of the globe in modern geological times. The terraces are not quite horizontal but rise to the south. On the frontier of Bolivia they occur from 60 to 80 feet above the existing sea-level, but nearer the higher mass of the Chilean Andes they are found at one thousand, and near Valparaiso at 1300 feet. That some of these ancient sea margains belong to the human period was shown by Mr. Darwin's discovery of shells with bones of birds, ears of maize, plaited reeds and cotton thread, in some of the terraces opposite Callao at a height of 85 feet. Raised beaches occur in New Zealand and indicate a greater change of level in the southern than in the northern end of the country." (R19) See ETE4 and ETE5 for additional material on the Andes and Lake Titicaca.

X4. Europe. In the spirit of W. F. Geyl, S. E. Hollingworth has collected evidence for very high erosion surfaces in Britain.

Britain. "It is concluded that south of the Midland Valley of Scotland a number of erosion platforms or shelves, now dissected and preserved largely as hill-top residuals, are developed. The principal levels of planation, at 430 feet, 730-800 feet (possibly two distinct shelves), 1000-1070 feet, and 2000 feet, occur throughout the western and northern parts of Britain. From their correspondence in altitude and in relative size and position, and from their relation to subsidiary shelves at intermediate levels, it is deduced that the platforms at any one level are contemporaneous and represent an unwarped shelf or notch formed during a halt in the emergence of the land. The order of formation of the platforms appears to have been one of decreasing altitude, indicating progressive fall in base-level interrupted by major and minor stand-still periods of considerable duration. The subsidiary platforms at about 320 feet, 550-570 feet, and 900-920 feet are also of widespread occurrence, and an erosion surface at 1130-1170 feet is well developed in most districts.

Between 1250 and 1800 feet evidence of shelves is somewhat inconclusive as there are no outstanding levels. But certain levels apparently of local significance (for example, the 1470- and 1660-feet levels in the Lake District) may prove to occur elsewhere.

Between 1800 and 2000 feet there are variations in the frequency of summit levels that suggest that, in addition to the 2000-foot platform, certain other levels may eventually provide clues to the early stages of the evolution of the present topography." (R16) Although Hollingworth does not speak of sealevel changes, opting for stepwise emergence instead, the worldwide correspondence of many of the erosion levels tend to strengthen the case for large, global changes in sealevel. (WRC)

Scandanavia. In Norway, there is evidence for marine action at the 600-foot level. In the Christiania fjord, there are found shell deposits at various levels up to 540 feet. (R2)

X5. Africa. Some of the highest marine terraces are found in the south of Africa.

South Africa. "Prof. Schwartz describes some remarkable platforms which fringe the southern coast of Cape Colony, all of which he attributes to marine denudation, though, with the exception of the well-known Agulhas bank, most are now elevated above sea-level. The most striking of the coastal plateaux is that extending from Caledon to Port Elizabeth at an elevation varying between 600 and 800 feet above the sea. In the west of this area the plateau form is to some extent obscured by the result of erosion, which has furrowed the surface with a labyrinth of steep-sided gorges, with narrow intervening ridges ('ruggens' of the Dutch). But it can be plainly seen that all the ridge-tops are cut to a level which slopes gently to the sea. East of Georgetown the plateau-form becomes much more prominent, the Table-mountain sandstone or granite of which it is composed having been far more resistant than the clay-slates further west. Some have considered this coastal plateau to be a peneplain or base-level of river-erosion, but Prof. Schwartz is

confident that it is a plain of marine denudation. He shows that there are other more or less extensive ledges, admittedly surf-cut, at various levels above and below tide-mark along this part of the coast, while further east coast-shelves occur as far as the native territories. At East London there is a remarkable succession of plateaux, each terminating in an abrupt drop, at altitudes varying from 151 to 5450 feet above the sea." (R7)

"In South Africa there are extensive terraces at altitudes of 4000, 2500, and 1000 to 800 feet and smaller terraces at roughly 550 to 450 and 250 to 150 feet. All five terraces are of Tertiary age, the last three being partly covered by a sheet of Mid-Pliocene sediments." (R11)

Morocco. "Elevated marine platforms, one extensive marine sedimentary formation, and three alluvial deposits are believed to record a succession of strand lines on the Atlantic Coast of Northern Morocco. The former strand lines lie at altitudes of 200 m., 165 m., 110 m., 85 m., 70 m., 53 m., 35-40 m., 23 m., 9 m., 5 m., and 1-2 m. above modern sea level. All are younger than mildly deformed rocks of Astian age. Although correlation depends in part upon altimetry, there is no evidence of deformation of the strand lines below 140 m. Intervals when sea level stood lower than that of the present preceded formation of the strand lines at 35-40 m., 23 m., 5 m., 1-2 m., and modern sea level. Other such intervals may have existed." (R17)

X6. Australia and New Zealand.

Australia. "On the basis of intensive visual map analysis of all the 1 inch to 1 mile contoured maps published (supported by a few altimetric analyses), it is thought possible to state that stepped erosion surfaces are widespread in Australia. There seems to be little doubt about the existence of undeformed surfaces at about 200, 400, and 600 ft. (60, 120, and 180 m.); but there may be others in this range, particularly at about 300 and 500 ft. (90 and 150 m.).

.....

Above 600 ft. more stepped erosion surfaces appear to exist, still without apparent deformation. Elevations noted are approximately 800, 900, 1,000, 1,200-1,250, 1,400, 1,600, and 1,800 ft. (244, 274, 305, 365-380, 427, 488, and 549 m.), while a surface at 2,000 ft. (610 m.) appears to have special significance; and where it occurs widely, it is very often capped by remnants of a surface at 2,200 ft. (670 m.). Still higher the stepped landscape appears to continue, but these surfaces have not been studied intensively enough to allow a positive statement.

The apparent regularity of interval (generally about 200 ft., (60 m.)) between the erosion surfaces suggests a regular spasmodicity of base-level movement. A point deserving mention is that an altimetric analysis by Maze of the Orange-Bathurst district (New South Wales) also shows a more or less marked frequency maximum every 200 ft. between 2,200 ft. (670 m.) and 4,000 ft. (1,219 m.).

It is of further interest to note the occurrence of many erosion surfaces (or marine terraces) in the Pacific region amongst which are the 200-, 400-, and 600-ft. surfaces. One of Baulig's major surfaces is at 600 ft. (180 m.); the others are at 925 ft. (280 m.) and 1,250 ft. (380 m.), but the 200- and 400-ft. surfaces are also listed as minor ones. In Britain also the 200-, 400-, and 600-ft. surfaces are mentioned." (R20) H. Baulig, mentioned in the last paragraph above, was an early proponent of worldwide stepped erosion surfaces. Underwater erosion surfaces. "The shelf around Australia, like many other continental shelves, has its edge chiefly at depths of 120 to 130 m and is marked locally by terraces and notches, which register low stands of the sea during the Quaternary. From radiometric dates of shallow water fossils recovered from terraces in different parts of the world the lowest eustatic level of the sea during the past 35,000 yr is estimated to be -130 m, 16,000 yr ago. More recent information, principally from Australian waters, suggests that the sea level may have stood much lower during this period. Dill and Conolly found submerged terraces with shallow water fossils and sediments between depths of 175 to 238 m in 39 of 78 narrow beamed echo sounder profiles made all around Australia. The continuity and consistent depth of the terraces indicate that there has been little tectonic warping of the continental margin since the terraces were formed. Similar features are reported off southern and Baja California, and a shallow water mollsuc from a deep terrace off Baja California has a radiocarbon date of 14,380 $\pm$ 190 yr BP." (R32)

New Zealand. "Between Wairau River and Banks Peninsula, New Zealand, a series of marine terraces has been distinguished by G. Jobberns. The terraces occur along the

greater part of the coast mentioned but are lacking in small portions---a fact difficult to explain. The altitudes of the members of the series are respectively 40-60 feet, 120-150 feet, 230-250 feet, 330-380 feet, 500-525 feet, 650-700 feet, 800-900 feet, and 1000-1200 feet (estimated). The inner edges of the terraces, when traced over several miles, are not regular in height; the outer margin may occasionally be as much as 150 to 200 feet higher than the inner edge; and the surface cover may have a pronounced landward tilt." (R11)

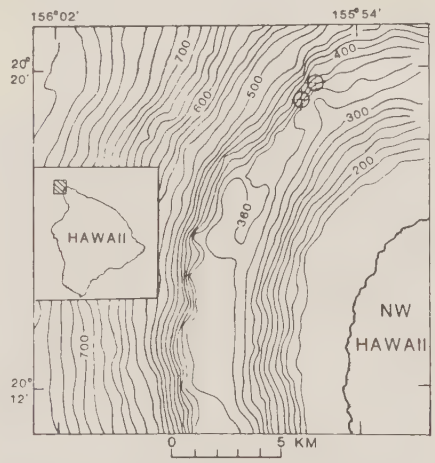
"Three types of evidence indicate that marine terraces are widespread in the Southern Alps of New Zealand. (i) Remnants of shore platforms occur as distinct levels of notced ridge crests and flat summits; degraded sea cliffs are common. (ii) Scattered quartz beach pebbles occur on 16 of 18 levels of exhumed shore platforms in the Fox-Franz Josef type area to altitudes as high as 1700 metres. (iii) Altitudinal spacings of New Zealand terrace flights allow correlation with 18 dated global marine terraces at New Guinea, which were formed during glacio-eustatic highstands of sea level within the last 336 x 10^3 years." (R38)

X7. Oceania.

Hawaii. "The highest fossiliferous marine limestone yet found in Hawaii crops out 5 miles southeast of Lanai City, Lanai, at an altitude of 1,069 feet. This and the presence of 30 feet, or more, of soil above an altitude of about 1,250 feet, and its nearly complete absence below this altitude, suggest that the island has emerged about 1,250 feet. A prominent shore line at 560 feet altitude is shown by fossiliferous marine conglomerate, a pronounced wave-cut notch in the bed rock, and abundant shingle at this level. The presence of these marine sediments in some of the canyons indicates that the canyons had reached essentially their present form prior to this stand of the sea. The determination of the age of these deposits awaits identification of the fossils. Below the 560-foot shore line are prominent younger shore lines at the 25- and 100-foot levels. Several others, indicated by wave-cut notches and marine deposits, occur between 100 and 560 feet, but their precise altitudes have not yet been determined. Stripping of the soil and the presence of shingle indicate that Oahu, Molokai, and West Maui have also emerged about 1,250 feet, and probably, similar evidence will be found on the other high islands of Hawaii when their geology is studied in detail." (R15) Even though 1200-foot terraces seem to occur worldwide, they are automatically explained in terms of local "emergence". (WRC)

"Abstract. A highly fossiliferous sample dredged in September 1961 from a submerged terrace at a depth of 500 to 520 meters off Honolulu contains a reef fauna suggesting deposition in depths of 10 meters or less. The corals and pelagic forminifers indicate a probable Miocene age. The Hawaiian rise was in existence prior to that time, and the submarine terrace and associated reef were subsequently submerged to their present position." (R24)

"Observations from a manned submersible vehicle indicate that the -360-m reef terrace northwest of the island of Hawaii is a drowned coral reef. The preferred uranium-series age of Coralline algae collected from the reef face is 120 $\pm$5ka. This age agrees with the notion that the reef was drowned during the sea-level rise following the major lowstand of the sea that occurred at 145 ka (oxygen isotope stage 6)." (R41)



Bathymetric map of northwest Hawaii showing the sunken reef at 360 meters depth. Beginning at 160 meters, the contour interval is 20 meters. (X7)

"Submerged carbonate reefs are preserved as a series of submarine terraces between Molokai and Hawaii along a 200-km span of the southeastern Hawaiian Ridge. Limestones from two of the terraces have been sampled from submersibles and dated radiometrically

at 13 and 120 ka. Recognition that the terraces are tilted permits assignment of about a dozen terraces from 150 to 1300 m depth to eight general reef platforms. These reefs were drowned by the combined effects of island subsidence and sea level rise at the end of successive glacial stages from 13 to 647 ka. The platforms are tilted 5 m/km southeast toward the locus of volcanic loading centered on the island of Hawaii." (R42) The very deep terraces at 1300 meters are as deep as some of the guyots (ETH1). Note that radical sealevel and geoid changes are customarily avoided in explaining very high and very deep beaches. See P.D. Nunn's comments on this situation in ETE2-X4.

The Marquesas Islands. "From the western edge of the plateau, 1,300 feet above Taa-huku, one can look eastward for eight or nine miles, one's line of sight just skimming the surface of the flat tops of the interfluves all the way. From its southern margin the plateau slopes gently upwards with an even gradient to a height of 1,600 feet at the foot of the central ridge, which rises sharply some hundreds of feet higher. Such a level surface could only have been formed either just above, or more probably just below, sea-level." (R13)

X8. The Middle East. Persian Gulf. "The absence of terraces on the Arabian side of the Persian Gulf is conspicuous. There are, however, traces of higher stands of sea level in the form of shell beds, serpulite reefs, and calcarenites, at several levels. East-facing cliffs in the Eastern Province, as opposed to west-facing cliffs in the Najd, and possible wave-cut benches on Jobal Dhahran, on Jabal Barri, and in the southwestern part of Qatar suggest the possibility of higher sea levels in Recent or Pleistocene times. (G.M.) Lees mentions terraces on the west side of the mountains of Oman at 1230 feet (and mentions that the northern end of this mountain range, the Musandum Peninsula, is submerged, forming a drowned coast). The coast lines of the Eastern Province and Trucial Coast are largely "emergent." Shingle, in what appears to be a beach remnant near Nibak at the eastern edge of the Sahbah deltaic gravel plains, stands at an elevation of about 110 meters." (R40) Again, the figure of about 1200 feet appears in beach elevations. (WRC)

References

R1. Howorth, H.H.; "Circumpolar Land," Nature, 5:420, 1872. (X3)

R2. Blytt, A.; "On the Variation of the Climate in the Course of Time," Nature, 34:220, 1886. (X4)

R3. "Rising of Land around Hudson Bay," Scientific American, 74:340, 1896. (X2)

R4. Bell, Robert; "Rising of the Land around Hudson Bay," Smithsonian Institution Annual Report, 1897, p. 359. (X2)

R5. Hershey, Oscar H.; "Raised Shore-Lines on Cape Maysi, Cuba," Science, 8:179, 1898. (X2)

R6. Geikie, Archibald; "Emergence and Submergence of Land," Nature, 70:111, 1904. (X4)

R7. "Coast-Ledges in Cape Colony," Geographical Journal, 27:629, 1906. (X5)

R8. Schwartz, Ernest Hubert Lewis; "The Coast Ledges in the South-West of the Cape Colony," Philosophical Magazine, 6:11:188, 1906. (X5)

R9. Smith, J.; "Thousand Foot Platform in Arran," Geological Magazine, 53:286, 1916. (X4)

R10. Kindle, E.M.; "The Terraces of the Lake Melville District, Labrador," Geographical Review, 14:597, 1924. (X2)

R11. Antevs, Ernst; "Raised Marine Terraces in New Zealand and South Africa," Geographical Review, 20:516, 1930. (X5, X6)

R12. Beebe, William; "A Submerged Beach off Bermuda," Science, 74:629, 1931. (X2)

R13. Chubb, L.J.; "The Elevation of the Marquesas Islands," Geological Magazine, 70:558, 1933. (X7)

R14. Johns, Cosmo; "The Quaternary Changes of Ocean Level: Causes and Consequences," Geological Magazine, 71:408, 1934. (X1)

R15. Stearns, Harold T.; "High Shore Lines on the Island of Lanai, Hawaii," Geological Society of America, Proceedings, 1936, p. 105. (X7)

R16. Hollingworth, Sydney Ewart; "The Recognition and Correlation of High-Level Erosion Surfaces in Britain: A Statistical Study," Geological Society of London, Quarterly Journal, 94:55, 1938. (X4)

R17. Stearns, Charles E.; "Pleistocene Geology of the Atlantic Coast of Northern Morocco," Geological Society of America, Bulletin, 59:1354, 1948. (X5)

R18. Bird, J. Brian; "Postglacial Marine Submergence in Central Arctic Canada," Geological Society of America, Bulletin, 65:457, 1954. (X2)

R19. Hapgood, Charles H.; "North America at the Pole," Earth's Shifting Crust, New York, 1958. p. 225. (X3)
R20. Geyl, W. F.; "Geophysical Speculations on the Origin of Stepped Erosion Surfaces," Journal of Geology, 68:154, 1960. (X1, X6)
R21. Geyl, W. F.; "Morphometric Analysis and the World-Wide Occurrence of Stepped Erosion Surfaces," Journal of Geology, 69:388, 1961. (X1)
R22. Stearns, Harold T.; "The Pattern of Some Pacific Island Chains," Geological Magazine, 98:170, 1961. (X6)
R23. Weaver, John D.; "Erosion Surfaces in the Caribbean and Their Significance," Nature, 190:1186, 1961. (X2)
R24. Menard, H.W., et al; "A Drowned Miocene Terrace in the Hawaiian Islands," Science, 138:896, 1962. (X7)
R25. Chubb, L.J., and Stearns, Harold T.; "Pattern of Islands," Geological Magazine, 99:279, 1962. (X7)
R26. Russell, Richard J.; "Recent Recession of Tropical Cliffy Coasts," Science, 139:9, 1963. (X1)
R27. "The Piece of Florida That Went Under," New Scientist, 20:530, 1963. (X2)
R28. Eardley, A.J.; "Polar Rise and Equatorial Fall of Sea Level," American Scientist, 52:488, 1964. (X1)
R29. Josselyn, Daniel W.; "How to Interpret Alaska's Raised Beaches?" Anthropological Journal of Canada, 3:24, no. 1, 1965. (X2)
R30. Whitmore, Frank C., Jr., et al; "Elephant Teeth from the Atlantic Continental Shelf," Science, 156:1477, 1967. (X2)
R31. Guilcher, Andre; "Pleistocene and Holocene Sea Level Changes," Earth-Science Reviews, 5:69, 1969. (X4)
R32. Veeh, H.H., and Veevers, J.J.; "Sea Level at -175 M off the Great Barrier Reef 13,600 to 17,000 Years Ago," Nature, 226:536, 1970. (X6)
R33. Hopkins, David M.; "Sea Level History in Beringia during the Past 250,000 Years," Quaternary Research, 3:520, 1973. (X2)
R34. Daly, Reginald; "Rise and Fall of the Floodwaters---Historical Record," Earth's Most Challenging Mysteries, Nutley, 1975, p. 117. (X1)
R35. Heirtzler, J.R., et al; "A Visit to the New England Seamounts," American Scientist, 65:466, 1977. (X2)
R36. Weyer, Edward M.; "Pole Movement and Sea Levels," Nature, 273:18, 1978. (X1)
R37. Smith, David; "Oceans that Go Up and Down," Geographical Magazine, 56:632, 1984. (X2)
R38. Bull, William B., and Cooper, Alan F.; "Uplifted Marine Terraces along the Alpine Fault, New Zealand," Science, 234:1225, 1986. (X6)
R39. Bell, Robert; "Proofs of the Rising of the Land around Hudson Bay," American Journal of Science, 4:1:219, 1896. (X2)
R40. Holm, Donald August; "Desert Morphology in the Arabian Peninsula," Science, 132:1369, 1960. (X8)
R41. Szabo, Barney J., and Moore, James G.; "Age of -360-m Reef Terrace, Hawaii, and the Rate of Late Pleistocene Subsidence of the Island," Geology, 14:967, 1986. (X7)
R42. Moore, James G., and Campbell, J. Frisbee; "Age of Tilted Reefs, Hawaii," Journal of Geophysical Research, 92B: 2641, 1987. (X7)
R43. Nunn, Patrick D.; "Implications of Migrating Geoid Anomalies for the Interpretation of High-Level Fossil Coral Reefs," Geological Society of America, Bulletin, 97:946, 1986. (X1)

ETE2 Raised and Submerged Fossil Coral Reefs

Description. Fossil coral reefs located hundreds of feet above or below the present sealevel. As with the raised and submerged beaches (ETE1), the major factors contributing to the anomalousness of this phenomenon are concordances of altitudes over wide areas and very large amplitudes of elevation and submergence.

Background. Just as wave action marked bygone sealevels, so do fossil reefs and carbonate platforms. Here, the mechanical action of the waves is replaced by the restricted building activities of various marine organisms; corals for example cannot survive above sealevel or below about 40 meters.

Data Evaluation. In many of the papers examined for ETE1, it is not clear if the "beaches" mentioned are associated with coral reefs. Some unintentional overlap may thus exist between ETE1 and ETE2. We currently do not have as much data on raised fossil reefs as we do for raised beaches. Because the origin of fossil reefs has been hotly debated for almost two centuries, this dearth is probably due to oversight rather than any real lack of data. In the data at hand, however, altitude concordance is not obvious, as it was in ETE1, although reef elevations and submergances are certainly very large. Rating: 2.

Anomaly Evaluation. The considerations here are essentially the same as they were for elevated and submerged wave-cut beaches. Please refer to ETE1. Rating: 1.

Possible Explanations. Please see ETE1.

Similar and Related Phenomena. Please see ETE1. It must be added, though, that submerged fossil reefs are very closely linked to the guyots (ETH). Guyots are often capped with carbonate platforms; and some coral atolls are apparently built on guyots.

Examples

X1. The Caribbean. A summary of a paper given by W.O. Crosby before the Boston Society of Natural History.

"Mr. Crosby describes, in this paper, the elevated coral reefs of Cuba, and draws from them the apparently well sustained conclusion that they indicate a slow subsidence during their formation, and hence, further, that Darwin's theory of the origin of coral islands is the true theory. The lowest reef terrace, of the northern side of the island, has a height of thirty feet, and varies in width from a few rods to a mile; it was once, plainly, the fringing reef of the shore. The second reef-terrace rises abruptly from the level of the lower to a height of 200 to 250 feet, and bears evidence of having been of like origin with the lower. The altitude of the third reef is about 500 feet; and the fourth has a height east of Baracoa, near the Yumuri River, 'of probably not less than 800 feet.' These old reef terraces extend, 'with slight interruptions, around the entire coast of Cuba; and in the western part of the island, where the erosion is less rapid than farther east, they are the predominant formation, and they are well preserved on the summits of the highest hills. Mr. Alexander Agassiz states that the hills about Havana and Matanzas, which reach a height of over 200 feet, are entirely composed of reef-limestone.'

In the precipitous mountain called El Yunque (the Anvil), five miles west of Baracoa, reef-limestone, 1,000 feet thick, constitutes the upper half of the mountain, the lower part, on which the reef rests, consisting of eruptive rocks and slates; and originally the upper limit of this modern limestone formation must have been 2,000 feet above the sea-level. Mr. Sawkins gives 2,000 feet as the maximum thickness of the Jamaica elevated coral reefs above the sea.

Evidence that the reefs were not formed during a progressive rising of the land is drawn from the thickness of the reefs. Mr. Crosby observes that the reefs reaching to a height of 500 and 1,000 feet---if not also that to a height of 2,000 feet---show, by the remains within them, that they were not made chiefly of reef-building corals, and hence, that they were not begun in deep water, as is assumed in the theory of Mr. Agassiz, but that they were made in shallow water during a progressive subsidence. Mr. Crosby concludes as follows:

'We have then apparently no recourse but to accept Darwin's theory as an adequate explanation of the elevated reefs of the Greater Antilles; and, therefore, to admit that upheaval of this portion of the earth's crust has been interrupted by periods of profound subsidence, during which the reefs were formed. The subsidence of 2,000 feet, of which El Yunque is a monument, must have reduced the Greater Antilles to a few lines of small but high and ragged islands; and, as Mr. Bland has shown, this fully accounts for the absence in these immense tracts of all large animals, although they were abundant here in the Pliocene and earlier times.'" (R1, R2) Note that changes in the volume of seawater are not considered. See ETE1-X2 for descriptions of the Cuban raised marine terraces, which are obviously closely related to the raised coral reefs. (WRC)

In his survey of high-level fossil coral reefs, P.D. Nunn lists Barbados at 335 meters and Antilles at 150 meters. (R7)

X2. Oceania. The so-called "Coral Reef Problem" has been laid out by C. Johns, with special reference to Oceania. Johns also has linked the reef and raised beach problems in ETE1-X1.

"The discussion which follows is restricted to the Coral Sea proper with its extension from 30°S. to 30°N. It forms a belt 1,200 to 2,000 miles wide and 6,000 miles long with its axis lying, nearly, parallel to the plane of the ecliptic in the Pacific Ocean. Atolls occur literally in hundreds and reef-encircled islands are numerous.

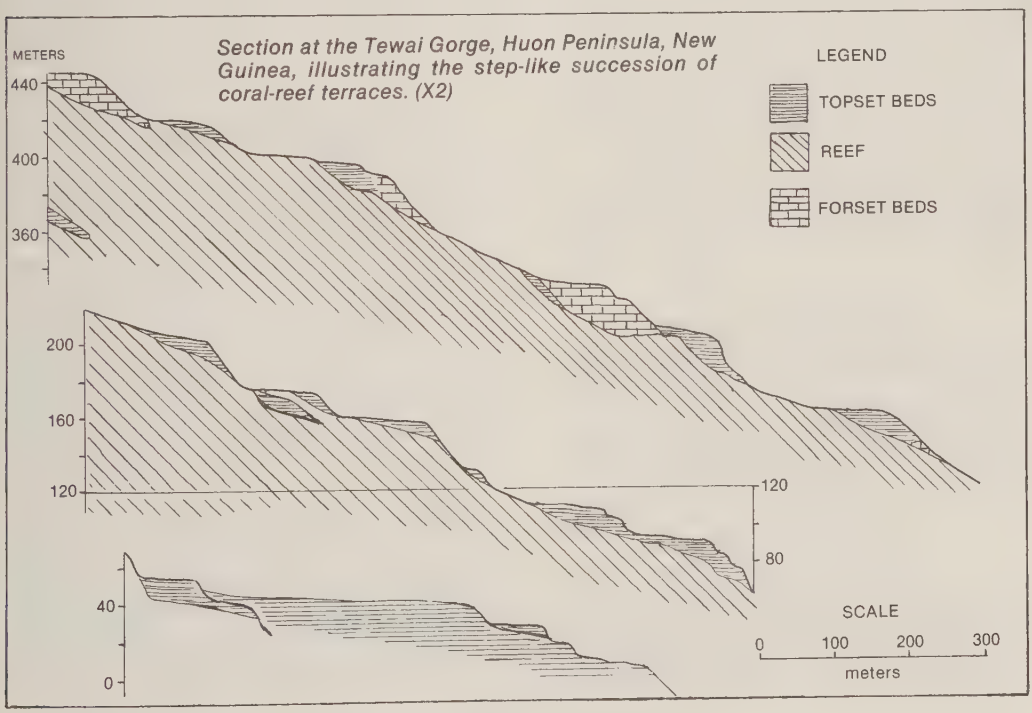
Coral reefs are so well known that only a brief notice of their classification need be given here. Fringing reefs have no moat or lagoon between them and the coast. Barrier reefs possess such lagoons. Atolls are reefs encircling a lagoon with no coast land above sea-level. It is generally inferred that as, with a very few exceptions such as New Caledonia and Viti Levu in the Fiji Islands, the coral islands are composed on volcanic rocks, the foundations of the atolls must also be volcanic in origin, rising from great ocean depths with a base covering a large area.

There is general agreement among observers that the reefs grow more rapidly on the outside where they are bathed by clean sea water, and that on a subsiding coast the reef would grow upwards while on a stationary coast it would increase in width by growing outwards.

Growth cannot take place above sea-level nor below a depth of about 40 metres. Lagoons are as a rule now being aggraded but in some instances are being excavated. This brief description includes, it is believed, all that is relevant to the present discussion.

The coral reef problem is the question of the relation of land- and sealevels before, during, and since the formation of the reefs. As a rule they are at sea-level, but some of all classes have undergone elevation varying in amount from a few metres to several hundreds. In several cases tilting has occurred. One of the most striking facts is the general, but not strict, accordance of the depths of the lagoons which are mostly 20 to 55 metres but occasionally 75 to 90 metres deep. There are also numerous drowned atolls most of which lie at depths less than 90 metres. Any explanation of the formation and present position of coral reefs that does not include these generally accordant depths of lagoons and drowned atolls is manifestly incomplete." (R3)

Two examples of elevated reefs in Oceania are those of islands in the Molucca Sea, which are recent and range up to 50 meters above sealevel, and the Plio-Pleistocene reefs of Timor 1283 meters above sealevel.



Section at the Tewai Gorge, Huon Peninsula, New Guinea, illustrating the step-like succession of coral-reef terraces. (X2)

(R8) Also pertinent is the fact, ascertained by drilling, that Eniwetok Atoll has subsided about 1200 meters since coral growth began there. (R9)

P.D. Nunn's tabulation of high-level fossil coral reefs includes Guam at 190 meters; Tewai, Huon Peninsula, Papua New Guinea, at 446 meters; Kume in the Ryukyus at 100 meters; and Choiseul, in the Solomons at 800 meters. (R7)

In particular, the coral terraces of Papua New Guinea are most impressive. "A spectacular flight of terraces occurs on the northeast seaboard of Huon Peninsula, New Guinea. The terraces are clearly developed for more than 80 km and rise to over 600 m. They are built dominantly of coral reefs but include subordinate deltaic gravel formations.....A record of sea-level changes relative to the rising land is determined for each section. Radiometric dating of the terrace reefs indicates Pleistocene sea-level maxima at the following times (yr. B.P.): 30,000, 40,000 to 50,000, 60,000, 80,000, 105,000, 120,000, 140,000, 185,000, 220,000." (R10; R11) Once again tectonic uplift and glacial-eustatic changes are deemed adequate explanations. (WRC)

X3. Europe. "Leg 48 of the internationally sponsored Deep Sea Drilling Project has shown that an ancient mountain range, which has now sunk to a depth of 4,000 feet below the sea surface, once existed between Greenland and Europe. Project scientists also discovered that the edge of the European continent, near Spain, was once bounded by a hitherto unknown swamp and shallow sea, abounding with coral reefs. Both are now 10,000 feet below the Bay of Biscay." (R4)

X4. Indian Ocean. Nunn in his compilation of high-level fossil coral reefs lists two examples in the Indian Ocean over 100 meters: Atauro Island at 600 meters; and Christmas Island at 357 meters. Fossil reefs at lower elevations exist, too. (R7)

X5. Australia. Great Barrier Reef. "Two rock samples were collected with the mechanical arm of the (Yomiuri) submersible, on either side of a terrace at 165m. At a depth of 175m in traverse BB', muddy sand and platy rocks were observed from the submersible on a terrace too narrow to be detected by the wide beam echo sounder in the ship. A large coral colony measuring 50 cm by 20 cm was collected from this terrace, and was identified as Galaxea clavus (Dana). It is a characteristic shallow water reef coral, although it has been observed to occur at 25 m in the Maldives and occasionally as deep as 75 m at Bikini and Jamaica." (R12)

X6. General observations. From the Abstract of a paper by P.D. Nunn: "The 'emergence' of selected islands with high-level fossil coral reefs in the Pacific, Atlantic, and Indian Oceans is reviewed and the likely contribution of geoidal eustasy highlighted, particularly in cases in which geotectonic reasons for island uplift are absent or doubted." (R7) In other words, Nunn seeks to explain the widespread existence of high-level fossil coral reefs through changes in sea level rather than by uplift and emergence. (WRC)

References

R1. Crosby, W.O.; "The Elevated Coral Reefs of Cuba," Scientific Americal Supplement, 16:6374, 1883. (X1)

R2. Crosby, W.O.; "Elevated Coral Reefs of Cuba," Philosophical Magazine, 5:16: 319, 1883. (X1)

R3. Johns, Cosmo; "Quaternary Raised Beaches and the Coral Reef Problem," Geological Magazine, 71:176, 1934. (X2)

R4. "Deep Sea Leg 48," Science News, 110: 71, 1976. (X3)

R5. Schlager, Wolfgang; "The Paradox of Drowned Reefs and Carbonate Platforms," Geological Society of America, Bulletin, 92:197, 1981. (X4)

R6. "Rise and Fall of Carbonate Platforms in the Bahamas," Nature, 315:632, 1985.

R7. Nunn, Patrick D.; "Implications of Migrating Geoid Anomalies for the Interpretation of High-Level Fossil Coral Reefs," Geological Society of America, Bulletin, 97:946, 1986. (X4)

R8. Fairbridge, Rhodes W., ed.; The Encyclopedia of Oceanography, New York, 1966, pp. 528 and 926. (X3)

R9. Cloud, Preston; "Reef," McGraw-Hill Encyclopedia of Science and Technology, 11:418, 1977. (X3)

R10. Chappell, John; "Geology of Coral Terraces, Huon Peninsula, New Guinea: A Study of Quaternary Tectonic Movements and Sea-Level Changes," Geological Society of America, Bulletin, 85:553, 1974. (X2)

R11. Chappell, John; "A Revised Sea-Level Record for the Last 300,000 Years from Papua New Guinea," Search, 14:99, 1983. (X2)

R12. Veeh, H.H., and Veevers, J.J.; "Sea Level at 175 m off the Great Barrier Reef 13,600 to 17,000 Year Ago," Nature, 226:536, 1970. (X5)

ETE3 Terraces along Rivers, Submarine Canyons, and Sea-Floor Channels

Description. Terraces along the sides of modern rivers, along the walls of submarine canyons, and parallel to channels cut in the ocean floors. These terraces may be multiple; that is, a series of steps, and either two-sided or one-sided. Although these terraces are all morphologically similar, they may have had different origins.

Data Evaluation. River terraces are frequently obvious to the most casual traveller. In contrast, submarine canyon and seafloor channel terraces can be appreciated only from a submersible or the examination of echo-sounding records. All of the types of terraces mentioned are rather common all around the globe, but little has been found in the way of scientific studies in the journals examined so far, with the exception of the submarine canyons. Rating: 1.

Anomaly Evaluation. The common riverside terraces are not extremely high and can be explained readily in terms of higher river levels (and sealevels) during past climatic periods. There is little that is anomalous here. In the cases of the terraces along submarine canyons and seafloor channels, though, origins remain unclear. If they were formed by subaerial erosion; that is, when ocean levels were thousands of feet lower, the anomaly would be significant, because geological theory does not envisage such large sealevel fluctuations in the past. The anomalousness of these types of terraces would be less if they were cut by underwater currents---in some way not yet fully understood---or formed by wall slumping. We assume the latter two possibilities in establishing a rating. Rating: 2.

Possible Explanations. Terraces may be cut by subaerial river erosion and/or by submarine currents. Valley wall slumping also occurs.

Similar and Related Phenomena. The famous "parallel roads" of the Scottish highlands (ETE4); raised beaches (ETE1), which sometimes merge with river terraces; submarine canyons and seafloor channels (ETV1 and ETV2).

Examples

X1. North America.

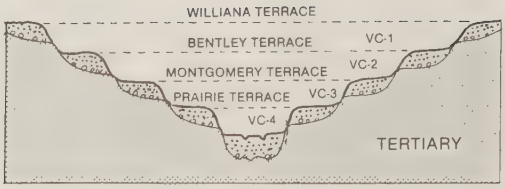
The Mississippi River. Four distinct terraces are found along the lower Mississippi. Geologists link them to the four glaciations of North America. At the time of the first glaciation, the lower Mississippi was 70 miles wide. (R3)

The Potomac. Horizontal terraces near Washington, DC, indicate that the waters of the Potomac Basin were once at levels 95, 160, 215, and 265 feet above the present level. (R4) Such modestly elevated terraces are within the explanatory capability of present geological scenarios of uplift and minor sealevel fluctuations.

The Spokane River. Terraces similar to those along the Potomac are found in the state of Washington. (R4)

X2. Europe.

The Thames. The Thames, in England, has terraces at 20, 50, 90, 150, and 300 feet



IDEALIZED RELATIONSHIP OF TERRACES

Terraces along the lower Mississippi River. (X1)

above the present sealevel. (R4)

The Rhine. Some parts of the Rhine Valley display strongly marked "parallel roads' or terraces. (R1)

X3. The Middle East.

The Euphrates. "Five well-marked terraces are well displayed one above the other on the right bank of the river along the great curve which it makes in passing from Rakka to Deir-el-Zor. Their heights above the river, as measured by M. Darrous, Topographer to the 'Mission hydrographique Heraud,' are given in metres in column 1 below:

77.13, 56.14, 30.52, 15.36, 3.60." (R2)

X4. Africa.

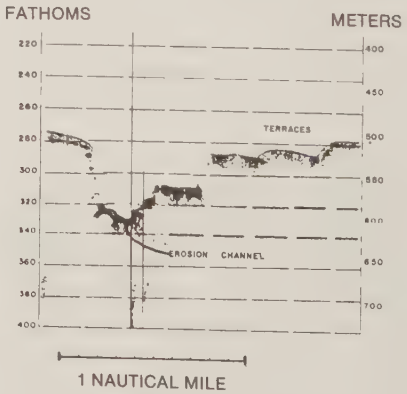
The Isser, in Algeria. Terraces along this river have been measured (in meters) at:

93-95, 55-57, 28-30, 15-16. (R2)

X5. Ocean-floor and submarine canyons.

The Atlantic. Fathometer traces made near the mid-Atlantic ridge, in about 2,600 fathoms, reveal terraces ocean-floor channels. (R3)

Submarine canyons in general, and the La Jolla Canyon in particular. "The transverse profiles in this, as in other fan-valleys, show terraces. Virtually all of these, and certainly all of the wider terraces, are found on the inside of the curves. At first it was thought that the terraces represented partial fill of the fan valley, followed by rejuvenation. If this were the case, there would be some sections showing matching terraces on the two sides, but this has never been found despite numerous close-spaced profiles. Furthermore, the profiles show that the terraces change radically in short distances down valley. Some of the terraces quite clearly slope in toward the valley walls. Also, the terraces occur at all levels, from near the upper rim to near the channel floor. Therefore, there is no indication from the available data that the terraces are the result of rejuvenation of erosion and entrenchment of an old valley fill. Terraces could also be the result of slump, similar to the terraces found on the sides of many land valleys." (R5) See ETV1 and ETV2.



An echo-sounder profile across the La Jolla Fan-Valley. (X5)

References

R1. Hall, Basil; "Account of the Parallel Roads in the Valley of Coquimbo," Edinburgh Philosophical Journal, 11:255, 1824. (X3)

R2. Sollas, W.J.; "River Terraces of the Euphrates," Nature, 118:692, 1926. (X3, X4)

R3. Hobbs, William Herbert; "Terraced Canyons," Science, 117:461, 1953. (X1, X5)

R4. Nelson, Byron C.; "The Period of Waning," The Deluge Story in Stone, Minneapolis, 1968, p. 97. (X1, X2)

R5. Shepard, Francis P., and Dill, Robert F.; "Submarine Canyons of the La Jolla, California, Area," Submarine Canyons and Other Sea Valleys," Chicago, 1966. p. 65. (X5)

ETE4 Inland High-Level Terraces and Erosion Surfaces

Description. Sets of terraces along the sides of mountains located well inland. Such groups of terraces may stretch for hundreds of miles. Elevations range from a few hundred to several thousand feet above the present sealevel. The terraces are usually not associated with any modern rivers of consequence.

Data Evaluation. The data are skimpy and generally quite old. Age, however, should not be a negative factor, because the observations and measurements required are elementary. As with the raised beaches (ETE1), systematic, global studies are scarce; and it is impossible to determine whether we have a common, worldwide phenomenon. Rating: 2.

Anomaly Evaluation. If all of the individual examples of inland, high-level terraces can be explained in terms of such local factors as ice dams, differential erosion, and valley-wall slumping, no anomaly exists. On the other hand, these terraces could be a worldwide phenomenon, like some raised beaches and fossil coral reefs, and thus be symptomatic of large-scale marine inundation, due perhaps to crustal warping or a great increase in seawater volume. If future analysis ever leads to such a conclusion, we would have a serious anomaly. At the moment, though, geologists seem satisfied with the explanations now in place. Rating: 3.

Possible Explanations. Erosion by ice-impounded lakes; differential erosion of horizontal strata; valley-wall slumping; and, improbably, worldwide marine transgressions of great magnitude. Stepwise uplifting of the land.

Similar and Related Phenomena. Raised beaches and the other correlations listed in ETE1.

Examples

X1. North America.

Southeastern Ohio. "About thirty years ago Professor J.J. Stevenson called attention to a considerable number of high level terraces or benches occurring in the upper Ohio river region, 'almost absolutely level' and ranging in height from 1100 to 2580 feet above sea level. They were more widespread than the river terraces of outwash gravel, and consisted of rock benches well covered with mantle rock. The latter 'contained little clay and no transported material but was mostly sand.' Although always above all the outwash terraces, they descend nearly to the upper ones, but never merge with them. They seem to consist of a rock notch, and the removed material laid just below the notch. These high level terraces are recent, having been made since the last warpings of the region, and being very well preserved.

Professor Stevenson explained that they are due to wave work on the valley walls and hillsides when the region was deeply submerged subsequent to the retreat of the ice sheet. The upper one was formed when the region was depressed nearly 2600 feet below the present level, admitting the sea into a complex, branching system of valleys; and the lower terraces developed at successive halts as the land slowly emerged from

These terraces have probably never been causally connected with the Cincinnati ice dam theory, but in 1890 Professor Chamberlin discussed them in connection with that theory, stating that the land on which the

dam occurred is 440 feet above sea level and that the dam as described by other students, and as required to force the water over the cols to the southward, was probably 500-625 feet thick, placing its summit at 1000-1100 feet above sea level. He concludes that such an obstruction could scarcely make a series of terraces, ranging in altitude from 1100-2580 feet. He shows that some of the terraces are structural or gradational and perfectly related to the strata.

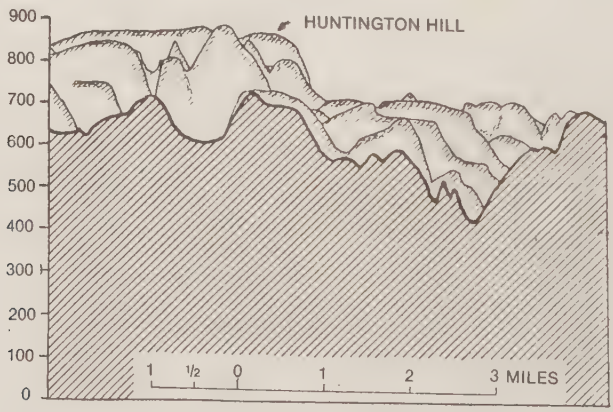
In 1903 W.G. Tight also discussed the high-level terraces, especially from southeastern Ohio, and considers them to be wave-cut forms, and suggests lake conditions due 'to obstructions to the drainage beyond the limits of the basin.' He further states that they bear no relation to the ice dam of Wright. The author does not believe an ice dam was ever effective near Cincinnati nor that any of the phenomena up the valley require such a dam for explanation." The remainder of this paper makes the case for differential weathering as the cause of the terraces. In other words, the softer strata have been eroded more than adjoining hard strata, producing a terrace effect. (R14) In X3, the so-called "parallel roads" of Glen Roy, in Scotland, are found to be still explained in terms of ice dams. (WRC)

Connecticut. This state displays many terraces: the Pitcher Mountain terrace, 280-320 feet; New Canaan terrace, 340-380 feet; the Towantic terrace, 700-740 feet; the Prospect terrace, 840-880 feet; the Litchfield terrace, 1100-1140 feet; the Goshen terrace, 1340-1380 feet; and the Cornwall terrace, 1640-1680 feet. The erosion record is very complex. (R18)

Massachusetts. "Geological work in western Massachusetts in 1911 showed remnants of four baseleveled surfaces at elevations of 2,250, 1,840, 1,400, and 1,100 feet." In Vermont, to the north, there are traces of even higher levels. (R18)

Maryland. Two of Maryland's Piedmont terraces have elevations of 520-540 and 730-745 feet. Water-worn pebbles and gravels are found on the latter. (R18) It should be noted that the survey paper from which the data for Maryland, Massachusetts, and Connecticut were taken was written in 1920. Undoubtedly more work on these terraces has been accomplished since then. (WRC)

Pennsylvania. Terraces similar to those mentioned above seem to extend into Pennsylvania, as remarked by J.P. Lesley: "I drew the contour curve of 1,300 feet above tide around the sides of all the valleys of Western Pennsylvania, to see how a submergence of that magnitude would account for the terraces (or some of them) and for the distribution of the perched azoic blocks, confined geographically to the country west of the Beaver River and north of the Ohio; and I concluded that a submergence to that extent was probable; also, that the upper clay terraces represent the sloping plains of mud which during that submergence were deposited in the valleys, by ordinary deposit from the surrounding and intervening coal-measure highlands. I have (it is needless to say) always considered our whole topographical sculpture nearly accomplished and finished previous to the commencement of this era of late and temporary submergence; and I am still unable to see any need for changing my old views. I still believe



Profile of southern Connecticut showing the Towantic and Prospect terraces. (X1)

that the valleys have been refilled and are being reexcavated; the terraces being only residual strips of Champlain clay left clinging to and upon older rock-terraces worn by the ancient erosion out of the hard and soft horizontal layers of the coal-measure mass." Lesley concludes with the statement that English geologists would undoubtedly account for the terraces by siting an ice dam at Pittsburgh, but that this would not explain "a phenomenon coextensive with half a dozen states of the Union." (R9) He does not specify the other states.

X2. South America.

Chile. The following (rather ancient) item was written in response to the debate over the origin of Glen Roy's "parallel roads." "On the 18th November, our friendly host accompanied one of the officers of the Conway and myself, in a ride of about twenty-five miles, up the valley of Coquimbo, during which, the most remarkable thing we saw was several series of horizontal beds, along both sides of the valley, resembling the parallel roads of Glen Roy, in the Highlands of Scotland, so carefully examined by Thomas Lauder Dick, Esq., and described in the ninth volume of the Edinburgh Royal Society's Transactions. They are so disposed as to present exact counterparts of one another, at the same level, on opposite sides of the valley. They are formed entirely of loose materials, principally water-worn rounded stones, from the size of a nut to that of a man's head. Each of these roads or levels, resembles a shingle beach, and there is every indication of the stones having been deposited at the margin of a lake, which has filled the valley up to those levels. These gigantic roads are at some places half a mile broad, but their general width is from twenty to fifty yards. There are three distinctly characterised sets, and a lower one, which is indistinct when approached, but, when viewed from a distance, is evidently of the same character with the others. The upper road lies probably 300 or 400 feet above the level of the sea, and 250 from the bottom of the valley; the next twenty yards lower, and the next about ten yards still lower. These distances are loosely estimated, and may be erroneous, for it is difficult to determine heights or distances in a country quite new, and without natural or determinate objects of comparison." (R1)

The Andes. "Abstract. Unsubstantiated reports of a sea horse in Lake Titicaca and elevated marine beaches in the Peruvian Andes Mountains repeatedly have been cited as evidence for a major post-Pliocene uplift of the range. This gives these items unwarranted stature and casts doubt on orogenic and erosional theories otherwise in good standing." The author of this article went back to the original claims of high level marine deposits and, quoting from the paper, shows that these deposits are not only "insignificant" but merely "thought" to be of marine origin from two unidentified shells. (R16) The sea-horse tale also seems to be very shaky and will be discussed more thoroughly in the series B catalogs.

X3. Europe.

Scotland. More has been written about the "parallel roads" of Glen Roy than any other terraces. We have room only to quote a short description.

"The earliest published allusion to these roads was made in a work brought before the public a century ago (1777), but no systematic description of them appeared before 1817. They are found in the district of Lochaber, Inverness-shire. On both sides of the steep, narrow glen through which the Roy runs, there are three perfectly horizontal and parallel roads, directly opposite on each side, those on one side corresponding exactly in elevation to those on the other. They are respectively 1,150, 1,070, and 860 feet above the sea, and are formed as shelves in the yielding drift which covers the sides of the mountains. They usually slope somewhat from the hill, and vary in width from one to twenty yards. The two highest stop abruptly at different points near the mouth of Glen Roy, although no barrier now remains to show any reason for it. At some points the grass on the shelves differs from that which is above and below, and, as the roads lie in the midst of heather-covered hills, the absence of the dark shrub from them adds greatly to their conspicuousness." Similar "roads" are found in at least three nearby glens. (R8) The 1150-foot road is close in altitude to many elevated beaches. (WRC)

An early and still preferred explanation of the terraces is that they were cut by lakes impounded by ice dams at the mouths of the glens during the Ice Ages. (R17)

Objections have been raised to the ice-dam

theory. To illustrate, there are no geological indications that an ice dam ever existed. And why do the two top roads disappear near the mouth of Glen Roy and the other glens? (R4)

More telling perhaps is the conclusion of J. Nicol: "The chief and fatal objection to the lake-theory is that it supposes rivers to have flowed in places where there is clear proof that no river has ever flowed, ---that it assumes a great lake to have been suddenly drained by a narrow glen where it is undoubted no stream of water, larger or more rapid than the tiny rill gathered from the sides of the neighbouring mountain, has ever existed since the ocean laid down the loose soil spread over its smooth unbroken declivities. The theory not only fails to explain the phenomena, but is in direct contradiction to them, and therefore must be rejected." (R6)

cavated; 3rdly, from the elevation of the terraces of alluvium in the valleys; and lastly, from the harmony of the results obtained from these three sets of observations, when compared together." A lengthy paper full of details follows this Introduction. A summary table at the end lists the elevations of many terraces, starting as high as 6190 feet. (R3)

X4. Australia, Tasmania. "Five major erosion surfaces are recognized in Tasmania: the higher plateau surface at about 3,900 to 4,300 feet, the lower plateau surface at about 3,000 to 3,500 feet, the St. Clair surface at about 2,400 to 2,700 feet, the higher coastal surface at about 1,200 to 1,500 feet and the lower coastal surface at about 800 to 900 feet.

The famous parallel "roads" of Glen Roy, Scotland. (X3)

The Alps. "In the following pages I have attempted to show, that, after the Alps had assumed their present form, and when they already stood as much above the surrounding lowlands as at present, they must have been nearly submerged below the sea, out of which their rise must have been, by a series of steps or starts of unequal amount, separated by long intervals of time. The evidence on which these views rest is derived from three sources; 1st, from the traces of erosion on the sides of the mountains, ending upwards in lines of uniform level; 2ndly, from the levels to which the valleys have been ex-

These are considered to be uplifted subaerial erosion surfaces although the lowest may be largely or even entirely marine. They appear to be unwarped except possibly in the north and have been subjected to no more than minor faulting. It is suggested that, in the evolution of the Tasmanian landscape, planation has followed major faulting and scarps have been formed by differential erosion along fault lines rather than directly by tectonic agency." (R20) As usual, sea-level changes are not suggested as possible explanations of high-level erosion surfaces. (WRC)

X5. General observations on worldwide concordances of plains and plateaus. L. C. King has found widespread concordances in the elevations of plainlands. "Summary. A review of the older plainlands and plateaus of the earth reveals a similarity in age and elevation sufficient to suggest that their independent origin and development in their situation is unlikely. It is claimed that continent-wide bevelled surfaces have been produced by 'pediplanation'. A world-wide correlation of pediplaned surfaces now standing at varying levels above O.D. is suggested by the following grouping: (a) pre-Cretaceous super-continental cycles of erosion ('Gondwana' and Laurasia' surfaces); (b) pre-Miocene intermediate continental cycles ('African', 'Prairie' etc. surfaces); (c) modern continental cycles. The difference in elevation between the fundamental surface (a) and the plains of the continental early-Tertiary cycle (b) is attributed largely to the altitude of the twin Gondwana-Laurasia super-continents at the time of their breakup. It is suggested that global forces, and probably continental drift, must be invoked in explanation of these world-wide pediplaned surfaces." Two major groups of concordant surfaces are mentioned; one at 3000-4000 feet, the other at 1500-3000 feet. (R19) Of course, King is discussing plains and plateaus rather than terraces per se, and his worldwide pediplaned surfaces are usually much older than the terraces mentioned in X1-X4. Nevertheless, there may be some connection. (WRC) See also ETV10.

References

R1. Hall, Basil; "Account of the Parallel Roads in the Valley of Coquimbo," Edinburgh Philosophical Journal, 11:255, 1824. (X2)

R2. Dana, James A.; "Review of Chambers' Ancient Sea Margins," American Journal of Science, 2:7:1, 1849. (X3)

R3. Sharpe, Daniel; "On the Late Elevation of the Alps," Geological Society of London, Quarterly Journal, 12:102, 1855. (X3)

R4. Jamieson, Thomas F.; "On the Parallel Roads of Glen Roy," Geological Society of London, Quarterly Journal, 19:235, 1863. (X3)

R5. Lubbock, John; "On the Parallel Roads of Glen Roy," Geological Society of London, Quarterly Journal, 24:83, 1868. (X3)

R6. Nicol, James; "On the Origin of the Parallel Roads of Glen Roy," Geological Society of London, Quarterly Journal, 25:282, 1869. (X3)

R7. Nicol, James; "How the Parallel Roads of Glen Roy Were Formed," Geological Society of London, Quarterly Journal, 28:237, 1872. (X3)

R8. "The Parallel Roads of Glen Roy," Popular Science Monthly, 10:309, 1877. (X3)

R9. Lesley, J.P.; "On Terrace Levels in Pennsylvania," American Journal of Science, 3:16:68, 1878. (X1)

R10. Prestwich, Joseph; "On the Origin of the Parallel Roads of Lochaber and Their Bearing on Other Phenomena of the Glacial Period," Philosophical Transactions, 170: 663, 1879. (X3)

R11. Melvin, James; "The Parallel Roads of Lochaber," Report of the British Association, 1885, p. 1035. (X3)

R12. Jamieson, T.F.; "Supplementary Remarks on Glen Roy," Geological Society of London, Quarterly Journal, 48:5, 1892. (X3)

R13. Geike, Archibald; "Emergence and Submergence of Land," Nature, 70:111, 1904. (X3)

R14. Hubbard, George D.; "Some High Level Terraces in Southeastern Ohio," American Journal of Science, 4:25:108, 1908. (X1)

R15. Hickok, William O.; "Erosion Surfaces in South-Central Pennsylvania," American Journal of Science, 225:101, 1933. (X1)

R16. Garner, H.F.; "Mountains from Molehills," Geological Society of America, Bulletin, 74:195, 1963. (X2)

R17. Sissons, J.B.; "Mysterious Roads on Highland Slopes," Geographical Magazine, 49:639, 1977. (X3)

R18. Robinson, H.H.; "The Piedmont Terraces of the Northern Appalachians," American Journal of Science, 4:49:227, 327, 407, 1920. A three-part article. (X1)

R19. King, Lester C.; "The Study of the World's Plainlands: A New Approach in Geomorphology," Geological Society of London, Quarterly Journal, 106:101, 1950. (X5)

R20. Davies, J.L.; "High Level Erosion Surfaces and Landscape Development in Tasmania," Australian Geographer, 7: 200, 1959. (X4)

ETE5 Periodically Created Beach Terraces

Description. The periodic formation of terraces on slowly rising shorelines. With a slowly rising shoreline---and receding high-tide line---unusually stormy years will leave a succession of steplike terraces. Periodicity of the terraces can be ascertained by radioactive dating. Such periodicities may be correlated with astronomical phenomena.

Data Evaluation. For the sole example in our files, the dates and physical dimensions of the terraces have been determined with standard radioisotopic dating methods and theodolite surveys. Nevertheless, confirming data from other regions would be desirable. Rating: 2.

Anomaly Evaluation. The anomalousness of the situation increases with each causal step. Step #1, the link between terrace formation and climate, is not at all mysterious. Step #2, the causal connection between climate and solar activity, is not well-explained but is no longer hotly contested. However, Step #3 is extremely controversial. Here, the periodicity of the terraces, the climate, and solar activity are linked to recurring planetary configurations. It is this aspect of the phenomenon that is highly anomalous, because the only recognized causal factor, gravitation, is much too weak to produce the claimed effects. Rating: 1.

Possible Explanations. See above for the description of one causal chain. Conceivably, the terrace periodicity could also be the consequence of variations in the rate of uplift.

Similar and Related Phenomena. The putative correlations between planetary configurations and sunspot number (ASO9); weather (GWS8), and radio propagation conditions (GER11). Periodicities in bivalve growth patterns are also related to astronomical events (see a later volume in this series). Could the much-larger-scale successions of raised beaches (ETE1) also have astronomical origins, perhaps including meteor impacts?

Examples

X1. North America.

Hudson Bay. Abstract. "A series of isostatically-emerged Holocene beach ridges on the east side of Hudson Bay have been precisely surveyed and dated back to 8,300 BP. They number 185 and show a nearly uniform rhythm of about 45 yr correlated here with the 'Double-Hale' solar magnetic cycle. (Time is in sidereal yr.) Longer correlations are suggested with eustatic sea-level curve and with planetary conjunction cycles. The coupling mechanism with terrestrial meteorological behaviour is believed to be by means of stratospheric generation of polar cirrus cloud and low-altitude ozone, affecting the planetary albedo." (R1) The link between planetary positions and solar activity is far from accepted by the scientific community. (WRC)

References

R1. Fairbridge, Rhodes W., and Hillaire-Marcel, Claude; "An 8,000-yr Palaeoclimatic Record of the 'Double-Hale' 45-yr Solar Cycle," Nature, 268:413, 1977. (X1)

ETH GUYOTS, PLATEAUS, UNUSUAL MOUNTAINS

Key to Phenomena

ETH0 Introduction

The overwhelming majority of the earth's mountain-sized structures of high relief are the consequences of folding, upthrusting, volcanism, and erosion. We have come across few significant "mountain" anomalies that cannot be explained rather easily by appealing to these familiar geological processes. The guyots (flat-topped seamounts) seem to be the most anomalous so far. The guyots all seem to be truncated volcanic cones, but the origin of the truncation is still being debated. Is it the consequence of wave-planing (the popular view) or is it a constructional feature? If the guyots are truly wave-planed, large changes in sea level and/or wide-area, very deep downwarping are implied. Like the guyots, there are several extensive oceanic plateaus which are now far below sealevel. Some of these relief features have the characteristics of oceanic crust. No consensus exists as to their formation.

ETH1 Flat-Topped Seamounts (Guyots)

Description. Truncated volcanic seamounts with tops that are now, in the Pacific, 1000-2000 meters below present sealevel. The flat tops are usually capped by sediments from the Cretaceous period. Hundreds of guyots have been mapped in the Pacific. In the Atlantic, where they are called seamounts, they are rarer and seldom truncated. The tops of the guyots are generally not concordant, although some claims have been advanced that there is limited concordance with some submerged marine terraces.

Data Evaluation. Guyots have been probed by echo sounders, by dredges, and by manned submersibles. The data are of good quality, but not quite good enough to prove conclusively that

the guyots were truncated by waves. Rating: 2.

Anomaly Evaluation. At present, guyots are almost universally believed to have been planed by wave erosion. If this is the correct interpretation (some doubts exist), the guyots are markers of ancient sealevels, after the fashion of the raised and submerged beaches (ETE1). Since the guyots span immense areas in both Pacific and Atlantic, local downwarping of the earth's crust seems an unlikely explanation of their subsidence. Consequently, large sealevel changes are implied---changes much larger than those usually contemplated for the Cretaceous. Our anomaly rating is based upon this possibility, even though most geologists seem satisfied with the explanation based upon local subsidence. Rating: 1.

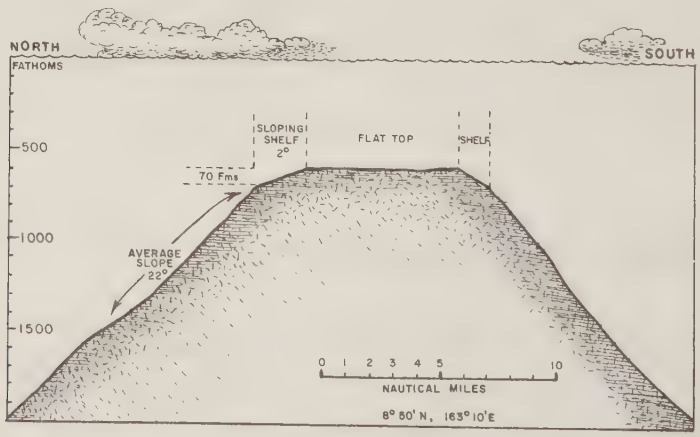
Possible Explanations. The submergence of the guyots is probably due to a combination of local and regional downwarping, large increases in the volume of ocean water, and changes in the volumes of the ocean basins themselves. On the other hand, some investigators think that the guyots' flat tops are produced naturally during submarine volcanic activity.

Similar and Related Phenomena. The raised and submerged beaches, fossil coral reefs, and anomalous terraces in ETE.

X1. The Pacific guyots.

Early survey results. "Abstract. Some one hundred and sixty, curious, flat-topped peaks have been discovered in the Pacific Basin between Hawaii and the Marianas. They appear to be truncated volcanic islands rising about nine to twelve thousand feet from the ocean floor. The flat summit levels generally range from three to six thousand feet below sea level. Some less-developed ones are deeper. The flat upper surface is commonly bordered by a gently sloping shelf a mile or two wide. The summit surfaces are apparently not all of the same age since adjacent peaks may have flat tops which differ in elevation by as much as a thousand feet, though in some cases groups of peaks do have the same elevation. The relationships to atolls of the Marshall Islands group indicate that the surfaces are older than the atoll formation. An hypothesis is tentatively advanced suggesting that the summit surfaces are very old and possibly represent marine planation surfaces in a Pre-Cambrian ocean in which reef building organisms do not exist. It is suggested that the present depths of the surfaces may be accounted for by the relative rise of the ocean surface as a result of accumulation of sediments on the floor. Thus the deeper the surfaces are the greater their age." (R1) Subsequent investigations revealed that the guyot surfaces are actually very young. (WRC)

Recent instability of the Pacific Basin. "Recent geophysical and geological investigations of the floor of the deep Pacific indicate that



Tracing of a fathometer record of a typical guyot, showing the characteristic flat top. (X1)

this area has been the scene of large-scale geologic activity during relatively late stages of earth history. Both seismic and paleontological evidence suggests that Bikini Atoll began to form on a volcanic base in Mesozoic or Early Tertiary time. Shallow-water fossils from dredgings on the Mid-Pacific Mountains show that the tops of the seamounts which form the summit of this range, now at depths of 2500 to 6000 feet, were near the sea surface during Early Tertiary or late Cretaceous time. The lower slopes of many deep topographic highs rising above the level of the sea floor appear to consist of talus unburied by sediment." (R3)

Guyot dredgings. "Five flat-topped seamounts ('guyots' of Hess, 1946) were dredged and cored in an area between 600 and 1100 miles west of Hawaii. The following faunas have been identified:

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

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

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

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

These investigations supported the notion that the guyots began as a chain of basaltic islands that were wave-planed and, during Cretaceous time were submerged and sank to their present depths. (R4)

Additional facts and observations; 1959. The fossils dredged up from the tops of the guyots are the oldest recovered from any of the oceans. Curiously, not all the guyot tops are level; some are tilted. Some guyots are surrounded by moat-like depressions---"good evidence that our so-called terra firma actually has failed." Finally, the non-concordance of most guyot tops seems to rule out general, large-scale changes in sealevel, while favoring the individual subsidence of the guyots. (R7)

Objections to the subsidence theory. "(E.) Hamilton, in his discussion of the extinctions of the Mid-Pacific Mountains, concludes that submergence brought on by local sinking of the ocean floor caused the death of organisms. We agree that submergence caused the death of the Albian-Cenomanian reef-dwelling fauna of the Mid-Pacific Mountains, but expand the thesis to include the Japanese Seamounts, and propose that eustatic rise of the sea level caused the drownings. The breadth of the area involved is great, stretching from Horizon Guyot in the east to guyot R in the west, and so the submergence is not local, as assumed by Hamilton, but involves a considerable portion of the Pacific plate. The concept of plate tectonics suggests no process whereby such a large segment of the ocean crust might founder, yet it does suggest mechanisms that would cause sea level to fluctuate, for instance, a change in the rate of spreading or in the configuration of the ridges causing a change in the volume of the oceanic ridges, and consequently a change in the volume of the water displaced. Other mechanisms have been proposed that correlate fluctuations of sea level with tectonic processes and climatic change. We have no evidence bearing on the cause of fluctuating sea level, but simply accept that sea level changes in the middle Cretaceous appear to have been global." (R11)

Seamount terraces. Some seamounts have distinct terraces rather than flat tops. They may be related to the guyots and certainly must be factored into the debate about sea-level changes.

"Two undersea mountains in the northeast Pacific, the Cobb and Bowie Seamounts, have terraces at a depth of about 216 meters that appear to have been cut by waves. Possible explanations for these terraces are that the mountains might once have been uplifted to above sea level and since subsided, or that the terraces might have developed during formation of the seamounts.

These explanations, says Maurice L. Schwartz of Western Washington State College, are unlikely. The uniform depth of the terraces, and the existence of other similar terraces at the same depth throughout the Pacific, suggest that they indicate a lowering of sea level. One terrace in the southwest Pacific has been dated at 13,600 to 17,000 years old."

X2. The Atlantic guyots. The Atlantic seamounts are predominantly conical rather than truncated. Typical guyots are rare, and even some flat-topped seamounts may not be wave-planed. Nevertheless, there is considerable evidence of deep submergence.

The Atlantis, Cruiser, and Great Meteor Seamounts. "The Atlantis, Cruiser, and Great Meteor seamounts rise from a broad ridge or plateau which extends from the Mid-Atlantic Ridge at 37°N. 32°W. southeast to Great Meteor Seamount at 30°N. 28°W. The Atlantis Seamount, briefly explored in 1947 and 1948, was found by echo sounding and submarine photography to have a fairly flat bedrock summit area at about 180 fathoms covered in some cases by cobbles and in other cases by current-rippled sand. Its slopes are covered with sand or ooze symmetrically rippled at 400 fathoms and marked by slump features at 570 fathoms. A small piece of volcanic agglomerate was dredged from 400 fathoms on the north slope. About a ton of flat pteropod limestone cobbles was dredged from the summit area. One of the cobbles gave an apparent radiocarbon age of 12,000 years ± 900. The state of lithification of the limestone suggests that it may have been lithified under subaerial conditions and that the seamount may have been an island within the past 12,000 years. Oxygen isotope paleotemperature measurements made by C. Emiliani give evidence that the depth of deposition was less than the present depth of the seamounts. The Cruiser and Great Meteor seamounts studied in 1952 have larger flatter summits at 150 and 165 fathoms depth. Photographs of the sandy summits do not show ripples or cobbles. Symmetrical ripples were photographed on the slopes in depths of 1200-1400 fathoms. A reversed seismic refraction station was made on Cruiser Seamount. These youthful 'guyots' may have originated as volcanoes which were later capped by limestone and more recently have sunk beneath the sea." (R5)

The Rockall Trough. The Anton Dohrn seamount, in the central part of the Rockall Trough (about 11°W, 57°30'N), has a flat top at about 600 meters depth. Rocks and corals dredged up appear to be Cretaceous in age. (R18)

Off the Azores. A small seamount, possessing the typical guyot shape, has been found west of Flores, in the Azores. (R22)

X3. Exposed structures similar to guyots. A few above-water volcanic structures with flat tops have been located, suggesting that the flat tops of the submerged guyots need not be wave-planed.

Mono Lake, California. "Abstract. A basaltic cinder cone was built beneath the waters of Mono Lake in Pleistocene time. This cone is now exposed. Its internal structure, external form, and petrography suggest that it was constructed with a flat top." The authors state that this cone indicates that flat tops may be "primary constructional features of submarine vulcanism." (R9)

Afar Rift, Ethiopia. "Abstract. A series of originally submarine volcanoes has been found in the Afar Depression. Some of the volcanic structures are morphologically similar to oceanic guyots. One of them consists of strata finely fragmented and pulverized basaltic glass. The fragmentation of the lava is probably the result of steam explosions taking place during the submarine eruption. The flat top of this guyot is considered to be a constructional feature; by analogy, it is suggested that not all oceanic guyots are necessarily the result of wave truncation of former volcanic islands." (R12; R13)

References

R1. Hess, H.H.; "Drowned Ancient Islands of the Pacific Basin," American Journal of Science, 244:772, 1946. (X1)

R2. Menard, Henry W., and Dietz, Robert S.; "Submarine Geology of the Gulf of Alaska," Geological Society of America, Bulletin, 62:1263, 1951. (X1)

R3. Revelle, Roger; "Evidence of Instability of Pacific Basin," Geological Society of America, Bulletin, 62:1510, 1951. (X1)

R4. Hamilton, Edwin L.; "Upper Cretaceous, Tertiary, and Recent Plankton Foraminifera from Mid-Pacific Flat-Topped Seamounts," Journal of Paleontology, 27:204, 1953. (X1)

R5. Heezen, Bruce C., et al; "Flat-Topped Atlantis, Cruiser, and Great Meteor Seamounts," Geological Society of America, Bulletin, 65:1261, 1954. (X2)

R6. Northrop, John, and Frosch, Robert A.; "Seamounts in the North American Basin," Deep-Sea Research, 1:252, 1954. (X2)

R7. Dietz, Robert S.; "Drowned Ancient Islands of the Pacific," New Scientist, 5:14, 1959. (X1)

R8. Pratt, R.M.; "Erratic Boulders from the Great Meteor Seamount," Deep-Sea Re-

search, 8:152, 1961. (X2)
R9. Christensen, M.N., and Gilbert, C.M.; "Basaltic Cone Suggests Constructional Origin of Some Guyots," Science, 143:240, 1964. (X3)
R10. Palmer, Harold D.; "Geologic Significance of Davis Seaknoll, Arguello Plateau, California," Geological Society of America, Bulletin, 76:379, 1965. (X1)
R11. Fisher, David E., et al; "Ages of Pacific Deep-Sea Basalts, and Spreading of the Sea Floor," Science, 160:1106, 1968. (X1)
R12. Bonatti, Enrico, and Tazieff, Haroun; "Exposed Guyot from the Afar Rift, Ethiopia," Science, 168:1087, 1970. (X3)
R13. "Guyot in a Desert," Science News, 97: 579, 1970. (X3)
R14. Karig, D.E., et al; "Sediment-Capped Guyots in the Mid-Pacific Mountains," Deep-Sea Research, 17:373, 1970. (X1)
R15. "Seamounts and Fluctuations in Sea-level," Science News, 100:328, 1971. (X1)
R16. Schwartz, Maurice L.; "Seamounts as Sea-Level Indicators," Geological Society of America, Bulletin, 83:2975, 1972. (X1)
R17. Merrill, Ronald T., and Burns, Robert E.; "A Detailed Magnetic Study of Cobb Seamount," Earth and Planetary Science Letters, 14:413, 1972. (X1)
R18. Jones, E.J.W., et al; "A Cretaceous Guyot in the Rockall Trough," Nature, 251:129, 1974. (X2)
R19. Matthews, J.L., et al; "Cretaceous Drowning of Reefs on Mid-Pacific and Japanese Guyots," Science, 184:462, 1974. (X1)
R20. Heirtzler, J.R., and Grassle, J.F.; "Deep-Sea Research by Manned Submersibles," Science, 194:294, 1976. (X2)
R21. Heirtzler, J.R., et al; "A Visit to the New England Seamounts," American Scientist, 65:466, 1977. (X2)
R22. Lambeck, Kurt; "Subsidence of a Guyot West of Flores, Azores," Canadian Journal of Earth Sciences, 21:960, 1984. (X2)

ETH2 Anomalous Oceanic Plateaus

Description. Submerged plateaus, often of large areal extent, which stand out from the normal ocean-floor topography morphologically and seismically. Some of the plateaus seem continental in nature; others appear of oceanic origin.

Data Evaluation. These plateaus have been delineated in shape and structure by modern echo- and seismic-sounding equipment; there seems to be no question about the reality of the phenomenon. Rating: 1.

Anomaly Evaluation. The continent-like plateaus fit in with the theory of continental drift, being considered fragments which broke off from the moving land masses and subsequently subsided. There is, however, no consensus on how the plateaus with ocean-floor-like structure originated. Rating: 2.

Possible Explanations. See above.

Similar and Related Phenomena. The common, above-water plateaus observed on the continents are usually the products of erosion and orogeny. However, see ETV10.

Examples

X1. General observations. Abstract. "Plateau-like features in ocean basins exhibit crustal structures which differ markedly from the relatively simple. three-layer model which applies to most of the oceanic crust. While some plateaus are known or thought to be fragments of continental crust (e.g. Rockall Bank, Lord Howe Rise), others appear to be of oceanic origin (e.g. Shatsky Rise, Broken Ridge), and their seismic structures, though variable, are significantly different. Continental fragments are similar in structure to continental shield areas: Depth to Moho is typically about 30 km, and the lower crust consists of a 6.8-7.0 km/s layer, 14-18 km thick, overlain by a 5.8-6.4 km/s layer of variable thickness, while velocity structures are variable at upper crustal levels. By contrast, the Moho apparently occurs at shallower levels beneath oceanic plateaus, which are characterized by the presence of a 7.3-7.6 km/s layer, 6-15 km thick at

the base of the crust. This basal layer is commonly overlain by units having velocities typical of oceanic layers 2 and 3. Refractors having velocities which correspond to layer 3 tend to occur at deeper layers in continental fragments than they do beneath oceanic plateaus." Additional continental-type plateaus are the Falkland Plateau, the Seychelles Plateau, the Mozambique Plateau, and the Saya de Malha Bank. Other oceanic plateaus are the Manihiki Plateau, the Fiji Plateau, and the Ontong-Java Plateau. (R2; R1)

References

R1. "Chips off the Plates," Nature, 227: 767, 1970. (X1)

R2. Carlson, R.L., et al; "Anomalous Crustal Structures in Ocean Basins: Continental Fragments and Oceanic Plateaus," Earth and Planetary Science Letters, 51:171, 1980. (X1)

ETH3 Miscellaneous Mountain Curiosities

Description. A catch-all category including small submarine buttes, the British tors, large erratics, moving mountains, and salt mountains.

Data Evaluation. The data vary wildly in quality. In the cases of the tors and Ayers Rock, there is undoubtedly much that our surveys have missed so far. Evaluation is not feasible under these circumstances, particularly for a miscellaneous category.

Anomaly Evaluation. The salt mountains (X5) and the moving mountains (X4) must be classed as mere curiosities. The British tors (X2) and the submarine buttes (X1) can probably be explained as artifacts of erosion, although if the buttes were eroded in their present depths (thousands of feet) the eroding mechanism is uncertain. If the buttes were eroded subaerially, we would have to contend with very low sea stands. As for Ayers Rock (X1), if it is not a relict mountain but rather a true erratic ferried in from some unidentified source, this huge rock presents serious problems in explanation. Composite rating: 2.

Examples

X1. Small submarine buttes. This description is from Heirtzler et al's account of their exploration of the New England seamounts in the submersible Alvin. The specific location is called Corner Rise. "Near the base of this cliff Alvin passed quickly over a series of very striking topographic features that can best be described as small buttes. They are no doubt erosional in nature and, in fact, resemble eroded basaltic structures in central Iceland. Because they have dimensions of a few meters it was awkward to photograph them with the narrow field of view in our cameras; Figure 3 is a sketch of them." (R7)

X2. The British tors. "The tors that dominate the landscape of Dartmoor, in Devon, create a distinctive character, peculiar to this region. The summit tors are immediately apparent but tors also rise from the ends of spurs and from the gentle slopes of the valleys. The tors are bare rock masses contrasting in striking manner with the smooth, gentle slopes of the moor and the vertical walls of the granite. The rock faces are usually traversed by two sets of vertical fissures or joints and one set of horizontal fissures known as pseudobedding planes. The pseudobedding planes when viewed from a distance appear to continue over the top of the tor to form a simple dome.

The appearance of the rock is governed by the spacing of the joints with tors ranging from massive to lamellar. Lamellar tors possess numerous closely-spaced pseudobedding planes but vertical joints are rare. Massive tors exhibit better developed vertical jointing and fewer horizontal divisions.

Many tors are composed of more than one rock mass, arranged around a central flat area or 'avenue'. Haytor, Great Staple Tor and Hound Tor are thus formed.

These startling landscape features pose

Sketch of the research submersible Alvin *inspecting undersea "buttes." (X1)*

many intriguing problems. The masses of rocks appear to be mere remnants of a once greater mass of granite---the abundance of boulders or clitter, as they are known on Dartmoor, which once made up the tor but which are now scattered downhill, are proof of this. One problem concerns the mechanisms that need to be invoked to explain the removal of thousands of tons of rock. Joints define tors and therefore they must have a prominent part in any theory." The several theories include differential weathering and periglacial phenomena. (R5; R4)

X3. Improbable erratics. Erratics are rocks and boulders that are unrelated to any nearby source, In theory, the erratics were transported from some distant source by ice sheets or icebergs. Some erratics, however, are so large that ice transportation seems unlikely. "The largest of these is the 'Ayers Rock." It is the world's most spectacular erratic boulder. 'Ayers Rock, in the Northern Territory, is the largest single rock in the world. It is dark red, especially red at sunset' (Jo McDonald, Australia, p. 16). It is 2¼ miles long, by 1¼ miles wide, with a height of 1143 feet showing above the ground. It is called 'The Red Heart of Central Australia,' because it is composed of red rock, shaped somewhat like a heart, and located at the heart of the continent near the geographical center of Australia. There are no nearby mountains from which it could have been derived. But there it is, out in the desert with the sagebrush and the cactus, a huge monolith for which modern geology can furnish no explanation." (R6)

X4. Moving mountains. "The movement of a mountain, Monte Arbino, 5560 feet in height, is giving rise to much anxiety in the neighborhood of Bellinzona, three miles to the east of which it is situated and not very far from the northern end of Lago Maggiore, that the authorities of the Ticino Canton in which it lies (the Italo-Swiss frontier crossing the northern end of the lake at Brissago) have ordered the evacuation of the zone of danger. The mountain has been moving horizontally since 1888, and in 1905, when the Federal Geological Survey directed attention to it, the summit had moved eastwards more than six feet in the interval. Since then it has been moving at an increasing rate per year, until during last year, 1926 alone, it had moved a foot. It has simultaneously lowered in height to a little more than the same extent, fourteen inches in 1926. The moving mass covers 2520 square yards." (R3)

In the county of Clausenburg, in Transylvania, the mountain "Geleztas" moved toward the

town of Monorokezek. Before the movement, the town was an hour's walk from the 1000-foot mountain; afterwards only 20 paces separated them! (R1) Obviously one must take this tale with a grain of salt. (WRC)

X5. Salt mountains. Exposed salt domes and other evaporite structures are well-known, but the following structure seems out-of-place. "The salt mountains located on the banks of the Virgin, an affluent of the Colorado River (in Nevada), cover an area of twenty-five miles, extending to within seven miles of the junction of the stream with the Colorado. The salt they contain is pure and white and clearer than glass, and it is said that a piece seven or eight inches thick is sometimes clear enough to see through to read a newspaper." (R2)

How did these salt mountains originate? It is possible that they should be classified along with evaporites and salt diapirs in a later volume. (WRC)

References

R1. "A Moving Mountain," Scientific American, 7:27, 1851. (X4)
R2. "Nevada's Salt Mountains," Scientific American, 62:314, 1890. (X5)
R3. Nature, 120:667, 1927. (X4)
R4. King, Lester, and Linton, D.L.; "The Problem of Tors," Geographical Journal, 125:289, 1959. (X2)
R5. Gerrard, John; "Mystery of the Dartmoor Tors," Geographical Magazine, 41: 606, 1969. (X2)
R6. Daly, Reginald; "The Cause of the Ice Age," Earth's Most Challenging Mysteries, Nutley, 1975, p. 154. (X3)
R7. Heirtzler, J.R., et al; "A Visit to the New England Seamounts," American Scientist, 65:466, 1977. (X1)

ETL PLANET-SCALE TOPOGRAPHIC ANOMALIES

Key to Phenomena

ETL0 Introduction

The peculiar shapes and the distribution of the continents attracted the attention of geologists and geographers as soon as the early navigators had compiled reasonably accurate maps of the globe. The antipodal arrangement of the land masses and ocean basins stimulated such theories as that of the Tetrahedral Earth. Scientists still search for theories that will explain the apparently nonrandom disposition of land and water. Since the 1970s, the hypothesis of continental drift or plate tectonics has been ascendant. In fact, most of the anomalies recorded in this chapter arise because of facts that seem incompatible with the theory of continental drift.

As is often the case, those scientists who have the most to say about these anomalies have a substitute theory. Usually, this is the hypothesis of an expanding earth. No one knows why the earth might have expanded significantly, but then no one is sure what makes the continents drift either, if they do! However, if one assumes that the earth has expanded during the past several hundred million years, with attendant increases in surface area, many apparent anomalies can be resolved. Even so, plate tectonics is well-entrenched and considered to be a "fact" by many geologists and geophysicists. Nevertheless, the history of science is littered with discarded theories once thought-to-be-fact.

Not treated here are the thousands of miles of mid-ocean ridges, which are well-accounted-for by the hypothesis of plate tectonics. Two other planet-scale phenomena, the Andesite Line and the anorthosite belts, not being topographical in character, are covered in a later volume in the Catalog of Anomalies.

ETL1 Land-Water Distribution

Description. The antipodal and asymmetrical distribution of land masses and ocean basins on the earth's surface, and their apparent disposition in regular geometrical arrangements.

Data Evaluation. The land-water maps of the earth and now well known. Rating: 1.

Anomaly Evaluation. Antipodal, asymmetrical, and regular arrangements of continents and ocean basins imply cause and effect; that is, these seemingly nonrandom conditions must have physical explanations. The physical explanations that have been proposed (see below) are generally radical departures from current geological and geophysical thinking. Rating: 1.

Possible Explanations. Cooling planets crack in regular ways, like drying mud. Internal convection cells control the positions of the continents and ocean basins. (Unfortunately, the present arrangement of these features is incompatible with the convection cells required for the generation of the earth's magnetic field. See X4.) The asymmetrical earth is the consequence of a large meteor strike. Electrostatic forces have been proposed as the agent maintaining the roughly equidistant positions of the land masses!

Similar and Related Phenomena. Island arcs (ETL2); continental drift and crustal gaps (ETL6).

Examples

X1. The general distribution of land and water. Several aspects of the continents and oceans have caught the eyes of geologists and, indeed, casual observers. Can these features be explained in causal terms and, if they can, how is the theory of continental drift affected? We now present some of these general observations.

J.W. Gregory, 1898."Geographical Symmetry. Two of these facts are stated in every geographical textbook. They are evident on the most casual examination of a map. The first is the concentration of land in the Northern and of sea in the Southern Hemisphere. The second is the triangular shape of the geographical units. The continents are triangular, with the bases to the north. The oceans are triangular, with the bases to the south. Accordingly the land forms an almost complete ring round the North Pole, and from this land ring three continents project southward. The oceans form a continuous ring round the South Pole, and from it three oceans project northward into the angles between the continents. The belts of sea and land are fixed on the earth's axis like a pair of cogwheels with interlocking teeth. These two belts may be referred to as the northern land belt and southern ocean belt.

The third striking feature in the earth's physiognomy is less conspicuous, but is even more significant. It is known as the antipodal arrangement of oceans and continents. It is most easily recognized by examination of a globe; but it can be easily be illustrated by a plain map. The antipodes of a point in the center of the continent of North America occurs in the Indian Ocean; and if we mark on a map the antipodes of all the points in North America, we should find that the whole of the continent is exactly antipodal to the Indian Ocean. Similarly, the elliptical mass of Europe and Africa is antipodal to the central area of the Pacific Ocean; the comparatively small continent Australia is antipodal to the comparatively small basin of the North Atlantic; the South Atlantic corresponds---though less exactly---to the eastern half of Asia; and the Arctic Ocean is precisely antipodal to the antarctic land." (R2)

C.D. Perrine, 1940. "(1) The large land excess in the northern hemisphere and a corresponding deficiency in the south. (2) The broadening out toward the equator of the continental areas from their pointed southern extremities and still more in the far northern regions where they form an almost continuous ring about the polar ocean. (3) An open polar ocean and surrounding land mass in the north, and a continental land mass surrounded by water about the south pole. (4) Generally greater elevations of the land above sealevel near the southern extremities of the continents than in their northern portions. This is especially noticeable in South America, Africa, Asia and, to some extent, in North America. (5) Low-lying and frequently marshy or desert areas of great extent in the northern and wider portions of the continental masses. (6) Carboniferous deposits in these basins, including forests. (7) As

already mentioned, the peculiar appearance of the Indian Peninsula and the Himalaya Mountains to the north. If we look at a contour map of those regions we find the Himalayas folded around the northern and broad part of the Indian Peninsula in just such a manner as is conceivable if the triangular peninsula had been thrust into the Asiatic Continent from the south where we now find the extensive Indian Ocean. (8) The distances from the South Pole of South America, Africa, India and Greenland, all pointed at the southern end, are roughly in the inverse order of their size." The list continues to (15) with biological and geophysical observations. (R5) Perrine's explanation of these observations involved meteor impacts on earth. (WRC)

F. F. Evison and P. Whittle, 1961. "Abstract. Five-sixths of all the continental area on the Earth's surface has antipodes in oceanic regions. This proportion is not significantly different from what one would expect on the assumption that the continents are randomly situated." (R6) But see the next item!

A. A. Meyerhoff and H. A. Meyerhoff, 1972. "The nearly antipodal relation between individual continents and ocean basins is a phenomenon that has been described by many geologists and geophysicists for nearly a century. The antipodal space relations are explicable in terms of a cooling earth, on the surface of which the continents have held stable positions since initial cooling. In fact, this explanation was widely accepted for man decades.

This relation between the continents and ocean basins seemingly has no significance in the new global tectonics. One well-known advocate told a group of more than 600 persons that the antipodal relations are a 'coincidence.' According to Harrison, this is a bet against heavy odds. He wrote that,

> The conclusion which can be drawn from (my) work is that there is less than 1 chance in 14 that the present antipodal distribution of continents and ocean basins is the result of a random process. Thus it appears probable that a nonrandom process ... has caused the present distribution of continents over the earth's surface.

We believe that the antipodal distribution eliminates continental drift in any form. The alternative, in our opinion, would be to postulate that, during each episode of drift, the continents always are redistributed in such a manner that their positions with respect to the ocean basins are antipodal." (R7) No mechanism for this "redistribution" was given. (WRC)

X2. The earth's asymmetry. This is a somewhat different perspective of the distribution of oceans and land masses. "A great circle whose northerly pole coincides with the intersection of the Tropic of Cancer and the prime meridian defines a plane through the center of the earth which roughly divides it into continental and oceanic hemispheres. Further, a majority of the great mountain ranges of the world are within a 1,000 kilometers of this dividing plane and there is evidence that these marked surface asymmetries are indicative of more deep seated differences. For example, it has been known for more than a century that the earth's magnetic field is not uniformly distributed about its axis of spin, but behaves as if the center of magnetic activity were displaced from the axis toward the Pacific Basin by some hundreds of kilometers." (R4) Note that the moon (ALE1), Mercury (AHE1), Mars (AME8), and other solar system bodies have asymmetrical surfaces. (WRC)

X3. Global geological trends. An 1852 view of the earth's "crystal-like" structure.

"This author after discussing the direction of mountains, and of dykes and cleavages among rocks, deduces some general principles with regard to their direction, and then explains his hypothesis that the surface of the globe presents approximately the faces of a great octahedron. In an octahedron there are three axial planes intersecting one another at right angles; and the positions of the circles on the earth's surface which he lays down as the limits of these planes (or their intersection with the surface) are as follows. The first circle is that of Himalaya and Chimborazo, passing from Cape Finisterre to the Himalaya, Borneo, eastern chain of New Holland, (having on its sides a parallel line in Malacca, Java and Sumatra,) to New Zealand, thence to South America near Chimborazo, the chain of Carracas, the Azores to Cape Finisterre. The second, passes along the South American coast and the north and south ranges of the Andes, the mountains of Mexico, the Rocky mountains,

Behrings' Straits, the eastern Siberian chains, going to the south of Lake Baikal, near Kiatcha, the Altai, Himalaya, the mountains of Bombay in Hindostan, a point in the northeast of Madagascar (where the summits are 12,000 feet high), the mountains of Nieuwefeld, 10,000 feet high, Cape Caffres, Cape Moro de Saint Martha, to Brazil, the rapids of La Plata, Paraguay, Parana, the elevated basin of Titicaca, the Andes, Illimani near Jaen and the defile of Maranova. The third circle cuts the two preceding at right angles, and passes by the Alps, the islands of Corsica and Sardinia, along the basin of the Mediterranean, the mountains of Fezzan, Lake Tschan, the Caffre mountains of Nieuwefeld, the Southern Ocean near Kerguelen's Land, the eastern or Blue Mountains of New Holland, straits of Behring, Spitzbergen, Scandanavia, Jutland, etc.

These three great circles point out the limits of the faces of the great hypothetical octahedron. Each of the faces may be divided into eight others by means of lines of accidents of minor importance, so as to take in all forty-eight irregular triangles, a form of the diamond. At the intersections, M. de Hauslab observes that there are nodes of dykes, and along the lines or near them, all the mountains of the globe occur." (R1) As remarked elsewhere, such regularity in the earth's features seem incompatible with the theory of continental drift. (WRC)

X4. Continent distribution incompatible with internal convection cells. It is widely supposed that the earth's magnetic field is generated by a system of convection cells in the earth's interior.

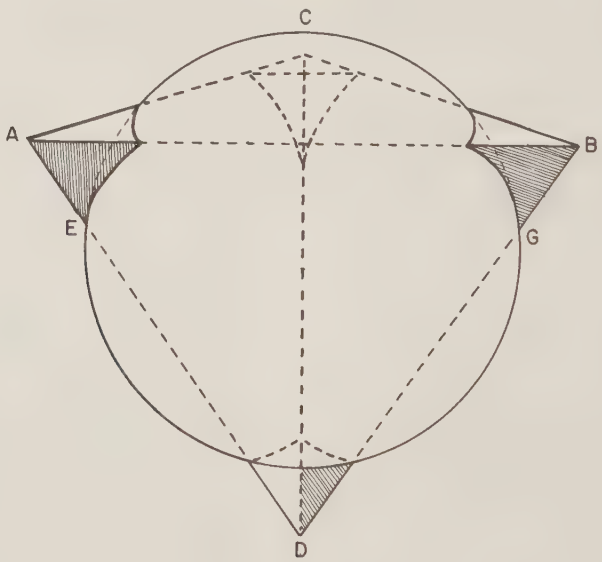
"The convection-current hypothesis requires that the continents be stacked either at the equator or at the poles, which is obviously not true either way. Convection cells may be directly inferred not to exist because there is no convection/geoid correlation, no convection/heat-flow correlation, and no convection/vulcanicity correlation." (R8)

X5. Supposed regularities in the earth's topography. Many crystalline shapes have been proposed, each with some justification.

de Hauslab's octahedron. See X3 for elaboration.

de Beaumont's "pentagonal reseau". Elie de Beaumont considered that the shrinkage of the cooling core resulted in a pentagonal dodecahedron. (R2)

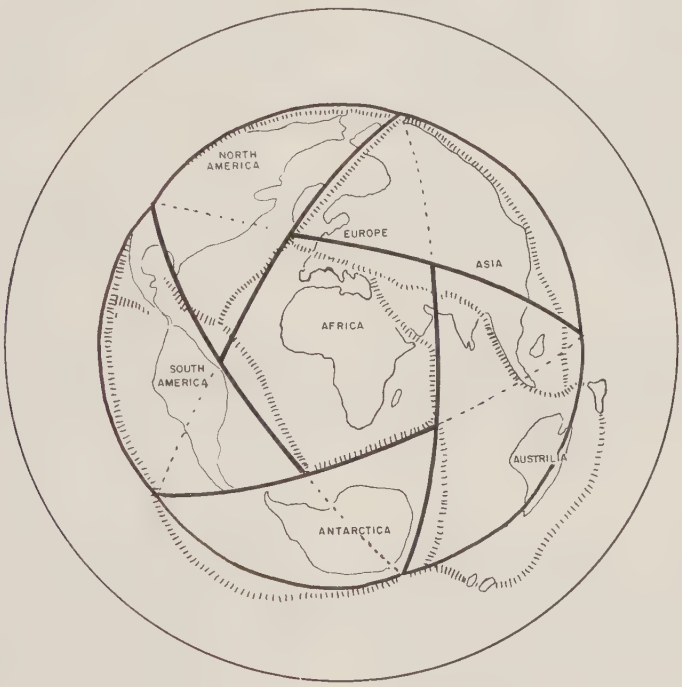
Green's tetrahedral theory. In 1875, Lowthian Green proposed that the earth was a tetrahedron: "This tetrahedral plan is shown by the existence of (1) a northern land belt,



Green's tetrahedral theory supposed that the four projecting points of a tetrahedron formed the earth's major land masses. (X5)

surrounding a northern ocean, and giving off three meridional land lines, which taper southward; (2) the southern ocean belt surrounding a south polar continent, and the three meridional oceans; (3) by the antipodal position of land and water; (4) by the course of the main watersheds and mountain chains." (R2)

Regularities seen in tectonic plates. A. Spilhaus reviewed the possibilities for new geometrical interpretations, given the new puzzle pieces called "tectonic plates." Two of these are figured: (1) An azimuthal equidistant projection of a regular icosahedron, compared with the major tectonic plates; and (2) Theoretically derived fracture lines, which approximate the edges of a cube, compared with actual fracture lines. (R9)



Major tectonic plates of the earth (broken lines) compared with projection of a regular icosahedron (solid lines) on an azimuthal equidistant projection. (X5)

An electrostatically controlled pentagonal pyramid. "The six continents of the earth markedly form a pentagonal pyramid. Africa is at the apex; lines drawn from its center to the centers of the other continents are evenly spaced at 72°. The other five centers are nearly on a common plane to form the pyramid's base plane." (R10, R11)

References

R1. de Hauslab, M.; "Researches on the Origin of the Present State of the Terrestrial Globe, or Its Crystal-Like Cleavage," American Journal of Science, 2:13: 268, 1852. (X3, X5)

R2. Gregory, J.W.; "Plan of the Earth and Its Causes," Smithsonian Institution Annual Report, 1898, p. 363. (X1, X5)

R3. Emerson, Benjamin Kendall; "The Tetrahedral Earth and Zone of the Intercontinental Seas," Geological Society of America, Bulletin, 11:61, 1900. (X5)

R4. Gunn, Ross; "On the Origin of the Continents and Their Motions," Franklin Institute, Journal, 222:475, 1936. (X2)

R5. Perrine, C.D.; "The Origin of the Earth's Land Formations," Science, 92:

210, 1940. (X1)
R6. Evison, F.F., and Whittle, P.; "The Antipodal Location of Continents and Oceans," Geological Magazine, 98:377, 1961. (X1)
R7. Meyerhoff, A.A., and Meyerhoff, Howard A.; "'The New Global Tectonics': Major Inconsistencies," American Association of Petroleum Geologists, Bulletin, 56:269, 1972. (X1)
R8. Wesson, Paul S.; "Objections to Continental Drift and Plate Tectonics," Journal of Geology, 82:185, 1972. (X4)
R9. Spilhaus, Athelstan; "Geo-Art: Tectonics and Platonic Solids," American Geophysical Union, Transactions, 56:52, 1975. (X5)
R10. Csuzdi, Michael; "Electrical Plate Tectonics," Eos, 62:1035, 1981. (X5)
R11. Csuzdi, Michael; "Electrostatic Forces in the Earth's Crust," Open Earth, p. 38, 1982. (X5)

ETL2 Anomalous Features of Island Arcs

Description. Features of island arc systems that are incompatible with plate tectonics; i.e., the theory of continental drift. Such features include multiple-arc structures, aseismic ocean basins between island arcs and continents, oceanic plate age anomalies, and the absence of evidence for subduction at some island arc trenches.

Data Evaluation. Island arcs have excited scientific curiosity for many years; and much is known about them through earthquakes and magnetic anomaly studies, seismic mapping, and physical sampling. Rating: 1.

Anomaly Evaluation. Most phenomena of island arc systems and their associated trenches support plate tectonics, but some contradictions do occur, as described below. These phenomena do not appear to be explicable within the framework of plate tectonics. Since plate tectonics is now a major dogma of geology and geophysics, contradictions automatically become important anomalies. Rating: 1.

Possible Explanations. None offered.

Similar and Related Phenomena. Other phenomena challenging plate tectonics, such as poor continental fits (ETL6) and land-water distribution (ETL1). Later volumes in the Catalog of Anomalies will also contain plate tectonics anomalies; see the indexes in the ES categories.

Examples

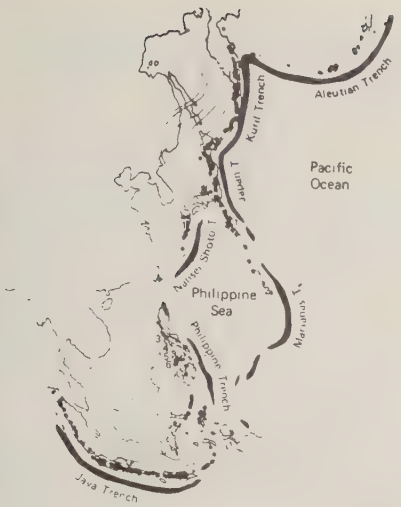
X0. Backgound.

Island Arcs. "Between some of the continents there are connecting mountain belts of the island-arc type, such as the Antilles between North and South America, the islands and submerged arc of the Scotia Sea between South America and Antarctica, and the East Indies between Asia and Australia. The smoothly curved festoons of islands in the western Pacific from Alaska to the East Indies have attracted great interest for many years; with modern oceanographic and geophysical instrumentation they are again an intriguing subject.

Characteristics. In the early stages of growth an island arc is a row of volcanic cones built on a great curved swell of the ocean floor; the tops of the cones generally protrude above water and form the islands. The arcuate rows of volcanoes are convex toward the ocean, and on the convex side of the island arc is a parallel trench. Whereas the general ocean floor is 12,000-15,000 ft deep, the trenches reach depths of 25,000-35,000 ft."

Many earthquakes occur along island arcs. Most of the seismic activity is distributed along a great curved surface dipping down at about 45° under the adjacent continent from the trench. Quakes are recorded as deep as 700 kilometers. This seismic activity and the gravity anomaly along island arcs have been interpreted in terms of an oceanic tectonic plate being subducted under a continental plate. (R8)

This is one of the basic tenets of modern plate tectonics, successor to "continental drift." Observations that do not support this interpretation of island arc structure must



Island arcs and trenches of the western Pacific, (Adapted from J. Kennett, Marine Geology, *1982) (X0)*

be considered anomalous. (WRC)

X1. Multiple arcs.

General observations. "Some forty years ago, H.A. Brouwer pointed out that island arcs sometimes consisted of single belts, but often displayed two ridges, which were almost invariably arranged with an inner belt of volcanoes ('inner volcanic arc') paralleled by a trough about 50-100 km wide, in front of which came a ridge or belt of islands with strong orogenic deformation ('outer non-volcanic arc'), which in turn is paralleled by the trench, another 50-100 km oceanward. In some places, (e.g., south of Java and the Sunda Arc) the outer ridge is so depressed that the inner trough (Bali Trough) and the trench (Java Trench) are almost merged. The outer trench is sometimes paralleled by a third (very reduced) elevation, a low oceanic rise, e.g., the Christmas Rise---Roo Rise, etc., south of the Java Trench." (R1; R8)

The Mariana Island Arc System. "The Mariana system includes a trench, frontal arc, inter-arc basin, and third arc. The frontal arc carries the raised limestone islands: Guam, Rota, Saipan, and others. On the rear, or western edge of the frontal arc is the chain of active andesite volcanoes, and behind it is a series of basins and arcuate submarine ridges forming the basin complex of the Philippine Sea." (R3)

Multiple arcuate structures may be explicable in terms of plate tectonic theory and, therefore, not anomalous. Since no explicit scenario has yet been found, this phenomenon is tentatively cataloged here. (WRC)

X2. Separation of island arcs from continents by oceanic basins. Such basins should not exist.

General observations. "In the western Pacific Ocean there are a number of arc and trench systems which are separated from the continental margin by deep ocean basins underlain by a crust of either oceanic or intermediate thickness. Evison questions whether or not mantle convection and sea-floor spreading can explain the position of island arcs in the southwest Pacific." The basins between the continents and island arcs are notably aseismic. Two examples of such basins are the South Fiji Basin and the Philippine Basin. The author ventures that these basins may contain extinct (i.e., no longer active) mid-ocean ridges. (R2)

X3. Apparent age decrease of oceanic crust as island arcs are approached. According to plate tectonics, new crust is created at the ocean ridges. The oceanic crust should get older the farther it is from the ridge and, in theory, as the island arcs and subduction regions are approached. This is not always the case.

The Aleutian Arc. "A concept of simple crustal transfer predicts that oceanic crust will become progressively older from source to sink, and it was anticipated that mapping of magnetic anomalies in the North-East Pacific would reveal such a pattern. Yet the contrary has proved the case, for approaching the Aleutian Trench the north-south magnetic anomalies paralleling the East Pacific Rise turn west, forming the Great Magnetic Bight. Consequently the age of the oceanic crust appears not to increase, but to decrease toward the trench: 'in this one area, where magnetic anomalies are well documented as being adjacent and subparallel to a deep-sea trench, the inferred chronology of the anomalies is opposite to what would be predicted for seafloor spreading...'" (R4)

X4. Undeformed sediments in trenches of island arc systems. If subduction actually takes place in the trenches paralleling island arcs, the trench sediments should show profound disturbance. See also X7 concerning "missing" sediments.

General observations. "Ocean-basin studies show that island-arc trench fills, where 'subduction' supposedly takes place, are undeformed. The volumes of undeformed sedimentary rocks...indicate (1) that sea-floor spreading has not taken place since Mesozoic or earlier time; or (2) that 'subduction' must take place seaward from the island-arc trenches; or (3) that there is no such process as 'subduction.'" (R5) The preceding comments are by A.A. and H.A. Meyerhoff, who see the undisturbed trench sediments as evidence against continental drift.

S.W. Carey, on the other hand, interprets missing and undisturbed trench sediments as facts supporting an expanding earth. "According to the fashionable model the trenches are the outcrops of stupendous underthrusts with thousands of kilometres of relative movement. The underthrust plate bears a veneer of soft sediments a few hundred metres thick, intense crumpling of which is inescapable. But this profound disturbance is not there. Some of the trenches are empty. Others show serenely slumbering sediments quite undisturbed. Others show horst-and-graben tensional movements with the sediments borne passively on the dilating basement blocks. Occasionally there are the inevitable gravity slumps. Menard has said: 'Almost everyone who sees an echogram of the side benches and bottom troughs of trenches believes they are produced by normal faulting...the topography of the trenches suggests tension and supports the hypothesis that the trenches owe their existence to tension rather than compression.' This would be impossible if trenches were the outcrop of multi-thousand-kilometre underthrusts." (R9)

The Peru-Chile trench. "Scholl et al observed that the sediments of the island-arc trenches of the circum-Pacific are undeformed. This lack of deformation in the Peru-Chile Trench prompted Scholl et al to write:

> Because decollement slippage of the oceanic crust beneath an overlying trench fill is unsupported by observational as well as theoretical data ..., we are left with the speculation that the sinking of the ocean plate may take place seaward of the trench ---the trench fill and bedrock floor remaining partially or totally isolated from much of the differential movement between the Pacific and South American plates.

This interpretation that the trench is a passive element which does not participate in alleged plate motions is a direct contradiction of one cornerstone of the so-called plate tectonics." (R5)

X5. Island arcs where features that should have been subducted have not been.

The Lesser Antilles arc. A.A. Meyerhoff and H.A. Meyerhoff claim that, if subduction has actually occurred along this arc, the Barbados Ridge and La Desirade Island should now be hundreds of kilometers beneath the Lesser Antilles. (R5)

X6. Directed structural features. Some topographic features have "polarity"; that is, their shapes are sensitive to the direction of the stresses generated by the motion of tectonic plates. In some instances, the observed polarities are opposite from what theory predicts.

General observations. "There are several types of major structures on the earth's surface that appear to reflect a predominant direction of stress---specifically, stress directed from west to east. One of these types comprises the convex-to-the-east island-arc systems detached from continents. A second is the presence in the eastern Pacific of island-arc systems without island arcs; deep-sea trenches directly abut the continents, as along the west coast of South America. A third consists of large-scale wrench-fault patterns apparently produced by eastward-directed stresses.

.....

However, as the new global tectonics evolved, numerous major crustal features were observed which did not fit readily into the simplistic schemes of the 'new' tectonics. One of these is the convex-to-the-east island-arc systems, and several papers have appeared to explain them. In contrast, the lack of true island arcs along the western margins of continents and the wrench-fault patterns which apparently formed in a west-to-east stress field have not yet been

explained by advocates of the new global tectonics." (R5) These generalities are followed by detailed discussions and specific examples.

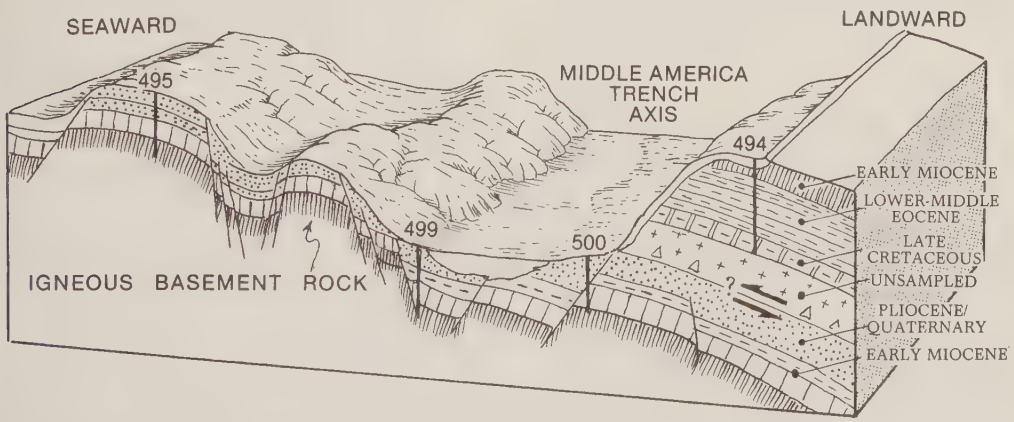
X7. Missing sediments in subduction zones. According to plate tectonic theory, one would expect to find great volumes of sediments scraped off the oceanic plates where they dive under the continents. In many places, however, these sediments are missing. (See also X4 on "undeformed sediments.")

General observations. Following a treatment of the subduction process. "But in 200 million years, an ocean floor accumulates considerable debris, the sedimentary evidence of biological and physical events in the waters above it. What happens to that material? At some trenches, 'sediments are probably being scraped off against the edge of the continental margins,' says N. Terence Edgar, former Deep Sea Drilling Project chief scientist and now the Geological Survey's chief for marine geology in Reston, Virginia. What appears to be 'a huge mass of deepwater sediments that is highly contorted' was turned up by drilling at sites on the landward side of the trench off Barbados in the Lesser Antilles, Edgar reports. Searches along the western side of South America and east of Japan, however, produced no such evidence. 'What we're seeing tells us that active margins must be very much more complex than we had thought,' Edgar notes.

Indeed, (R.) von Huene observes, results from the drilling indicate that 'a lot of sediment is not scraped off but continues down under the continent, riding on the subducting ocean crust, and we don't know where it ends up. It's very difficult to imagine a mechanism whereby these soft sediments continue to be subducted along with the ocean crust after they meet the continental margin.... There is evidence, mostly unpublished at this point---but convincing in my own mind---that much of the sediment added to the continental framework may be added not at the front of the margins, but farther back, and at great depths."

The volumes of sediment involved are immense. Scientists aboard the Challenger drilled into the oceanic Cocos plate on the seaward slope of the mid-America trench off Guatemala and into the North American plate on the trench's landward side. They found that although the incoming deep-ocean sediments are up to some half a kilometer thick, scarcely any sediment had accumulated at the base of the trench's continental side. Thus about 350 kilometers of ocean plate up to half a kilometer thick had passed through the trench and presumably been subducted in the last four million years." (R10) Some scientists question the reality of subduction when confronted with such evidence. (WRC)

X8. Nonexistence of subduction zones. Adherents of the expanding earth hypothesis have cast much doubt on the reality of subduction as a geological process. Take, for



Drilling at the Mid-American Trench off Guatemala revealed a puzzling absence of ocean sediments among the subducted rocks. (X7)

example, the view of B.M. Ciric. "Abstract. Benioff supposed that oceanic plates plunged under the continental ones on reverse faults, causing trenches, and thus explained earthquakes down to 700 km, as well as volcanism. Plate tectonicists willingly accepted Benioff's hypothesis to explain why, in spite of widening of the oceanic floor the volume of the Earth is not increased. Considerably later the imagined phenomenon was called subduction. However many geotectonic phenomena cannot be explained by subduction: the Atlantic Ocean has neither oceanic nor marginal trenches, so accretion is not compensated by subduction; volcanism and seismicity in Africa are not related to subduction. Marginal trenches and subduction are absent in the Indian Ocean beside India, Madagascar, and Africa, and around Australia and Antarctica. Current earthquakes and volcanism are connected with isolated regions and not with extended zones parallel to and dependent on trenches. The volcanoes of Lipari Islands, Etna, and Mt St Helens can be cited as examples, active on the same spot for millions of years. Recent catastrophic earthquakes in the Mediterranean region: Agadir, El Asnam, Naples, Montenegro, Mt Kopaonik and Bucharest are transverse to the Alpine orogen; their hypocentres, moreover, were not deeper than 20 km. Benioff considered that the initial slope of subducting plates in marginal trenches was 34°. At such a slope and speed of subduction (2-16 cm/yr) the sediments must have been folded. The slope of sides in deep-sea trenches, however, is mostly 5°, and the Neogene sediments in them are horizontal. Such examples indicate that the idea of subduction was taken into the literature without rigorous check, and is not maintainable as a geotectonic phenomenon." (R11)

References

R1. Fairbanks, Rhodes W., ed.; "Trenches and Related Deep Sea Troughs," The Encyclopedia of Oceanography, New York, 1966, p. 934. (X1)

R2. van der Linden, Willem J.M.; "Extinct Mid-Ocean Ridges in the Tasman Sea and in the Western Pacific," Earth and Planetary Science Letters, 6:483, 1969. (X2)

R3. Karig, Daniel E.; "Structural History of the Mariana Island Arc System," Geological Society of America, Bulletin, 82:323, 1971. (X1)

R4. Jones, J.G.; "Aleutian Enigma: A Clue to Transformation in Time," Nature, 229: 400, 1971. (X3)

R5. Meyerhoff, A.A., and Meyerhoff, Howard A.; "'The New Global Tectonics': Major Inconsistencies," American Association of Petroleum Geologists, Bulletin, 56:269, 1972. (X4, X5)

R6. Coleman, Patrick J.; "On Island Arcs," Earth-Science Reviews, 11:47, 1975.

R7. Karig, Daniel E.; "Evolution of Arc Systems in the Western Pacific," Annual Review of Earth and Planetary Sciences, 2:51, 1974. (X0)

R8. Eardley, A.J.; "Tectonic Patterns," McGraw-Hill Encyclopedia of Science and Technology, 13:434, 1977. (X0)

R9. Carey, S. Warren; "The Expanding Earth---An Essay Review," Earth-Science Reviews, 11:105, 1975. (X4)

R10. Ludwigson, John; "Ocean Margins: The Scars of Creation," Mosaic, 12:38, March/April 1981. (X7)

R11. Ciric, Branislav M.; "Is Subduction a Real Phenomenon?" in The Expanding Earth: A Symposium, University of Tasmania, 1981, p. 247. (X8)

ETL3 Large-Scale Patterns of Lineaments

Description. Systems of linear crustal features, such as rifts and ridges, often parallel and persisting for hundreds and thousands of kilometers. Global geometric patterns seem to exist. Lineaments are often associated with mineral deposits.

Data Evaluation. Large-scale lineaments are best appreciated from satellite photographs. These are of excellent quality. Rating: 1.

Anomaly Evaluation. Although widely recognized, terrestrial lineament systems have no generally accepted explanation. Since some transgress tectonic plate boundaries, it is not clear how their origin is related to continental drift, if indeed it is. An impact origin would be consistent with current scientific thinking. Much more radical would be global cracking due to core contraction or general terrestrial expansion. In the final analysis, we do not know what the import of terrestrial lineament systems is. Rating: 1.

Possible Explanations. Planet-wide systems of lineaments could be caused by impact or by changes in the volumes of the earth's core or the earth-as-a-whole.

Similar and Related Phenomena. Land-water distribution (ETL1); the Andesite Line and the anorthosite belts (ES); the complex of ocean ridges and rifts (not considered anomalous today); large circular structures associated with mineral deposits (ETC2-X4). Large lineament systems are common in the solar system: Mars (AME2, AMO1); Mercury (AHO4); the moon (ALE7); Venus (AVO6); and Europa (AJL5).

Examples

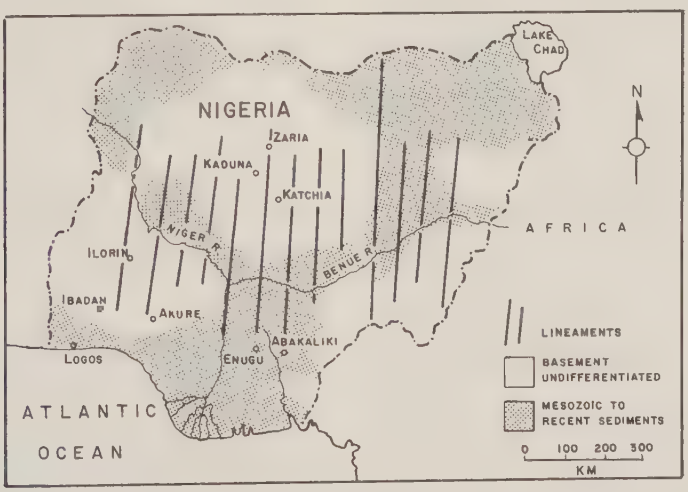
X1. Africa. Nigerian lineaments revealed in satellite photographs. "Figure 1 shows one of a number of sets of parallel lineaments in Nigeria revealed by the multispectral scanner carried by NASA's Landsat spacecraft. Most geologists will be surprised that there should be such a long, parallel, closely and regularly spaced system, and that all the lineaments should be so uniformly straight over such lengths. The spacing is of the order of the thickness of the Earth's crust. In the field only vertical movements are detectable along these lineaments... Two other less continuous sets cross these meridional lineaments at 45°. Unlike the first set these show horizontal shearing, displacing the first set by up to several kilometres in places. These directions show the type of failure pattern that would be caused by a horizontal principle compressive stress in an east-west direction.

But what huge stress could cause such a regular pattern of straight failures, each hundreds of kilometres long? Perhaps the near-meridional orientation is a clue and the force may have been related to the Earth's spin." The authors speculate that the cracks may be the result of a change in the earth's angular velocity due to a near miss or oblique impact with a large cosmic body. (R1)

X2. Global lineament pattern. "Contemporary studies of the earth's surface reveal continental tectonic patterns containing many large linear belts and trends that follow systematic directions. The same directions appear to be repeated in tectonic patterns in the northern and southern hemispheres.

At continental scale, four major lineament directions appear to dominate, viz., WNW, NNW, NNE, and ENE, and reflect the same trend directions that emerged in studies of Australian lineaments by Sherbon Hills more than three decades ago. They have since been confirmed through the integrated results of studies of Landsat imagery, gravity, magnetic and seismic data.

Major linear features in the system are



Long lineaments in Nigeria that may have been created by crustal failures 500 million years ago. (X1)

found to be associated with major ore deposits and major basin patterns of various ages. Correlations with sub-surface data indicate that the linear features are zones of crustal disturbance and attenuation characterised by discontinuities such as faults and shear zones.

A synthesis of continental data with sea-floor data suggests that there is a fundamental spiral pattern encircling the globe. This pattern, sinistral in sense, appears to have two spiral arms or zones of maxima diametrically opposite one another, forming what is analogous to a double helix. One of the spiral arms corresponds to the west-northwest zone of Tethyan torsion which follows a course from the southwest Pacific area to India and on through the Mediterranean region. The other arm follows a course south of continental Australia through southern Africa and on through the West Indies. This spiral system has been referred to as the Tethyan system. Left-lateral crustal movements associated with it are indicated by appropriate sinistral displacements of continental features and mid-ocean ridges. This movement is in consonance with the widespread development in many parts of the globe of elliptical configurations, including the development of folds with north-northwest axes corresponding to the long axes of the appropriate deformation ellipsoids.

A subordinate global counter-spiral, dextral in sense, is named the Laurasian system. The Tethyan and Laurasian spiral systems together appear to influence global deformation phenomena, including island arc (volcanogenic) development. They are regarded as fundamental shapers of continents through geologic time. The spiral trends appear to transgress some plate boundaries and follow along others. A plot of the principal pattern on a polar projection resembles the two arms of a spiral nebula and offers a comentary on the ultimate origin of the earth." (R2)

Four global lineament trends were also charted by Russian scientists, but their directions differ somewhat from those of the preceeding study. "Abstract. Earth, Mars, and the Moon have three types of lineament systems on their surfaces: global (or planetary), regional (radial-concentric), and local systems.

On the basis of a statistical analysis of more than 250 000 measurements, the quantitative and spatial relations between planetary and local fracturing were determined and data concerning global lineaments of the Earth, Mars, and the Moon compared. The theoretical, experimental and empirical approaches to the study of global systematic fracturing lead irrespectively to one and the same conclusion, i.e. the existence in the planetary lithosphere in general, and in the Earth's crust in particular, of four series of lineaments which are coupled into two genetic systems of dia- and ortho-structures. Local tectonic fractures may be of most diverse orientations.

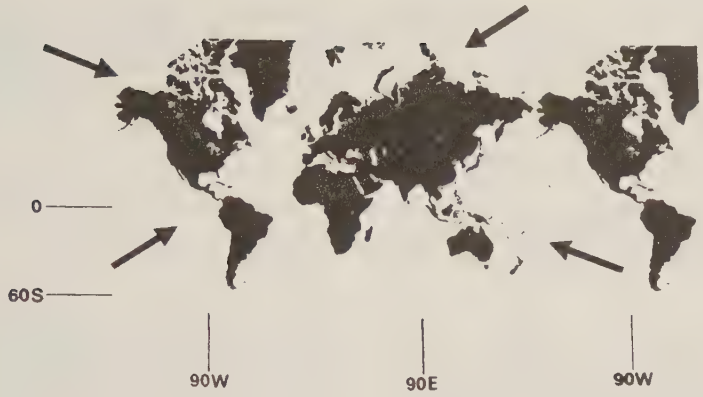
A study of the relation between planetary and local fractures on the Earth leads to a conclusion that systems of planetary fractures become most prominent on maps of a half-a-million scale (i.e. when the area analyzed is about 250 x 330 km) or of a smaller scale. A comparative study of data concerning the fracturing of sediment layers of different age in the Russian, Siberian, and other platforms as well as the Caucasus' folded area indicates that the orientation of this systematic fracturing is independent of the age of the sediments. The fractures' frequency decreases with the increasing thickness of strata according to a parabolic law.

Networks of the Earth's global faults and the so-called canals of Mars are analyzed and compared. Such analysis and comparison lead to a conclusion that, from the comparative geological and statistical points of view, the Martian 'canals' are of tectonic nature, i.e. they are related to tectonic zones of weakness.

As a result of an analysis of the world's geological literature and, in particular, of works dealing especially with faults of planetary significance, a map of prominent faults of the Earth has been compiled. A statistical analysis of the orientations of those faults has revealed that the deep faults of the Earth form four principal series corresponding to the directions of N-S and E-W, NW and NE, with a dispersion of 355-5° and 85-275°, 315-325° and 45-55°, respectively. With respect to their representativeness these four series are in the following (decreasing) sequence; NW, NE, E-W, N-S. Similar four principal series are distinguished in the network of Martian 'canals.'

.....

A comparison of Earth with Mars, Mercury, and the Moon shows that global systems of lineaments determined for the Earth are common to the terrestrial planets. The origin of such regularly oriented general planetary grids is attributable to planetary causes, i.e., deformation of the planet due to changes in its size, internal constitution and rotation rate." (R3)



Directions of global linear trends. (X2)

X3. Italy. The analysis of raised relief maps of Italy revealed 5372 lineaments. Azimuthal correlation of these yielded 48 local swarms and "8 noncontiguous but azimuthally compatible super-swarms covering much of Italy."

"The most prominent of the super-swarms are greatly expanded versions of regional structural grains: trend of the Po Basin, axis of the upper Adriatic Basin, zone of the south Alpine underthrusting, and landward extensions of structural grain of the Tyrrhenian Sea. From these relationships, a model for lineament-swarm origins is proposed, involving very minor regional stretching of the thin, brittle carapace of extremely large, sometimes subtle, structures deforming by ductile mechanisms at depth." (R4)

References

R1. Norman, John, and Chukwu-Ike, Muo; "The World Is a Bit Cracked," New Scientist, 73:320, 1977. (X1)

R2. O'Driscoll, E.S.T.; "The Double Helix in Global Tectonics," Tectonophysics, 63:397, 1980. (Cr. R. Molnar) (X2)

R3. Katterfield, G.H., and Charushin, G.V.; "General Grid Systems of Planets," Modern Geology, 4:253, 1973. (X2)

R4. Wise, Donald U., et al; "Topographic Lineament Swarms: Clues to Their Origin from Domain Analysis of Italy," Geological Society of America, Bulletin, 96:952, 1985. (X3)

ETL4 Measurements of the Relative Velocities of Continents

Description. The indirect measurement of intercontinental distances and, as a derived result, the relative velocities of the continents, through the precise observation of celestial bodies, particularly quasars, from observatories on the various continents.

Data Evaluation. The early optical measurements (X1) were subject to many sources of error, some of which have only recently been recognized. No one takes such measurements of intercontinental distance changes seriously anymore; they are included here for background only. The modern long baseline radio interferometers, which use distant quasars for references, are thought to be highly precise. Nevertheless, it is difficult to measure changes of a few inches over distances of several thousand miles. Also, when one reflects on the importance of measuring continental drift velocities, it is surprising that our surveys have come across few reports. Undoubtedly, there are more. Rating: 2.

Anomaly Evaluation. A 1983 report indicated no relative velocity between North America and Europe---contrary to the expectations of plate tectonics. However, in 1987, relative velocities between the continents were detected astronomically and found to be consistent with those anticipated by theory. Assuming these results are confirmed, what was an anomaly in 1983 disappears in 1987. Rating: 4.

Possible Explanations. None required.

Similar and Related Phenomena. Measures of global expansion (ETL5); other objections to the theory of continental drift (see index).

Examples

X1. Early astronomical measurements of intercontinental distances. "Dr. Harlan T. Stetson, of the Massachusetts Institute of Technology, suggested to the section on astronomy of the American Association for the Advancement of Science that the sun and moon may both be responsible agents for causing the apparent distance between New York and London to vary during the day and year. Dr. Stetson, on eliminating the effect of the moon by averaging intervals of observation from new moon to new moon, has been able to show that there results a curve of an annual variation in longitude with a maximum about January 1, when the earth is nearest the sun, and a minimum about July 1, when the earth is farthest away from the sun, actually some four million miles farther distant. From three years' observations (1929-1931), it appears that London on the average was 39 feet farther from Washington on New Year's than on the Fourth of July. This is about two thirds of the value (63 feet) which was attributed to the effect of the moon four years ago. Just how much of the 63 feet then supposed due to the moon may be indirectly laid to the sun, Dr. Stetson would not say until further investigations make possible a more complete separation of the effects of the principal disturbing sources. There is as yet no adequate explanation of the phenomenon." (R2; R1) Actually, many other variables besides "apparent distance" are involved here; and this old study should not be taken too seriously. (WRC)

X2. Modern radiointerferometric estimates of intercontinental distances. The following data, from A.E.E. Rogers et al, used the Mark III recording and processing system in conjunction with data provided by very long baseline radio-telescope interferometers. "Rogers et al used Mark III on six telescopes, one each at Owens Valley, Calif.; Fort Davis, Tex.; the Haystack Observatory in Massachusetts; Onsala, Sweden; Effelsberg, West Germany; and Chilbolton, England. They have done geodetic and astronometric measurements since 1979 and in that time have noticed no significant changes in the distances between the telescopes. Theories of continental drift and gravity theories in which the earth expands over time would expect changes. The longest baseline they have is between Fort Davis and Onsala, which they give as 7,940,732.17 $\pm$ 0.10 meters." (R3)

1987 update. Contradicting the earlier null results above, continental velocities consistent with the predictions of plate tectonics were reported at the 1987 spring meeting of the American Geophysical Union by J. Ryan. "In a subprogram of the project called the Great Alaska-Pacific Experiment (GAPE), large radio antenna in western North America, the central Pacific, and Japan were used to record radio noise from immensely distant quasars that act as stationary reference points. The millisecond differences in the arrival times of the same signals at different sites yielded the distance between the receivers.

Thanks to the relatively high speed of the Pacific plate, there is no doubt that real plate motion has been detected. After only 3 years of observation, Ryan noted, the calculated shortening of the distance between Hawaii and a site near Fairbanks in central Alaska appears to be 52.3 $\pm$ 5.5 millimeters per year. Hawaii is moving toward Japan at a rate of 83 $\pm$ 8 millimeters per year." (R4)

References

R1. "Time Studies Suggest Distance to Europe Varies with the Moon," Science News Letter, 23:14, 1933. (X1)
R2. Science, 85:42, 1937. (X1)
R3. Thomsen, D.E.; "Mark III Interferometer Measures Earth, Sky and Gravity's

Lens," Science News, 123:20, 1983. (X2)
R4. Kerr, Richard A.; "Geophysics Smorgasbord Was Spread in Baltimore," Science, 236:1425, 1987. (X2)

ETL5 Geological Indications of an Expanding Earth

Description. The use of: (1) seafloor-spreading vs. subduction rates; (2) paleomagnetic field measurements; and (3) hot-spot traces to estimate changes in the earth's radius over long periods of time. Three other possible indicators of an expanding earth are: (4) paleogeographical data (dry land area vs. ocean area over the eons); (5) the lack of evidence for the existence of ancient ocean crust; and (6) the poor fits of reconstructed ancient continents. (This last indicator is included to complete the list but is actually treated in ETL6.)

Data Evaluation. All classes of data listed above are inexact, depending upon various assumptions. They must be considered as rough estimates only. The intense criticisms of these data and, to an even greater degree, the conclusions drawn from them, betrays their lack of precision. Rating: 3.

Anomaly Evaluation. All of the six classes of measurements support the expanding earth theory---at least for modest rates of expansion. Since the expanding earth theory is not accepted geological dogma, data that support the theory are highly anomalous. Rating: 1.

Possible Explanations. The data suggesting an expanding earth are in error; or, less likely, the earth actually has expanded significantly over the past several hundred millions years.

Similar and Related Phenomena. Gaps and poor fits of the continents in continental drift theory (ETL6).

Examples

X1. Sea-floor spreading has exceeded subduction. If more sea floor has been created than has been removed, the earth must have expanded in order to accomodate the excess area. Estimates here are difficult-to-make and naturally highly controversial.

"Abstract. Measurements of areas of sea floor broken up into age groups show that apparent areal global sea-floor spreading rates increase exponentially from Jurassic to Holocene time, proving that subduction has taken place in that time. The sea-floor spreading phenomenon is a coordinated global process where, at a given time, high spreading rates in one ocean basin are compensated for by low rates in another. Sea-floor spreading is symmetric within 15% over periods of 60 to 165 m.y. This study shows that both global and sea-floor spreading and subduction rates have increased with the passage of time. It is estimated that during the past 165 m.y. sea-floor spreading exceeded subduction by 33%. This is interpreted as an increase of the Earth's surface area by expansion, which yields a Jurassic paleoradius of 5,668 km $\pm$ 13% (0.89 of the present radius). In spite of the high error margin, due to global extrapolation of subduction and spreading in the time dimension, an expanding earth is strongly indicated." (R1; R10)

Comments on the above study were rather intemperate, involving assertions of serious errors, dubious assumptions, omissions, etc. Steiner, however, answered all these objections at some length and stood by his results. (R3) See ETL2 for additional discussion of the possible nonexistence of subduction.

Steiner's estimates were based, in part, upon detailed maps of magnetic striping of the sea floor constructed by H.G. Owen. Others have used Owen's data and have arrived at estimates of terrestrial expansion that are more modest than Steiner's. For example, W.B. Harland states, "H.G. Owen (British Museum (Natural History)) has plotted the striping in a series of detailed maps that also require a more modest, but nevertheless significant, expansion of

the Earth during the past 200 Ma at least. Owen's expansion is less than Carey's because he recognises the existence of subduction zones. It might be added that most plate tectonic reconstructions seem to get by with a steady size Earth but they generally do not plot ocean floor spreading details. In this respect Owen's work is so thorough that it cannot be ignored." (R4) The Carey mentioned above is S. Warren Carey, a vigorous proponent of an expanding earth.

X2. Paleomagnetic estimates of the earth's change of radius in geological time. By measuring the inclinations of the paleomagnetic field at sites of the same age but separated widely in distance, one can estimate the radius of the earth at this point in time.

1963. Early correlations. An analysis by D. Van Hilten suggests an expanding earth. "To summarize, it may be stated that palaeomagnetic evidence seems to indicate a noteworthy increase in the Earth's radius since the Carboniferous, the rate of which agrees roughly with the hypotheses of Carey and Heezen." (R8)

1978. Negative evidence accumulates. A later study by M. W. McElhinny, employing better data, refutes the above conclusion. Abstract. "New estimates of the palaeoradius of the Earth for the past 400 Myr from palaeomagnetic data limit possible expansion to less than 0.8%, sufficient to exclude any current theory of Earth expansion." This study also concludes that the moon, Mars, and Mercury have not expanded in time either. (R2)

In response to these paleomagnetic data denying an expanding earth, S. W. Carey (champion of the expanding earth), maintains that paleomagnetism cannot be used to measure paleoradii of the earth. "Carey contends...in a long and involved geometrical argument that during expansion of the Earth a continent will deform in such a way and to such an extent as to make nonsense of any simplified model used in the determination of palaeoradius from palaeomagnetic data. If he is completely right, palaeomagnetism presumably has no role in detecting any possible increase in the terrestrial radius. If he is right in principle but not practice (perhaps because the continental deformation is too small to invalidate Ward's model), palaeomagnetic methods will be acceptable as long as the basic data are good enough. If he is wrong, there is nothing to worry about. The fact is, however, that whether Carey is right or wrong his criticism exists and has apparently never yet been refuted explicitly. Until someone chooses to do so, there must be lingering doubt in the minds of disinterested observers." (R11)

1981. Even later paleomagnetic measurements support an expanding earth. "The second new line of evidence favouring expansion comes from palaeomagnetism. Embleton and co-workers showed that for quite long periods during the Proterozoic, continental blocks such as North America and Australia in their present relative positions had common polar wandering paths. They interpret this surprising result, coupled with the missing oceanic crust, as arising from Earth expansion during the late Proterozoic. Pure Earth expansion has the effect of leaving continental centres in the same coordinate position and so has no effect on the polar wandering paths. The problem is to see how the relative continental motions during the Phanerozoic, which palaeomagnetism brings out so clearly, could have returned the continents to the relative positions they had in the Proterozoic." (R12)

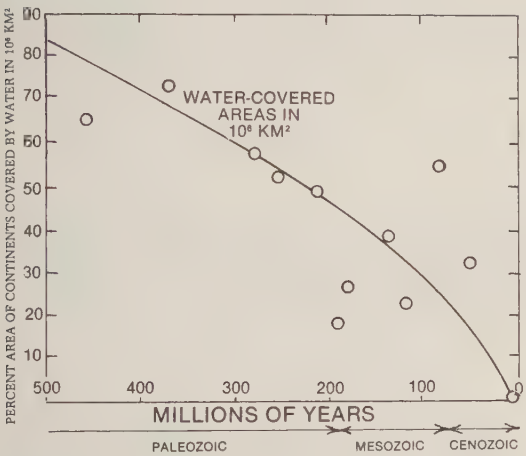
X3. Traces of hot spots on the earth's surface. In his response to his critics (X1), Steiner notes that I. C. F. Stewart, working with hot-spot data, estimated that the earth's radius 120 million years ago was only 88 $\pm$ 5% of the present radius---essentially in agreement with his own result. "Specifically, Stewart looked at distances between pairs of hot spots and their traces for different ages, which generally indicate less separation earlier in time. Stewart concluded that the apparent changes on great-circle distances between mantle plumes may be consistent with constant separation in terms of geocentric angles, with increase in the Earth's radius of as much as 12% over the past 120 m.y." (R3; R9)

X4. The paleogeographical approach. "The problem of the constancy or otherwise of the volume of the Earth can be solved...on the basis of palaeogeographical data. We have only to establish the amount of the areas

covered by sea water in different geological ages: a definite increase in the average values means a shrinking Earth, whereas their constancy indicates that on balance the volume of the Earth has not appreciably changed.

Fig. 1 represents the water-covered continental areas computed from the palaeogeographical maps of T.M. Strahow; Fig. 2 (not reproduced) is a similar diagram compiled from thirty-four palaeogeographical maps recorded by H. Termier and G. Termier.

In both diagrams the data plotted show a definite decrease in the course of the geological ages, indicating that there has been a cumulative increase of the radius of the Earth. Indeed, palaeogeographical data provide evidence for the hypothesis that the Earth has expanded." (R5; R6)



Water-covered continental area versus geological time. (Figure 1 in X4)

X5. Lack of evidence for an ancient oceanic crust. Two lines of evidence point to a reduction of ocean crust area as one looks farther and farther back in time. (1) There is no geochemical evidence that oceanic crust or any mantle-derived crust survived from the Proterozoic. (2) The global abundance of ophiolites and turbidites, both indicators of oceanic crust, decreases exponentially with increasing age back to the end of the Proterozoic (about a billion years ago), at which time they completely disappear from the geological record. (R12)

X6. General observations. "There appears to be a remarkably close agreement between the rate of increase of the Earth's radius and that of the universe according to Hubble's law. Using the present accepted value for Hubble's constant, H = 100 km/s/megaparsec, which is 1.65×10^{-4} mm per year per mile, and substituting the value of the Earth's radius in the Hubble equation, v = RH, we obtain a radial expansion for the Earth of 0.66 mm per year." (R7) This is a most interesting observation, but it must be remembered that the value of Hubble's constant is not at all certain. In fact, in our AO Catalog volume, one finds some doubts about the expanding universe concept. (WRC)

References

R1. Steiner, J.; "An Expanding Earth on the Basis of Sea-Floor Spreading and Subduction Rates," Geology, 5:313, 1977. (X1)

R2. McElhinny, M.W., et al; "Limits to the Expansion of Earth, Moon, Mars and Mercury and to Changes in the Gravitational Constant," Nature, 271:316, 1978. (X2)

R3. Faul, Henry, et al; "An Expanding Earth on the Basis of Sea-Floor Spreading and Subduction Rates: Comments and Reply," Geology, 6:377, 1978. (X1, X3)

R4. Harland, W.B.; "An Expanding Earth?" Nature, 278:12, 1979. (X1)

R5. Egyed, L.; "Determination of Changes in the Dimensions of the Earth from Palaeogeographical Data," Nature, 178:534, 1956. (X4)

R6. Egyed, L.; "The Expanding Earth," New York Academy of Sciences, Transactions, 2:23:424, 1961. (X4)

R7. MacDougall, John, et al; "A Comparison of Terrestrial and Universal Expansion," Nature, 199:1080, 1963. (X6)

R8. Van Hilten, D.; "Palaeomagnetic Indications of an Increase in the Earth's Radius," Nature, 200:1277, 1963. (X2)

R9. Stewart, Ian C.F.; "Mantle Plume Separation and the Expanding Earth," Geophysical Journal, 46:505, 1976. (X3)

R10. Smith, Peter J.; "Evidence for Earth

Expansion?" Nature, 268:200, 1977. (X1)
R11. Smith, Peter J.; "The End of the Expanding Earth Hypothesis?" Nature, 271: 301, 1978. (X2)
R12. Stewart, A. D.; "The Expanding Earth," Nature, 289:627, 1981. (X2, X5)

ETL6 Continental Fits—Good and Bad

Description. The fitting together---like puzzle pieces---of present and past continents to form larger land masses. Continental shelves rather than extant coast lines are usually employed in such fits. Good fits, determined visually or mathematically, are considered by some as evidence that the continents were once joined into larger groups.

Data Evaluation. Good bathymetric data are now available for almost all continental shelves. Rating: 1.

Anomaly Evaluation. An anomaly exists here if the various continental fits do not support the hypothesis of continental drift---the presently dominant theory in this area of knowledge--- or if they support instead some unacceptable theory, such as the hypothesis of an expanding earth. Some fitting experiments do support the expanding earth theory. But the entire "fitting game" is compromised to some extent by the fitability of several obviously unrelated coast lines. Also, the classical continental fits so essential to the rise of the continental drift theory can be shown to be very questionable in some areas. Continent fitting evokes many doubts about continental drift. Rating: 2.

Possible Explanations. The expanding earth hypothesis is superior to that of continental drift.

Similar and Related Phenomena. Topographical paradoxes in continental drift (ETL7); land-water distribution (ETL1); measures of the relative velocities of continents (ETL4). Paleontological and other geological objections to continental drift may be located in the indexes of other Catalog volumes in the Geology (E) and Biology (B) series.

Examples

X1. Continental fits on a smaller earth. "The continents, down to the 500 fathom line where topographic charts show their steepest gradient, now cover about 30 per cent of the Earth's surface. This available sialic continental material might thus have covered a primitive Earth having a radius of about 0.55 of the present value. A simple model experiment could be carried out to investigate the fit by making 'Perspex' shell models of the continents scaled and moulded to the curvature of the 50-cm globe and then remoulding these to the curvature of a 27-cm diameter globe, 0.55 times the size of the globe modelling the present Earth. These models of the continents would comprise pieces of a jig-saw to be fitted together on the surface of tne 27-cm globe which they should cover. In fact, the experiment was carried out by making fibreglass shell models of the continents with great circle distances from a central point increased by $0.55^{-1} = 1.82$ and fitting these together on the 50-cm globe. The fit obtained is illustrated in Figs. 1a and 2a (not reproduced)."

Although there is some overlap of Patagonia and Antarctica and in the region of the East Indies, there are good reasons for the few regions of bad fits, such as erosion and tectonic motions. Creer evaluates his experiment thus: "At this stage, however, I have formed the impression that the fit of the continents on a smaller Earth illustrated in Figs. 1a and 2a appears too good to be due to coincidence and hence requires explaining. The simplest explanation appears to be expansion of the Earth, and one purpose of this article is to suggest that this hypothesis should be taken seriously." (R1) In the reigning theory of continental drift, the continents were once all assembled into one or two supercontinents on an earth of present dimensions. In other words, the perimeters of the supercontinent(s) did

not have to "fit" into a complete spherical shell, as they do on Creer's smaller globe. Creer's "fit" is therefore more remarkable than the simple reconstructions of one or two supercontinents surrounded by ocean. (WRC)

In a long, often-referenced paper, H. G. Owen also concluded that the continental jigsaw puzzle fits together better on a smaller earth. In his Abstract, Owen states: "It is shown that an exact fit of the various continental fragments together to reform Pangaea, which agrees with the geometric and geological matches, is obtained when the value of the Earth's surface curvature is increased to the point at which the diameter of the globe is 80% of its current mean value. This corresponds in time to the late Triassic-early Jurassic. It is asserted that the early Upper Jurassic to Recent ocean floor spreading data now available, displayed here in maps, also demonstrate progressive global expansion commensurate with an increase in diameter of 20% of the Earth's current mean value." (R5)

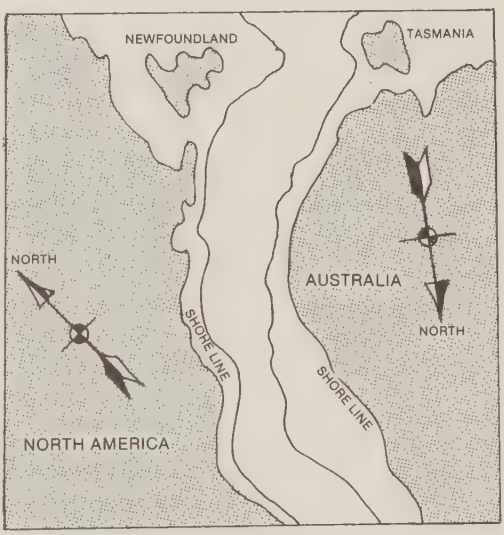
X2. The ubiquity of good "fits". Earth scientists are wont to call the fits of continental coastlines "compelling." Unfortunately, many unlikely coasts can be fitted together nicely, greatly devaluing the fitting process as a proof of anything.

"(1) Since nearly all coastlines fit, there seems little point in continental drift reconstructions. (2) The congruence of coastlines that can never have been in juxtaposition, even if drift is valid, has been demonstrated by Lyustikh, and (3) Australia has even been connected to the east coast of America by Voisey as a demonstration of the ubiquity of possible fits... It is important to realize that coastlines need never have been in actual contact to show parallelism; some influence connected with the midocean ridge system may have given the impression of a fit while the real fit is in fact a remote one." (R3; R2)

X3. The badness of some "good fits." Many of the "compelling" fits of the continents run into problems with overlaps and missing pieces.

'If one excludes Cretaceous-Cenozoic additions to the continents, the Bullard et al. fit ---and some others---looks good surficially. On analysis, however, the Bullard et al. fit leaves the observer feeling uneasy when he notes overlaps of Paleozoic and older rocks of 100-300 km between Australia and Antarctica, Europe and North America, and Africa and South America. The alleged 'fits' worked out by Smith for various islands and peninsulas of the modern Mediterranean Sea do more than simply boggle the mind; they violate the geology---absolutely. The least-squares fitting method is fine for working out a mathematical curve, but it has serious shortcomings where solid rocks are involved.

In the Bullard et al. fit, one notes immediately the omission of early Paleozoic and Precambrian Middle America, between the Mexican volcanic belt and the Nicaragua graben, and from the Northern Central America orogen to Jamaica, Cuba, the Bahamas, and southernmost Florida. This is an area measuring 2,400,000 sq km. The Nafe and Drake reconstruction, which postulates the presence of a Paleozoic proto-Atlantic Ocean, does not account for some geologic and geographic incongruities imposed by the Bullard et al. 'nonfit' in this area. It also eliminates the necessity to postulate an east-west shear zone through the present Mediterranean, a



When rotated, eastern Australia fits well with eastern North America—an improbable "good fit." (X2)

shear which does not exist. Moreover it removes the need to rotate Spain---a rotation which field geology demonstrates conclusively never took place. The Nafe and Drake model also obviates the need for superfluous hypotheses, such as that by Dietz et al., who interpreted the Bahamas (which overlap well into Africa) to be an accretionary structure built southeastward onto supposedly oceanic crust. Dietz et al. alluded to, but chose to ignore, the extensive geophysical and geologic data from the Bahamas. However, the Nafe and Drake model of a proto-Atlantic Ocean is unnecessary if the positions of the continents have not changed." (R2)

The forgoing excerpt is taken from a 77-page critique of continental drift by A.A. and H.A. Meyerhoff, one of several extensive and detailed attacks on this now-dominant hypothesis. It is impossible to include all objections here. One more quotation must suffice.

"The gist of his (H.G. Owen's) argument is geometric, that the celebrated Bullard fit of the Atlantic continents, and its successors such as the Smith and Hallam fit of the Gondwana continents, pose awkward problems of continental overlap and misfit which have not been adequately explained away. For example, many geologists have been worried by the loss of much of Central America in the Bullard fit, despite the fact that extensive areas of old continental rocks occur there, and attempts to get around this problem by seemingly arbitary and ad hoc tectonic displacements and rotations, have lacked plausibility.

Likewise, if one adopts the Smith-Hallam fit, West Antarctica does not run naturally into its obvious geological continuation in Patagonia. More disturbing perhaps, a large gap is left west of Australia, which has led to the suggestion that the Wharton Basin in that region was ancient ocean, now disproved by the Deep Sea Drilling Project which has demonstrated that the basin is underlain by oceanic crust as young as elsewhere. On the other hand fitting India against Australia, as others have done, leaves a corresponding gap in the Western Indian Ocean." (R4)

References

R1. Creer, K.M.; "An Expanding Earth?" Nature, 205:539, 1965. (X1)

R2. Meyerhoff, A.A., and Meyerhoff, Howard A.; "'The New Global Tectonics': Major Inconsistencies," American Association of Petroleum Geologists, Bulletin, 56:269, 1972. (X2, X3)

R3. Wesson, Paul S.; "Objections to Continental Drift and Plate Tectonics," Journal of Geology, 82:185, 1972. (X2, X3)

R4. Hallam, A.; "How Closely Did the Continents Fit Together?" Nature, 262:94, 1976. (X3)

R5. Owen, H.G.; "Continental Displacement and Expansion of the Earth during the Mesozoic and Cenozoic," Philosophical Transactions, 281A:223, 1976. (X1)

A possible arrangement of the continents before drift began some 250 million years ago. (X3)

ETL7 Topographical Anomalies and Continental Drift

Description. Topological impossibilities and topographical embarrassments created by the hypothesis of continental drift. Some of the "embarrassments" are: (1) Regions that have obviously been expanding when they should have been under compression; (2) The existence of too much area on the present-sized globe for the required faunal and paleogeographical proximities; and (3) The absence of subduction zones where, according to the theory, continent-sized sections of crust should have been swallowed up.

Data Evaluation. The "facts" employed in this section are actually syntheses of diverse geophysical, geographical, and paleontological data. They are not the basic observables but rather inferences from them. For examples, in X3 below, the statement that the Arctic region has been expanding for millions of years requires the integration of considerable data and not a few lower-level inferences. When working with higher-level syntheses instead of field data, there is much more room for bias, particularly at the hands of proponents and opponents of specific theories. Rating: 2.

Anomaly Evaluation. The "paradoxes" outlined below run strongly against the widely accepted hypothesis of continental drift (plate tectonics). Rating: 1.

Possible Explanations. The expanding earth hypothesis is more nearly consistent with the facts presented below. But, it is well to caution that most of the authors cited are proponents of this hypothesis.

Similar and Related Phenomena. Continental fits (ETL6); land-water distribution (ETL1); measures of the relative velocities of the continents (ETL4). Paleontological and other geological objections to continental drift may be found in the indexes of other Catalog volumes in the Geology (E) and Biology (B) series.

Examples

X1. General observations. "Abstract. Certain continents in the past have moved with respect to each other in a manner clearly implied by sea-floor spreading and other data. However, the resulting collective motion of all the continents was apparently not topologically possible on the present-sized earth. An expanding earth might resolve this difficulty." (R1) Several other authors have expressed the same opinion. (R2-R9) It should be recorded, however, that most of these authors strongly oppose the theory of continental drift; a smaller number also promote the expanding earth theory as the better explanation of continental dynamics. (WRC)

In Carey's expanding earth hypothesis, the earth's mantle is cracked right down to the fluid core. The first-order lithosphere blocks are surrounded spreading diapirs. (X1)

X2. The Pacific perimeter paradox. "Topology is a discipline of mathematics that deals with the study of those properties of a geometric body (such as a point set) that remain unchanged if the configuration of the geometric body is subjected to a one-to-one continuous transformation in both directions. Topology applies to the new global tectonics in that the perimeter of the Pacific rim encloses only a third of the area of the earth's surface. Yet it is much of this very rim which supposedly moved with Eurasia and Africa to isolate the Americas. For this to be possible physically, Meservey wrote, in a carefully documented paper, that

> ...the perimeter of the Pacific must have at some time enclosed at least half of the earth's area in order for it to pass over the earth's circumference (as we go back in time) and be assembled on the opposite of the earth. Thus there is no topologically possible transformation of the continents on an earth of the present size from their present positions to even approximately

the (predrift) positions if we accept the constraints on the perimeter.

Meservey's observation is not 'a minor detail' which one can dismiss, yet most 'new global tectonicists' ignore his paper. Meservey's observations are independent of all variables except earth diameter. For this reason, Meservey observed that, 'The only hypothesis that has been suggested...that resolves the paradox is that in the past the earth's interior has expanded considerably...The most direct interpretation of the evidence...seems to be that a large expansion of the earth has taken place in the last 150 million years.'" (R3; R8) This topological argument requires that, for continental drift to have occurred at all, the earth must have expanded substantially. (WRC)

X3. The Arctic paradox. Based on fossils and paleomagnetic data, S.W. Carey observes:"So since the Permian the continents have converged from three sides on the Arctic, which consequently should have contracted by some 5000 km. Did it? Just the opposite. During all that time the Arctic has been an extending region, opening the Arctic Ocean. This is impossible except on an expanding Earth." (R8; R10)

X4. The India paradox. India has close faunal and paleogeographical ties with Australia, Antarctica, Madagascar, Afghanistan, Kazakhstan, Tibet, East Africa, Iran, and Arabia. The theory of continental drift has trouble in explaining all of these connections. "The India paradox resolves into one of total surface area. It is impossible to satisfy the valid proximity demands of one insistent neighbour without leaving wide blank spaces between India and others whose proximity demands are equally compelling. On a smaller Earth the unwanted space vanishes (by the elision of younger ocean crust) and all proximity demands are satisfied." (R8) See ETL6-X1 for continental fits on a smaller earth.

X5. The Africa paradox. "Like all continents, Africa is surrounded by its ocean-floor-spreading rift zone, shaped like an inflated caricature of Africa, more than twice its own area. New crust, youngest at the rift, ages from Quaternary through Tertiary and Cretaceous. Somewhere within Africa, plate theory demands a sink which has swallowed an area of crust lithosphere greater than the whole of Africa. Where is it? Such just does not exist! On the contrary, between the Atlantic and Indian Ocean ridges is the great rift valley system of latitudinal extension, itself a nascent spreading ridge." (R8; R3) The Africa paradox is part of a more general problem: the apparent absence of subduction zones in some places we would expect to find them and the lack of sediments at these zones. For further discussion, see ETL2-X7 and X8. (WRC)

References

R1. Meservey, R.; "Topological Inconsistency of Continental Drift on the Present-Sized Earth," Science, 166:609, 1969. (X1)

R2. Barnett, C.H.; "Oceanic Rises in Relation to the Expanding Earth Hypothesis," Nature, 221:1043, 1969. (X1)

R3. Meyerhoff, A.A., and Meyerhoff, Howard A.; "'The New Global Tectonics: Major Inconsistencies," American Association of Petroleum Geologists, Bulletin, 56:269, 1972. (X2)

R4. Carey, S. Warren; "The Expanding Earth---An Essay Review," Earth-Science Reviews, 11:105, 1975. (X1)

R5. Beloussov, V.V.; "Why I Do Not Accept Plate Tectonics," Eos, 60:207, 1979. (X1)

R6. Wood, Robert Muir; "Is the Earth Getting Bigger?" New Scientist, 81:387, 1979. (X1)

R7. Harland, W.B.; "An Expanding Earth?" Nature, 278:12, 1979. (X1)

R8. Carey, S. Warren; "The Necessity for Earth Expansion," The Expanding Earth: A Symposium, University of Tasmania, 1981, p. 377. (X1-X6)

R9. Owen, Hugh; "The Earth Is Expanding and We Don't Know Why," New Scientist, p. 27, November 22, 1984. (X1)

R10. Wilson, J. Tuzo; "Room at the Top of the World," Nature, 316:768, 1985. (X3)

ETM MOUNDS AND HILLS

Key to Phenomena

ETM0 Introduction

The existence of a single pile of dirt, sand, and/or rocky debris rarely evokes much popular or scientific excitement. It could, after all, be merely man-made, or even the work of industrious insects. But when mounds or low hills number in the hundreds or thousands, some special explanation seems required.

The most widely known and certainly the most widely debated of these low-lying geological structures are the Mima Mounds and the drumlins. The Mima Mounds occur in the hundreds of thousands in North America west of the Mississippi; drumlins number in the tens of thousands in regions claimed to have been once glaciated. The debates about the origin(s) of the Mima Mounds have always been spirited, although the scientific stakes are not high. The course of science will not be altered if the Mima Mounds were constructed by rodents, wind, or water. On the other hand, the genesis of the drumlins is rarely argued these days, even though some of their features are anomalous. The probable reason is that the drumlins are an integral element supporting the hypothesis of the Ice Ages---an important fixture in scientific thought today. For this reason, some drumlin phenomena are highly anomalous.

The other mounds and small hills described in this section attract little popular or scientific attention. These structures are not as common as Mima Mounds and drumlins, and they often are found only in remote areas. With one possible exception, they constitute only minor anomalies; some are simply curiosities. The one exception is the widespread existence of sandhills of unknown or suspect origin. Too often, sandhills are written off as the consequence of "wind" or "water". Such statements may be too glib.

ETM1 Mima-Type Mounds and Small Hills

Description. Rounded mounds of soil, usually symmetrical, measuring from a few inches in height to roughly 100 feet, with diameters from a few feet to as much as 1000. These mounds occur by the hundreds of thousands and represent a major geological phenomenon. Although they have been reported from scattered localities around the world, such mounds find their best expression in North America, west of the Mississippi. The majority of mound sites are low-lying and near the sea or some other body of water.

Data Evaluation. Mima mounds have excited the curiosity of many scientists. The literature is imposing; although most papers are restricted to a single mound field and/or are influenced by a single theory of origin. Although we catalog many mound sites here, it seems likely that many have not been described in the scientific literature. In particular, Asia is not represented at all. Rating: 1.

Anomaly Evaluation. Small mounds seem innocent enough---hardly important enough to overturn any basic tenets of geology. If, in the final analysis, gophers, noncatastrophic water erosion, periglacial action or some similar "low key" mechanisms are collectively responsible, the anomaly value is low. Alternatively, if, as A.O. Kelly proposes, most mound fields result from catastrophic ocean flooding, due to a relatively recent meteoric impact, we have a highly anomalous phenomenon. Our rating here assumes that a suite of noncatastrophic causes suffices. Rating: 3.

Possible Explanations. See the list of eleven possible explanations in X1. Of these, the most highly regarded---at the present time---are the gopher and water-erosion theories. In all probability, the mounds described in this section are polygenetic; that is, there is no single explanation.

Similar and Related Phenomena. All of the other entries in this chapter (ETM) are also mound-like to character. Especially closely related are gilgai-soil mounds (ETM2), mud-lumps (ETM3), drumlins (ETM4), and basalt-debris mounds (ETM5).

Examples

X1. General observations. In response to a letter in Nature from A.R. Wallace (of evolution fame), J. Le Conte produced an early overview of American "hog wallows" and "prairie mounds."

"The peculiar configuration of surface so well described by Mr. Wallace, is very widely diffused in America, and has been described under different names. In California the mounds are called Hog-wallows, but elsewhere they are known as Prairie mounds. This latter is the better name since they are found only in grassy, treeless, or nearly treeless regions. They occur over much of the Prairie region or "plains"east of the Rocky Mountains; also over portions of the basin region, e.g., in Arizona; also over much of the bare grassy portions of California, e.g., along the lower foothills of the Sierra and adjacent portions or the San Joaquin plains; also over enormous areas in middle Oregon, on the eastern slope of the Cascade mountains, an undulating grassy region; also on the level grassy Prairies about the southern end of Pugit (sic) Sound, Washington Territory.

They have been ascribed to the most diverse causes. In Texas, where they are very small, Prof. Hilgard thinks they are ant-hills. In Arizona, where thay are also imperfectly developed, Mr. Gilbert thinks they are the ruined habitations of departed Prairie dogs. In some portions of California, also, where they are small, they have been popularly ascribed to burrowing squirrels. In the Prairies, about Pugit Sound, where they are splendidly developed, their great size and extreme regularity has suggested that they are burial mounds, and that the Prairies are veritable cities of the dead. It is possible that the causes may be different in different places, but I am sure that no one who has examined them in California, and especially in Oregon and Washington, can for a moment entertain any of these theories for the Pacific slope." Le Conte prefers water erosion in proximity to an ice sheet as the explanation for the West Coast mounds. (R3) It is historically interesting to remark that burrowing animals were on the earliest lists of causes. The pocket gopher theory is still popular.

An overview from 1906. Following a lengthy spate of letters in Science, beginning in 1905,

M. R. Campbell summarized the situation in the Journal of Geology.

"Recently the subject of natural mounds has attracted unusual attention, and a number of persons have described their occurrence and attempted an explanation of their origin.

What are here designated as natural mounds are low, broad mounds, varying from 10 to 140 feet in diameter, and from a few inches to 5 or 6 feet in height. They are wonderfully symmetrical, both in plan and elevation, and generally they closely approach a circle in outline, but in places they are slightly elliptical, and where such is the case the major axes of all mounds in the vicinity have a common direction.

mounds of similar character occur in abundance in Louisiana, Texas, Arkansas, Missouri, Kansas, Indian Territory, Arizona, California, Oregon, Washington, Mexico, and Argentine Republic. Generally they are reported as occurring on low, flat lands; but Turner has described and figured similar topographical features covering low hills on the east side of the San Joaquin valley in California, and recently Hill has noted their occurrence on the high plateau of Mexico, nearly 7,000 feet above sea level.

To account for the origin of these mounds various hypotheses have been advanced, but in most cases they are speculative only and have little or no foundation in fact, or are based upon limited observations and fit only

Typical Mima Mound topography. Contour interval is 2 feet. (X1)

Figure 1 (omitted here) is reproduced from a photograph of a group of slightly elliptical mounds occurring on the old sea terrace back of San Diego, Cal., at an altitude of about 380 feet. Frequently the mounds are closely bunched, as shown in the figure, but they occur also singly and in small groups.

According to the descriptions of various writers, the composition of the mounds vary considerably, probably being affected by the character of the local material. As the writer has observed them in California and Arkansas, they are made up of clay, or clay with a slight admixture of gravel, depending upon the character of the underlying subsoil; but in Texas and Louisiana, according to report, they are made up largely of sand, and in Missouri of chert fragments from the Carboniferous limestones.

So far as the writer has observed or has been able to obtain references to them, the conditions prevailing in one locality.

It is altogether probable that the mounds which have been noted in various parts of the country are not exactly similar and have not had a common origin, but this cannot be proven until they have been more carefully studied, and studied by one person who can compare the mounds in different localities and judge whether or not they are all due to the same cause.

The principal hypotheses may be summed up as follows:

1. Human agency,
2. Animal burrows, such as ground squirrels, gophers, and prairie dogs,
3. Ant hills,
4. Water erosion,
5. Chemical solution,
6. Wind action,
7. Physical or chemical segregation,
8. Glacial action,
9. Uprooted trees,

10. Spring and gas vents,
11. Fish nests." (R17)

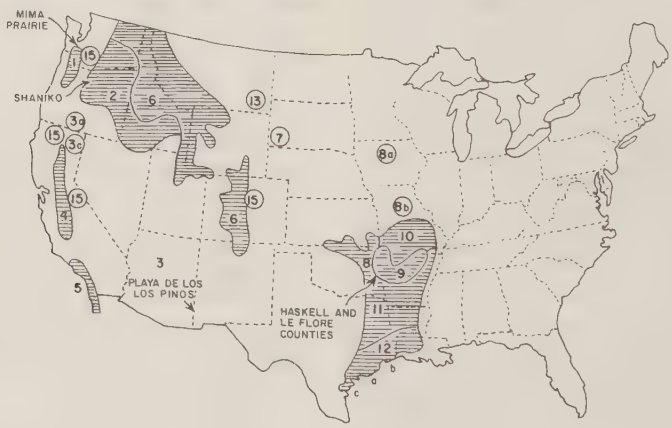
An overview from 1949. From 1906 through 1949, many papers were published on possible origins of the "pimple mounds". In particular, the pocket gopher theory attracted many adherents. Then, in 1949, E.L. Krinitzsky came out strongly for "mulitple origins".

"Summary. (1) Pimple mounds reported from various areas, such as Washington, Missouri, Arkansas, Texas, and Louisiana, are essentially similar. (2) In meander belt areas, pimples conform to patterns of accretion ridges on point bars. (3) Sandy towheads and point bars are observed as containing water- and wind-developed sand mounds which have identical sizes and orientations as have pimples. (4) It is suggested that such mounds are preserved by mantles of vegetation and later are exposed as the familiar pimple features. (5) In coastal sand-flat areas, dunes are observed to have orientations which indicate the beach origin of typical pimple mounds. (6) Glacial outwash areas, such as in Washington and Iowa, have developed mound forms on their surface which are identical to typical pimples. (7) Pimple mounds, in conformity to the eolian dune and river mound hypotheses of origin, are generally restricted to areas of alluvial deposits. (8) These hypotheses of origin appear to have more universal applications than do other modes of pimple mound origin previously advocated, although the latter theories may remain valid in many special instances." (R32)

Rebuttal by a gopher proponent. Krinitzsky's paper was strongly anti-gopher. W.A. Price quickly published a scathing attack on Krinitzsky's paper.

"Krinitzsky has missed (1) the critical item of mound structure, the bi-convex lens of top (A zone) soil, forming a wholly abnormal thickening of the top soil, inexplicable under any origin except the sort of diligent underground cultivation done only by the pocket gopher, among burrowing animals of a size adequate to produce these mounds and to move gravel, (2) the present writer's statement that the bi-convex structure has been found to be characteristic of the mounds in all regions of occurrence of the type---nearly every state west of Mississippi River ---and (3) that the mounds do occur abundantly (contra Krinitzsky) where gophers live in thin 'residual' soil above hard rocks and soil claypan." (R33) The bi-convex structure mentioned above by Price seems to have been missed by almost all earlier writers.

The study of similar mounds in Argentina (X5), Kenya (X12), and elsewhere has revealed mound associations with other types of burrowing animals. It is fair to say, at



Map of the United States indicating the geomorphic provinces where pimpled plains occur: (1) Puget trough; (2) Columbia plateaus; (3) Scattered localities in the Basin and Range Province; (4) California trough; (5) Pacific Border terraces; (6) Southern Rocky Mountains; (7 and 13) River terraces in the Great Plains; (8) Central Lowlands; (9 and 10) Ozark-Ouachita region; (11 and 12) The Gulf Coastal Plain. (X1)

the moment, that the burrowing animal theory is the most successful, but the issue is certainly not completely decided. (WRC)

In considering the origin of natural mounds, other animals besides gophers and their kin should not be forgotton. Fish, for example, may construct substantial mounds when nesting. The chub, a North American fish, will build mounds as high as four feet. (R52, R53)

While termites are known to be extraordinary mound engineers, Brazilian ants build mounds 1-4 feet high, 10-20 feet across, and 50-100 feet long. (R54)

X2. South-Central United States. Millions of mounds occupy this region. The literature is vast, and we have room for only a few excerpts. It will be seen that the mounds in this region are far from identical in fine detail.

Texas. A very early (1840) sketch. "While in Texas the second time I had full opportunity to study the phenomenon of 'hog-wallow prairies.' The long droughts in summer cause the woodless surface of the prairies to crack deeply, and oftentimes symmetrically; subsequent rains wash the adjacent earth into these cracks, filling them up, converting them into little valleys, and leaving intermediate hillocks. Next year the same round of cause and effects occurs in the same places, and thus successive years contribute for a long time to produce a maximum effect, the appearance of which is very striking. When the prairie is level, the hillocks are exactly hexagonal, and usually eight or ten feet in diameter. The depressions between them are commonly twelve or eighteen inches deep. If the surface is inclined, the hexagons become elongated at right angles to the direction of the dip, when they frequently resemble the waves of the ocean. From difference of surface, soil, and exposure, there arises a great diversity in the size, depth, and general appearance of the hog-wallows. They never occur in a sandy soil, consequently they are not seen on the sandy prairies near the sea coast. I do not remember to have seen them among the mountains in the Camanche country; but else they frequently greet the eye of the traveller in most every part of Texas." (R1) The erosion of deeply cracked prairie soil is not on the list, in X1, of potential origins. Also, we shall see below that mounds do exist near the Gulf shore in profusion. (WRC)

Northeast Texas, southern Arkansas, northern Louisiana. "The apparently inexplicable 'natural mounds' have been the subject of much controversy, some of which has been at the same time humorous and absurd. In the Gulf Coastal Plain and in the older Mississippi delta region the 'natural mounds' are small hillocks, which in the main are composed of very fine sandy soil and which are remarkable for their uniform circular outline and for their symmetrical dome-shaped profile. Their diameters range from 10 to about 100 feet, though the majority have diameters from 30 to 50 feet. Their heights range from about 1 foot to 6 feet, and the majority rise 3 to 4 feet above their surroundings. They are most abundant on strata of Pleistocene age, though they are found on different geologic terranes ranging in age from Cretaceous to Pleistocene. They occur at many places throughout the state of Louisiana, in southern and eastern Texas, in southern and eastern Arkansas, and in southeastern Missouri." This author believes the mounds were formed by gullying. (R20)

During the spate of papers in Science, in the 1906 period, on the possible origin of the mounds, speculation was rampant. They were merely the dirt left from uprooted trees; they were anthills; they were caused by differential settling; they were aeolian; and so on. (R56, R57)

The Gulf coastal plain. "The mounds are present by the hundreds of thousands in a broad belt along that part of the Gulf Coastal Plain extending from near the Corpus Christi region of Texas eastward to the vicinity of Lafayette, Louisiana, when the mound-containing sediments are abruptly truncated by Mississippi alluvium. They are best developed and are nearly everywhere present in southeast Texas and southwest Louisiana on level or almost level ground, where they form the the so-called 'pimple prairies.' They are most commonly present and they are of most perfect form immediately to the landward of coastal lagoons, whereas inland the mounds are generally more scattered and less well-preserved. Mounds, of the type referred to here, are completely absent from the barrier beaches and related beach deposits and, also, are absent from the extensive area covered by wind-blown sand in the region between Corpus Christi and the Rio Grande River. In fact, the mounds are wholly confined to areas which appear to be brackish-swamp-deposited facies of the two extensive Quaternary formations, the Beaumont and the Lissie.

The mounds are symmetrical in form and rather uniform in size and shape. They are circular in ground plan and in vertical section they have the shape of a low flattened dome. Although they may vary in diameter from ten to one hundred feet, and in height from one to five feet, they average about thirty to fifty feet across and about two to three feet in height. Where the hillocks are well developed, they are scattered at intervals of about one hundred feet and occupy from ten to twenty-five per cent. of the land.

The mounds consist of dark gray loamy sand which at a depth ranging from two to four feet grades into a loamy clay similar to that of the inter-mound areas. No gravel is present either in the mounds or in the areas between them." (R25) This author thinks that the mounds are water-deposited.

Eastern Oklahoma. "Pimpled plains are extensively developed in the Arkansas River valley and the Ouachita Mountains. They appear on air photos as multitudinous small, rather uniformly spaced, bright or dark patches of ground, most of which are subcircular. The center of each patch coincides approximately with the apex of a mound 2 to 4 feet high. The distance from center to center, generally between 50 and 100 feet, is rather uniform for any one locality, and commonly the margins of the patches are separated by approximately half that distance. Locally, however, the patches are much broader than the interspaces and are of various polygonal shapes.

Many road cuts expose the materials of the mounds and the surfaces on which they rest. A typical mound consists of loess-like material that is partly clay and contains small pellets of limonite, as well as a few subangular fragments of sandstone lithologically like that of local bedrock units of Pennsylvanian age. Most of the rock fragments are 2 inches or less in greatest dimension and are distributed at random. The loesslike material rests with a sharp contact on a flat, nearly level floor that commonly consists of heavy clay, or claypan, lighter in color than the material composing the mound. In places the floor material approaches the consistency of hardpan. The origin of the materials of the mounds and the deposits immediately underlying them calls for more study and is not dealt with here." Here, the author prefers the shrinkage-polygon theory mentioned in the forgoing 1840 sketch. (R34)

X3. The Pacific Northwest. Once again, an early geological assessment. "At the southern extremity of Puget Sound, in the midst of the dense fir forests, and separated from them by the sharpest line of definition, there are remarkable narrow, irregularly ramifying glades, or prairies, entirely destitute of trees or shrubs. These are doubtless old bottoms of Puget Sound, made dry by elevation. They are covered with drift-soil. These grassy prairies are covered as thickly as possible with mounds, about three to four feet high, and thirty to forty feet diameter. There are probably millions of them. The general appearance is that of almost perfect regularity of size and shape. The soil of the mounds is a rather fine drift, with pebbles not larger than a pigeon's egg. The intervals between the mounds are strewed with larger pebbles. The mounds are occupied by ferns, the intervals only by grass. These treeless spaces are called 'mound prairies.'

There has been much speculation as to the origin of these remarkable mounds. Some suppose them to be burial mounds, and that we have here veritable cities of the dead; others, that they were raised as foundations for huts, on a wet soil; others, that they were made by a species of fish, when these spots were still the shallow bottom of the Sound---that they are huge fish-nests. No careful observer can for a moment entertain any of these views. The mounds have been frequently explored, and although from time to time there have been reports of relics having been found in them, the author feels quite confident that nothing has ever been found." Le Conte, the author here, ascribes the mounds to surface erosion. (R2)

The Mystery of the Mima Mounds. V.B. Scheffer coined this title for his classic 1947 paper. However, Scheffer did not actually consider the Mima Mounds a real mystery, for he was a strong proponent of the pocket gopher theory. Here is how he described these mounds.

"On the prairies of western Washington near the southern tip of Puget Sound are scattered thousands of large earth mounds whose origin has puzzled observers for more than a century. On Mima Prairie some of the mounds are higher than a man's head and have a content of 50 cubic yards. The mounds are smooth and round, like great spheres nearly buried in the earth. In many cases, the hollows between the mounds are filled with cobblestones up to the size of a football. In the spring of the year, when the mounds are covered with white-and-yellow daisies and green bracken ferns, they stand out clearly

from their duller surroundings.

Wherever a mound has been sliced open by a roadway, a peculiar cross section is revealed. The typical mound is made up of soft black prairie silt mixed with pebbles up to the size of a walnut. The mound rests in a slight depression, or bed, in coarse stratified glacial gravel, which continues downward for an unexplored distance. Thus, the typical mound is a biconvex lens, with the greater curvature exposed to the sky and the lesser curvature pressed against the gravel. At the base of the mound, armlike structures of black silt extend into the gravel. These have been called 'mound roots' by certain investigators.

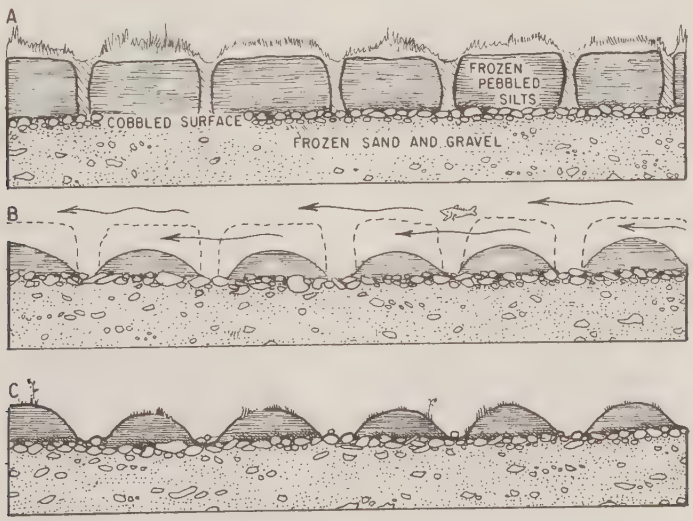
The origin of the mounds has long been disputed." (R26)

The Mima Mounds described by a proponent of periglacial origins. "Abstract. The Mima Mounds of southwestern Washington are from 10 to 70 feet in diameter and range from barely perceptible forms to 7 feet in height. The mounds are round or oval in plan and in cross-section commonly resemble a segment of a circle. They lie upon glacial outwash gravels are are composed of a structureless dark pebbly sand and silt; many contain ice-rafted erratics. The mounds are restricted to the outwash valleys of the Vashon glacial stage, and in this region nearly all the outwash valleys bear mounds. The mounds were probably formed from a partially thawed pebbly-silt mantle, possessing a polygonal-fissure ice network, and by running water, which removed the thawed material from around the hemispheroidal frozen cores of each polygon. Afterward, the frozen cores thawed in place and formed the Mima Mounds.

A mainly hexagonal pattern of fissure ice in a pebbly-silt mantle determined the mound spacing and is represented by most of the intermound space and by the remains of branching trenches in unmounded prairies. The mounds have strong curved alignment, rather regular spacing, and a common maximum height in any one mound field. Evidence for the erosion of a polygonal-fissure ice network in a pebbly silt mantle consists essentially of low mounds with wide intermound areas, mounds that lie upon pedestals of submound gravel, intermound cobbles that have been uncovered, parallel asymmetrical development of the mound surface with the steep side up-gradient, and parallel elongation of oval mounds. Many of the lowest prairie channels are lacking in mounds but possess, instead, a few widely separated bars of mound material." (R36)

X4. California. The California mounds are so diverse that a single origin seems doubtful.

The Merced-Mariposa area. "On the stage-road from Mariposa to Merced---a portion of the Yosemite Valley route---for a distance of twenty miles, the surface of the ground, as far as the eye can see, is singularly characterized.



Development of mounds according to the "frozen-ground" theory. (X3)

Circular elevations, like mammae, about two feet high and twenty feet in diameter, are divided by shallow ditches, or swales, about ten feet wide. These mounds are surprisingly symmetrical, and occupy the whole surface. Where the rising ground meets the sky, the outline is regularly scalloped. The freshets have in some places cut through to the depth of three feet, leaving the vertical section exposed to view.

All the stones contained in the mounds are rounded, and in size are from half an inch to four inches in diameter. None larger were seen. The bottoms of the dry water-courses are paved with these round stones to a considerable depth, the largest on top. For six inches in depth of the surface of the mounds the soil is free of stones; below that, the stones are distributed without much regard to size, the spectator being impressed with the apparent fact that the larger ones are nearer the surface.

Rising ground equally with level surface is covered by these mammae. In rare cases are two mounds thrown together, so as to interfere with the generally symmetrical arrangement." (R4)

The San Diego area. "In their most common type the mounds may be described as rounded eminences, or knolls, rising from one to four feet above the surrounding surface or the depressions between them, and ranging from ten to fifty feet in diameter. They are generally nearly circular and distinct, but are, in some instances, confluent or elongated. They are separated by wide and irregular areas or by narrow intervening depressions, the latter containing, in stony places, accumulations of cobblestones. They are confined to no geological structure or quality of soil, and are found on sloping lands, on the higher mesas and lower levels.

Any attempt at an explanation of their origin and the mode of their formation must be based upon the assumption that they are modern modifications of the earth's surface and are due to natural agencies; and evidences abound on every hand that the causes concerned in their production are still active in the formation of new and in the maintenance of the old ones; and hence in this vicinity they may be seen in all the stages of their growth, from small rudimentary cones to the fully developed knolls." (R5) The San Diego mounds often have, or can be shown to have had, shrubs growing on their tops. Wind action, therefore, is prominent in some theories of their origin. (WRC)

A.O. Kelly has added some pertinent observations about the San Diego mounds. "In San Diego County these mounds are found in all manner of places---on Otay Mesa at 200 feet elevation, in Otay Canyon on steep hillsides, in Ramona Valley at 1,500 feet, in Cuyamaca Valley at 4,000 feet, and in San Marcos Valley at 500 feet. Some of those in San Marcos Valley are elongated ripple marks and others are high mounds containing

Sketch of the San Diego mounds. (X4)

boulders as large as footballs, certainly never pushed up into mounds by pocket gophers." (R48)

Near Los Angeles. "West of the Los Angeles Municipal Airport there is an area of several hundred acres of giant mounds. These mounds are exactly like the small ones except that they are from 30 to 40 feet high and some four to five hundred feet in diameter. They may be seen to good advantage when approaching or leaving the airport by airliner. They resemble closely the so-called Drumlins of north-eastern America which are attributed to glacial action. These mounds are not old sand dunes, although they are only a few miles east of presently active sand dunes near Playa Del Rey." (R47) The author, A.O. Kelly, favors catastrophic marine flooding as the mode of origin for all such mounds.

X5. Argentina. The presence of Mima-type mounds in Argentina was mentioned briefly by J.C. Branner in 1905 (R10), but it has only been in recent years that more details have been available in English.

"The moundfield in the pampean grassland region are well-developed examples of Mima microrelief. Together with the observations of Pearson in Peru, this extends recognition of the Mima-mound phenomenon to a third continent and a fourth family of fossorial rodents. Based on geographical location and the inadequate taxonomy of the genus Ctenomys, the subspecies present on the pampean grassland sites is probably C. mendocinus puncti (= C. azarae), whereas the form on the monte sites is probably C. mendocinus mendocinus.

Because of the sandy soil at all of the mound sites, and because of the presence of clearly developed dune systems near many of the localities, these mounds have doubtless been regarded heretofore as dunes. However, they possess the symmetrical, domed form typical of Mima mounds, and occur only in sites where shallow soils overlie a basement layer that creates impeded drainage or severely limits the depth of rodent burrowing, an invariable characteristic of Mima mounds in North America and East Africa. Moreover, all mound areas examined showed extensive activity of ctenomyid rodents, centered on the mounds.

The mounds of the pampean region, compared to those so far examined in other regions of the world, are unique in size and spacing. Mounds over 3 m high occur at both the La Pampa and Rio Quinto sites; these considerably exceed in height, although not in diameter, Mima mounds in North America and Kenya, which are usually less than 2 m high. In addition, the pampean mounds are aggregated, rather than uniformly spaced, as in North America and Africa. The characteristics of Argentinian mounds may be related to unique features of the social system of ctenomyid rodents. Some Ctenomys species are colonial, whereas others are solitary and territorial. A tendency toward coloniality might, for example, be responsible for the aggregation and unusual heights of pampean mounds." (R46)

X6. Mexico. Only a passing comment has been found on the Mexican mounds.

"While writing upon this subject, I might add that last year I observed mounds exactly similar to those of the southern coastal plain region upon the Bavicora plain near the top of the Western Sierra Madre of Mexico at an altitude of nearly 7,000 feet. This plain, like the coast prairie, is an extensive flat upon which the rainfall stands for a considerable time after falling." (R16)

X7. South Africa. In Cape Colony, now the Republic of South Africa, unexplained mounds occur in several regions. Some seem to be of the Mima variety, but others clearly are not.

"In the colony the mounds may be seen in any sandy ground near the coast, covering the surface with bare patches; but the want of vegetation is due, I think, not to the nature of the soil, but to the baking of the surface, after it has been wetted by the rain, by the intense heat of the sun. Where a wheel has gone over one of the mounds and broken the hard crust, bushes spring immediately. In cultivated land the farmers aver that these hillocks are more productive than the rest of the soil, and Mr. Juritz, senior analyst of the colony, mentioned in his address to the British Association in Cape Town, that a leveling of these hillocks results in an increase of the fertility of the soil all round.

The most accessible place for seeing these mounds is on the lower slopes of the hills of Bokkeveld and Witteberg beds on the top of the Hex river pass, on the main line to Johannesburg; they appear as red splotches on the bush-covered slopes. The elevation here is only a few inches, and the diameter some 5 or 6

yards. In the Malmesbury district they occur on the flats below the hills, and are formed of light yellow argillaceous sand. Here they have usually a depression in the centre, which is often occupied by a clump of arum lilies, although the surrounding country is far too dry for these moisture-loving plants to exist.

After seeing these Malmesbury mounds I went into the Ceres Karroo, and at Hartnek's kloof found an actual spring bubbling up from sandy ground, and round each of the eyes there was a perfect circle of grass, raised a few inches above the general surface. I afterwards saw many of these sand fountains, and for a time my mind veered round to an aqueous origin for the hillocks.

East of Worcester, however, near the station Over Hex, there is a large tract of country under the Langebergen, covered by a fine yellow alluvium, not unlike loess in texture, and a great portion of this is occupied by gigantic hillocks some 8 to 12 feet high and some 10 yards in diameter. In places these are so closely packed that the bases mutually impinge; the angle of slope varies, but often is as acute as in a volcanic cone. There are many good sections of the mounds available along the railway here and in the road-cutting, but nowhere is there any internal structure visible; the whole substance of the hillock is the same throughout, and consists of fine argillaceous sand like the surface soil, without the least sign of vegetable or animal remains included in it. The soil becomes so hard where it is allowed to dry quickly after being moistened, that square blocks can be dug out and sun-baked, and can then be built into walls, where they will stand unprotected for many years.

In the red-sand country of Bushmanland the mounds also occur, and the substance of the hillock is more argillaceous than that of the surface soil; the bushes grow closely packed together on these spots, which are perfectly circular, although the rest of the ground is sparsely covered except after rain, when the grass grown." (R18)

X8. Alaska. The mounds in the Fairbanks area are attributed, by this author, to the deformation of the surface following the melting of a polygonal network of ice wedges.

"The Alaska mounds are in silts and fine sands. They vary in diameter from 10 to 30 feet and are 1 to 8 feet in height. These mounds are best developed in areas cleared for agriculture on the low slopes of the hills or on the flat-lying land between the hills and the Chena River floodplain. No mounds were noted on the floodplain." In comparing the Alaskan mounds with those on Washington's Mima prairie, T. L. Pewe remarked that both sets of mounds occasionally displayed polygonal shapes. Further, the so-called "mound roots", attributed by some to gopher activities, might well be created by small ice wedges. (R29)

Other Alaskan mounds, found offshore, may have a different origin. "Abstract. Contour maps with 0.5-m depth interval were prepared for a small area seaward of Reindeer Island, a barrier island in the Beaufort Sea, Alaska, by repeated surveys with very accurate navigation and very close trackline spacing. The maps reveal numerous closed depressions and mounds about 50 to 100 m in diameter and 2 to 3 m in relief, presumably related to grounded ice floes common in the area year round. Some of the features were obliterated over the course of three seasons while new ones formed. Although the depressions resemble kettles, they are formed by very different mechanisms. We believe that these bedforms represent erosion and deposition caused by: a) intensified flow around stationary ice floes serving as obstacles and b) pulsating currents generated by vertical oscillations or rocking motions of grounded floes in a seaway. Because sediment transport occurs around the ice, not where it directly touches the sea floor, the depressions are much larger that the base of the acting floes." (R61) One theory for the formation of the Carolina Bays (ETB1) invokes stranded icebergs. See also X14.

X9. The Rocky Mountain region.

Colorado. "Earth mounds in south-central Colorado occur in discrete clusters from 2377 m in the San Luis Valley to 3841 m on an alpine ridge in the Sangre de Cristo Mountains... The height of an earth mound increases with altitude and distances between mounds corresponding decrease. The largest earth mounds are located in the highest field; however, length and width values do not change systematically with elevation." (R49)

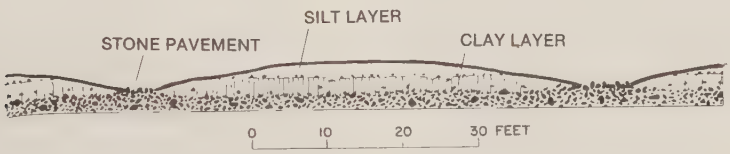
Another group of mounds is found farther east. "Abstract. On the coarse alluvium of the Rocky Flats pediment, randomly spaced mounds of sorted gravel occur upon a pavement of cobbles and small boulders. The mounds are elliptical in plan view and sym-

metrical in cross section. Average length is 42 feet, average width 38 feet and average height at the center is 9.6 inches. Mound form, sorting of gravel and subsidence of the pavement beneath the mounds are attributed to the tunneling activity of pocket gophers. Stresses of a brief period of saturated soil during spring snowmelt stimulate mound construction by the gophers. Territorial behavior of the gopher is responsible for the mound pattern and size limits. (R59)

Idaho. On the Snake River Plain large soil mounds are associated with other types of patterned ground. "The mounds lie closely packed and are monotonously uniform in size, shape, and spacing. They usually stand alone, with their centers from 60 to 85 feet apart. A typical mound is circular, from 50 to 60 feet across, and has a convex upper surface that rises to a height of 3 feet. Flat surfaces on mounds are rare. In rocky areas stone pavement outlines mounds, but in non-rocky terrain the mounds are set off only by a surrounding graded surface, above which they rise as bumps." The material within the mounds is divided into two layers: a lens-shaped cap, about 18 inches thick, consisting of silt, clay, and a few small stones; and a layer of brown clay, 1 to 2 feet thick, with a strong prismatic structure." (R58) Although burrowing animals live in the region, these mounds are considered a type of patterned ground. (WRC)

X10. Peru. O.P. Pearson has provided a description (and an impressive photograph) of a field of mounds near Ninacaca.

"At the northern end of Lake Junin, Department of Pasco, Peru, between 13,500 and 14,000 feet elevation, there is an extensive series of first-class mima mounds, as good as any I have seen in California. Some of the series cover well over a square mile. The first one that I investigated was on an appreciable slope with fairly evenly spaced mounds, varying from 5 to 12 yards apart and 1 to 2 feet high. I camped overnight in the middle of another series of mounds that were slightly larger, but not over 2 feet high, and seemed to be spaced farther apart. Some of the mound systems are on gentle slopes and some on flat pampa. The vegetation is very short, dry grass and low herbs---nothing higher than 3 inches. The country is grazed by livestock. The mounds seem to have a higher concentration of stones in them than do the surrounding flats. In road cuts, every place a mound system is dissected I saw about 10 inches of stony topsoil underlain sharply by a very stony foundation. The foundation is mostly rounded stones with just enough dirt to fill the interstices. No place had mounds that did not show this layering. A few places had layering but no mounds, and between Tinyahuaroo and Huallay was a large pampa with layering and just a trace of mima mounding." (R40)



Section of a large soil mound on the Snake River plain, Idaho. (X9)

Wyoming. An aerial photograph appearing in R40 shows hundreds of pimple mounds 20 miles southwest of Laramie. Gophers and prairie dogs do live in this area. (R40)

A.O. Kelly provides a photograph of pimple mounds taken from Highway 80, a few miles east of Cheyenne. Examination of a cutbank showed coarse river sand with an occasional pebble of pea gravel size. (R48)

X11. Virginia. Except for the mounds described below, all U.S. mounds are located west of the Mississippi, according to data presently at hand.

Parramore Island is a very low offshore island off the Virginia coast. Isolated and privately owned, visits are difficult. "The

mounds of Parramore Island have major features in common, but no general description will suffice. Variety, however, seems to be primarily in size. Aerial photographs have established that the mounds are concentrated in the central five-mile section of the island, where they occur from the beach inland for not more than three-quarters of a mile and occupy about 25 percent to about 75 percent of the area. From the ground they are seen to occupy closer to 25 percent, since vegetation exaggerates the area on the aerial photographs.

The pattern of occurrence appears to be oriented to the pond and marsh inland and to be at a variance with the present beachline. The overall pattern suggests an original orientation to a former beachline now destroyed by migration of the beach. There is a definite arrangement of largest features on the lagoon side and more numerous, but much smaller, mounds adjacent to, and apparently extending into, the surf.

Aerial photographs show that the mounds have a well-defined circular shape except where two or more have coalesced. With few exceptions they have a white, sandy, more or less barren center, often depressed but usually appearing as the high point. This center may be crudely outlined by trees or shrubs that considerably overtop the adjacent vegetation.... On the Wachapreague Quadrangle many mounds in the area under discussion rise to the ten-foot contour, but none reach fifteen feet. Examination of a number of mounds in the field has substantiated this low range in relative relief, though no height measurements were taken." The largest single mound was 500 feet in diameter. (R41) The author suggested that the mounds might be the consequence of differential loading; that is, they were squeezed up due to forces acting upon the plastic sediments!

X12. Kenya. In Kenya, East Africa, mounds up to 6 m in diameter and 1.5 m in height have been described at elevations of 1,950-3,600 m on Mt. Kenya, and the occupation and possible formation of some of these mounds by fossorial rodents mentioned. We have recently observed such mounds in several grassland areas at elevations of 2,250-2,440 m on Mt. Kenya, in the Aberdare Mountains, and along the eastern edge of the Mau Escarpment; in July 1981 we studied in detail two such areas near Nyahururu, Kenya, in the Aberdare highlands. All of these localities lie at elevations above those at which species of fungus-gardening termites (genera Macrotermes and Odontotermes), which are definitely known to produce large mounds, have been reported. All lie within the geographical and altitudinal range of the rhizomyid mole rat, Tachyoryctes splendens (Ruppell), a rodent convergent in morphology and behavior with pocket gophers.

The site examined in greatest detail, a fenced pasture 1.3 km E. Nyahururu, elev. 2,375 m, exhibited nearly circular mounds up to 2.0 m high and 17.8 m in diameter; the mean density of the mounds was 30.5 per ha. Analysis of distance-to-nearest-neighbor relationships gave a dispersion index, R, of 1.22, indicating a significant tendency toward uniform spacing of mounds. The mounds were underlain by a horizontal laterite rock hardpan that varied in depth from a mean of 38.6 cm at mound edges to a mean of 24.6 cm at the centers of intermound basins. At the second site, 24 km S. Nyahururu, this hardpan was exposed in roadcuts. It lay at a depth of 45 cm in locations between widely separated mounds, and was about 16 cm thick." Mole rats were present at both sites. (R45)

X13. Arizona. A.O. Kelly has photographed Mima-like mounds in two Arizona localities. (1) In the White Mountains, on a lava plateau about 8,000 feet elevation. (2) The Seligman Valley, near Ash Fork. This is a high desert area at about 4,500 feet. (R48)

X14. Floor of the Beaufort Sea. "Another area of large mounds in a far different climate is reported from the Beaufort Sea on the continental shelf off the mouth of the MacKenzie River, where mounds were discovered by scientists on a Canadian ice breaker in 1971: 'Unexpectedly, this detailed survey revealed a large number of undersea mounds interrupting an otherwise smooth sea bottom. As far as could be inferred from detailed topographic examinations by means of launches, the mounds are generally irregular and asymmetric in form and one side steeper than the other. The diameter of the bases averaged 400 meters and the elevation from base to peak, 30 meters. In most cases a shallow moat or depression surrounded each feature.'" Similar underwater mounds have been reported in Chesapeake Bay and off the Florida coast. No details available on these. (R48) See also X8.

X15. Mounds in sedimentary strata. Many inclusions in strata as well as stratigraphic convolutions have been reported (ES), but mounds, such as seen on the Mima Prairie, do not seem to have been preserved in the stratigraphic record. However, one case of small carbonate mounds has been found.

"Carbonate mounds are a conspicuous sedimentary feature in a number of Lower Ordovician stratigraphic horizons present in the Franklin Mountains of west Texas.... The size of the mounds varies markedly. Mostly they are rather small sedimentary features usually about 3-5 feet in length and about 2-5 feet in height. Lechuguilla Mound, the largest mound encountered to date, is approximately 45 feet long and 19 feet high, and is the primary subject of this paper. Some of the larger mounds may contain conspicuous channels filled with coarse calcarentic debris; this channel-fill is sometimes cross-bedded. The mounds are massive non-bedded muddy carbonates containing a distinctive biota, and enclosed and surrounded by thinner well-bedded carbonate units containing much elastic skeletal debris." (R50) Similar mounds occur in other strata.

References

R1. Riddell, J.L.; "Hog Wallow Prairies," American Journal of Science, 1:39:211, 1840. (X2)

R2. LeConte, Joseph; "Prairie Mounds," California Academy of Sciences, Proceedings, 5:219, 1873. (X3)

R3. LeConte, Joseph; "Hog Wallows or Prairie Mounds," Nature, 15:530, 1877. (X1)

R4. Mead, S.H.; "Curious Mounds in California," Popular Science Monthly, 14: 233. 1878. (X4)

R5. Barnes, G.W.; "The Hillocks or Mound-Formations of San Diego," American Naturalist, 13:565, 1879. (X4)

R6. Blankinship, J.W.; "Peculiar Earth-Heaps in Missouri," American Antiquarian, 11:117, 1889. (X2)

R7. Rogers, G.O.; "Drift Mounds near Olympia, Washington," American Geologist, 11: 393, 1893. (X3)

R8. Turner, Henry W.; "Further Contributions to the Geology of the Sierra Nevada," U.S. Geological Survey Seventeenth Annual Report, 1895-1896, part 1, p. 521. (X4)

R9. "Pimpled Prairies of Southwest Louisiana," Science, 4:163, 1896. (X2)

R10. Branner, J.C.; "Natural Mounds or Hog-Wallows," Science, 21:514, 1905. (X4, X5)

R11. Hilgard, F.W.; "The Prairie Mounds of Louisiana," Science, 21:551, 1905. (X2-X4)

R12. Spillman, W.J.; "Natural Mounds," Science, 21:632, 1905. (X2)

R13. Purdue, A.H.; "Concerning Natural Mounds," Science, 21:823, 1905. (X2)

R14. Bushnell, D.I., Jr.; "The Small Mounds of the United States," Science, 22:712, 1905. (X2)

R15. Veatch, A.C.; "On the Human Origin of the Small Mounds of the Lower Mississippi Valley and Texas," Science, 23:34, 1906. (X2)

R16. Hill, Robt. T.; "On the Origin of the Small Mounds of the Lower Mississippi Valley and Texas," Science, 23:704, 1906. (X2, X6)

R17. Campbell, Marius R.; "Natural Mounds," Journal of Geology, 14:708, 1906. (X1)

R18. Schwartz, Ernest H.L.; "Natural Mounds in Cape Colony," Geographical Journal, 27: 67, 1906. (X7)

R19. Melton, F.A.; "Unusual Aerial Photographs from Southwestern Arkansas," Geological Society of America, Bulletin, 39:205, 1928. (X2)

R20. Melton, Frank A.; "'Natural Mounds' of Northeastern Texas, Southern Arkansas, and Northern Louisiana," Oklahoma Academy of Science, Proceedings, 9:119, 1929. (X2)

R21. Rich, John L.; "Soil Mottlings and Mounds in Northeastern Texas as Seen from the Air," Geographical Review, 24: 576, 1934. (X2)

R22. Melton, Frank A.; "Vegetation and Soil Mounds," Geographical Review, 25:431, 1935. (X1)

R23. Bryan, Kirk; "Soils and Periglacial Phenomena in the Carolinas," Science, 91:523, 1940. (X2)

R24. Dalquest, Walter W., and Scheffer, Victor B.; "The Origin of the Mima Mounds of Western Washington," Journal of Geology, 50:68, 1942. (X3)

R25. Dietz, Robert S.; "The Small Mounds of the Gulf Coastal Plain," Science, 102: 596, 1945. (X2)

R26. Scheffer, Victor B.; "The Mystery of the Mima Mounds," Scientific Monthly, 65:283, 1947. (X3)

R27. Kelly, Allan O., and Arkley, Rodney J.; "The Mima Mounds," Scientific Monthly, 66:174, 1948. (X3, X4)

R28. Stallings, J.H.; "The Mima Mounds," Scientific Monthly, 66:269, 1948. (X1)

R29. Pewe, Troy L.; "Origin of the Mima Mounds," Scientific Monthly, 66:293,

1948. (X8)
R30. Koons, Frederick C.; "The Sand Mounds of Louisiana and Texas," Scientific Monthly, 66:297, 1948. (X2)
R31. Whitney, Dudley J.; "San Joaquin Valley Hog Wallows," Scientific Monthly, 66:356, 1948. (X4)
R32. Krinitzsky, E.L.; "Origin of Pimple Mounds," American Journal of Science, 247:706, 1949. (X1)
R33. Price, W. Armstrong; "Origin of Pimple Mounds, by E.L. Krinitzsky," American Journal of Science, 248:355, 1950. (X1)
R34. Knechtel, Maxwell M.; "Pimpled Plains of Eastern Oklahoma," Geological Society of America, Bulletin, 63:689, 1952. (X2)
R35. Newcomb, R.C.; "On the Origin of the Mima Mounds, Thurston County Region, Washington," Journal of Geology, 60: 461, 1952. (X3)
R36. Ritchie, Arthur M.; "The Erosional Origin of the Mima Mounds of Southwest Washington," Journal of Geology, 61:41, 1953. (X3)
R37. Arkley, Rodney J., and Brown, Herrick C.; "The Origin of Mima Mound (Hogwallow) Microrelief in the Far Western States," Soil Science Society of America, Proceedings, 18:195, 1954. (X4)
R38. Hult, Ruby E.; "A Million Mysterious Mounds," American Mercury, 80:55, February 1955. (X1)
R39. Jackson, Howard E.; "The Mystery of the Mima Mounds," Natural History, 65: 136, March 1956. (X3)
R40. Scheffer, Victor B.; "Do Fossorial Rodents Originate Mima-Type Microrelief?" American Midland Naturalist, 59: 505, 1958. (X9, X10)
R41. Cross, Clark I.; "The Parramore Island Mounds of Virginia," Geographical Review, 54:502, 1964. (X2, X11)
R42. Scheffer, Victor B., and Kruckeberg, Arthur; "The Mima Mounds," BioScience, 16:800, 1966. (X3)
R43. Aten, Lawrence E., and Bollich, Charles N.; "Archeological Evidence for Pimple (Prairie) Mound Genesis," Science, 213:1375, 1981. (X2)
R44. Cox, George W.; "Mounds of Mystery," Natural History, 93:36, June 1984. (X12)
R45. Cox, George W., and Gakahu, Christopher G.; "The Formation of Mima Mounds in the Kenya Highlands: A Test of the Dalquest-Scheffer Hypothesis," Journal of Mammalogy, 65:149, 1984. (X12)
R46. Cox, George W., and Roig, Virgilio G.; "Argentinian Mima Mounds Occupied by Ctenomyid Rodents," Journal of Mammalogy, 67:428, 1986. (X5)
R47. Kelly, Allan O., and Dachille, Frank; "The Waters Mould the Earth," Target: Earth, Carlsbad, 1953, p. 146. (X4)
R48. Kelly, Allan O.; Impact Geology, Encinitas, 1985, various pages. (X4, X9, X10, X13, X14)
R49. Vitek, John D.; "Morphology and Pattern of Earth Mounds in South-Central Colorado," Arctic and Alpine Research, 10:701, 1978. (X9)
R50. Toomey, Donald Francis; "An Unhurried Look at a Lower Ordovician Mound Horizon, Southern Franklin Mountains, West Texas," Journal of Sedimentary Petrology, 40:1318, 1970. (X15)
R51. Wallace, Alfred R.; "Glacial Drift in California," Nature, 15:274, 1877. (X4)
R52. Meigs, M.C.; "The Stone Pile Meadow, Washington Territory," Scientific American, 53:98, 1885. (X1)
R53. Holder, C.F.; "Constructive Ability of Fishes," Scientific American, 53:215, 1885. (X1)
R54. Branner, John C.; "Decomposition of Rocks in Brazil," Geological Society of America, Bulletin, 7:255, 1896. (X1)
R55. Veatch, A.C.; "The Question of the Origin of the Natural Mounds of Louisiana," Science, 21:350, 1905. (X2)
R56. Farnsworth, P.J.; "On the Origin of the Small Mounds of the Lower Mississippi Valley and Texas," Science, 23:583, 1906. (X2)
R57. Udden, J.A.; "The Origin of the Small Sand Mounds in the Gulf Coast Country," Science, 23:849, 1906. (X2)
R58. Malde, Harold E.; "Patterned Ground in the Western Snake River Plain, Idaho, and Its Possible Cold-Climate Origin," Geological Society of America, Bulletin, 75:191, 1964. (X9)
R59. Murray, David F.; "Gravel Mounds at Rocky Flats, Colorado," Mountain Geology, 4:99, 1967. (X9)
R60. Cloud, Preston, et al; "The Works of Living Social Insects as Pseudofossils and the Age of the Oldest Known Metazoa," Science, 210:1013, 1980. (X1)
R61. Reimnitz, Erk, and Kempema, Edward; "Dynamic Ice-Wallow Relief of Northern Alaska's Nearshore," Journal of Sedimentary Petrology, 52:451, 1982. (X8)

ETM2 Mounds in Gilgai Country

Description. A variation of gilgai soils in which mounds are the predominant topographical expression. Most gilgai soils exhibit circular and rectangular depressions, as described in ETB4. Australia possesses large tracts of gilgai country.

Data Evaluation. Several of the articles employed in preparing ETB4 mention mound-type gilgai soils as "special cases." As was the case in ETB4, geologists and soil scientists, especially in Australia, have carefully documented gilgai phenomena. Rating: 1.

Anomaly Evaluation. The precise mechanism by which gilgaies are created is obscure, even though they are observed forming today. It is also not clear why some areas are affected while, nearby, equally likely tracts are not. Nevertheless, no important geological principles are at risk here. Rating: 3.

Possible Explanations. Cycles of wetting and drying are thought to be the primary mechanism leading to gilgai formation. The soil where gilgaies occur develops deep cracks when dried, and this characteristic probably contributes to gilgai creation.

Similar and Related Phenomena. Gilgai topography where depressions predominate (ETB4); Mima Mound topography (ETM1); patterned ground (ETP1); the polygonal cracking of soils (ETP3); anthropogenic artifacts, such as the South America ridged fields and some mining operations.

Examples

X1. Mushroom gilgai. "A variation of the normal or round gilgai (See ETB4) is found where the puffs are raised above an otherwise level surface, the shelves being flat and continuous. The diameter of the puffs ranges from 2 to 6 feet. and their surface structure is strongly granular or gunshot and 'puffy'. These have been termed 'mushroom gilgai'. (R2)

X2. Melon-hole gilgai. "These occur under high rainfalls on the north coast of New South Wales, extending along the Richmond and Tweed rivers. The complex consists of large mounds and depressions in the centre of which are holes of varying shapes. These holes are from 3-9 feet wide, 6-9 inches deep, and the break in the level from the depression to the hole is quite abrupt. The mounds may show abrupt subsidiary hummocks 3-6 inches high and 12-18 inches wide. They show some resemblance to the normal gilgai, but with large, abrupt sinkholes, whilst the mound is compact and massive and shows none of the crumb structure and puffy character of the normal form." (R2; R1)

References

R1. "'Gilgai' Country in New South Wales," Geographical Journal, 41:288, 1913. (X2)

R2. Hallsworth, E.G., et al; "Studies in Pedogenesis in New South Wales," Journal of Soil Science, 6:1, 1955. (X1, X2)

R3. Crook, Keith A.W.; "'Finger-Print' Pattern on Certain Calcareous Soils--- A Suggestion," American Association of Petroleum Geologists, Bulletin, 42:3001, 1958. (X1)

ETM3 Mudlumps and Mud Islands

Description. Huge masses of mud and other sediments that rise to the surface from the bottoms of river deltas, offshore banks, and swampy regions. Mudlumps and mud islands may occupy several acres and stand as high as 25 feet above water or land level. Mudlumps and mud islands often discharge copious quantities of gas and salt water. Those structures appearing in deltas and offshore are soon eroded by currents and tides.

Data Evaluation. Although the literature is not extensive, both mudlumps and mud islands are well-observed phenomena. Rating: 1.

Anomaly Evaluation. Mudlumps and mud islands are thought to be extruded from plastic sediments under the influence of tectonic forces and/or subterranean gas pressures. The lumps, rendered buoyant by contained gases float to the surface. This scenario is attractive, but it is not supported by direct observation. Even if this theory is not completely accurate, no important geological laws are at risk. Mudlumps and mud islands belong more to the category of curiosities rather than anomalies. Rating: 4.

Possible Explanations. See above.

Similar and Related Phenomena. The Virginia "Mima mounds", which may also be extrusions (ETM1-X11); salt diapirs (ES).

Examples

X1. Mississippi delta mudlumps. "In a recent 'Professional Paper' of the United States Geological Survey (No. 85 B) E.W. Shaw gives an account of the remarkable clay formations which occur at the mouths of the Mississippi, and are locally designated 'mud-lumps.' Such an immense amount of material is brought down annually by the Mississippi, and deposited at its mouths, that land is built out at an estimated rate of three hundred feet per annum, and, consequently, the channels, islands, and bars are constantly changing their positions. The mud-lumps, however, differ from the usual delta deposits in a number of ways. They occur some distance off the shore, near the submarine bars at the various 'passes' through the delta, and form islands up to an acre in extent. They rise in a few weeks to a maximum height of from two to eight feet above sea-level, and at first are elliptical in shape, but soon become irregular, owing to erosion by tide and river action. After attaining their maximum height, they become quiescent, and finally disappear as the result of being worn down by the water. Sometimes they appear to subside in much the same manner as they rise.

The central core of the 'lumps' is composed of a sticky bluish-grey clay, very fine-grained, and containing little of the coarser delta deposits. Surrounding this are various beds of sand and silt, which have been thrust up in an anticlinal fashion by the rise of the core. The whole is very much fissured and faulted, but the clay itself is structureless, and contains practically no organic remains. Apparently connected with the fissures are numerous active mud-springs, which discharge salt, 'sludge,' and gas. The gas is mainly methane, with subordinate amounts of nitrogen, oxygen, and carbon dioxide, and seems to be formed by the decomposition of organic matter.

Various theories have been put forward to account for their origin. They cannot be 'uplifted by subterranean gas, as borings have failed to reveal any gas reservoirs, while their uniform height and occurrence only at the ends of the 'passes' also militate against such an origin. The most probable explanation is that they are due to the seaward flow of a semi-fluid clay under the shallow water near the ends of the passes, and that this flow is caused by the pressure of the sediments deposited by the river, the upward buckling being due to the resistance offered by the so-called 'foreset' beds, which are comparitively thick deposits of coarse sandy material just off the shore." (R4)

A more recent study of the delta mudlumps mentions that they may rise from depths of 300-500 feet and form islands 30 acres in extent. (R5)

X2. Mudlump-like structures upriver. Unusual mounds well upriver from the Mississippi delta may be related to the delta's mudlumps.

"While attached to a Coast Survey party working on the Mississippi river, I was informed that there were three 'Indian mounds' back in the edge of the swamp; on examination they proved to be 'mud lumps,' but of a shape and material different from those at the mouth of the river. I have looked over various works on geology, but can find no notice of any of these elevations so far above the river mouth, and no very satisfactory explanation of the manner in which they are formed or of the forces forming them. The mounds above spoken of are on the left bank of the river, on the place of Mr. Louis Le Bourgeois, fifty-five miles above New Or-

leans, they are about one and a half miles back from the river and just in the edge of the swamp. The largest one is 40 feet in height and 144 feet in diameter, conical in shape with no signs of a crater. 300 yards N. x E. from it is a smaller one, 15 feet in height and 80 feet in diameter. 250 yards E.N.E. is another, not more than 5 feet in height and 20 feet in diameter. Formerly the large mound was entirely surrounded by a circle of these small elevations, but they have been leveled during the process of cultivation. The surface soil around the mounds is the usual black alluvium of the valley.

Mr. Ogden, U.S. Navy, and myself cut into the large mound from the top to a depth of 18.5 feet, and found as follows: There were less than two inches of vegetable mold, and the remainder of the excavation was cut through a hard orange sand; it was so hard that the pick had to be used continuously; single valves of shells, apparently Corbula, were abundant as far down as we went; to a depth of ten feet the shells were mostly soft and calcareous, below that they were all silicified; limestone concretions were very abundant, though generally small; six feet below the surface there was a layer or bed of these shells, with the valves separate; this bed was three feet wide and long, and about three inches thick, and immediately underneath it the sand was black; in some cases rough concretions were attached to the shells.....

At Southwest Pass there is a mound, or elevated area, called a 'salt mound,' from the well of salt water in the center. The pilots told me that when these lumps, or areas, are thrown up, there are, at first, salt wells on them; the wells are very deep and boil up, apparently from escaping gas; ultimately the wells fill up and disappear. There are frequent vibrations, and horizontal and vertical movements of the land in the passes. One of the lumps in Southwest Pass there is a well discharging an inflammable gas." (R1) The final paragraph refers, of course, to the delta mudlumps at the river passes.

X3. A Trinidad mud island. This structure resembles closely the Mississippi mudlumps.

"Abstract. In August, 1964, a new mud island appeared above the sea about 1½ miles offshore from Chatham on the south coast of Trinidad. It rose to a maximum height of approximately 25 feet above mean sealevel and had an original area of about 10½ acres at low tide. It lay close to the axis of the Southern anticline, a tectonic feature that shows well-marked mud-volcano activity on the adjacent island.

The mass of the island was composed of silty clay containing numerous boulders that ranged from a few inches to 2½ feet in diameter. The components ranged in age from Late Cretaceous to Miocene but it is considered probable that all those older than Miocene were derived from rubble beds of that age associated with the Southern Range anticline.

Extrusion of soft mud took place during the first 2 days, apparently beginning from the east and extending along a line trending NNW-SSE. Growth ceased in a few days and compaction and erosion followed until the island disappeared below sea-level 8 months later.

The main force causing the extrusion of the mud and the formation of the island could have been tectonic, the result of gas pressure, or a combination of both. Although gas was given off in quantity, the lack of evidence for the high pressures necessary to extrude the estimated 9 million cubic feet of material leads the writers to believe that tectonic movement was the principal reason for the phenomenon." (R6) See ETM6-X1 for a similar phenomenon occurring near Trinidad.

References

R1. Simons, M.H.; "'Mud Lumps' and Mounds near New Orleans," American Naturalist, 16:418, 1882. (X1, X2)

R2. "The 'Mud-Lumps' of the Mississippi Delta," Geographical Journal, 44:318, 1914. (X1)

R3. Shaw, Eugene Wesley; "The Mud Lumps at the Mouths of the Mississippi," American Journal of Science, 4:37:356, 1914. (X1)

R4. Scott, A.; "Mud-Lumps," Knowledge, 12:19, 1915. (X1)

R5. Morgan, James P.; "Mudlumps at the Mouths of the Mississippi River," Geological Society of America, Bulletin, 63:1282, 1952. (X1)

R6. Higgins, G.E., and Saunders, J.B.; "Report on the 1964 Chatham Mud Island, Erin Bay, Trinidad, West Indies, "American Association of Petroleum Geologists, Bulletin, 51:55, 1967. (X3)

ETM4 Drumlin Anomalies

Description. Drumlin features that are difficult-to-explain using the currently ascendant theory of glacial abrasion and accretion. Such anomalous features, listed in X2 and X3, include the occurrence of bedrock and drift drumlins in the same fields and the association of drumlins and giant ripple marks.

Data Evaluation. Drumlins have been mapped and excavated by geologists for over a century. The drumlins we know well, however, are usually located in immense and justly famous fields of drumlins. Isolated drumlins may be very common, too, but unrecognized. Rating: 1.

Anomaly Evaluation. Drumlins have long been proclaimed to be the products of glacial sculpturing. In fact, drumlins are often held up as "proofs" of ice-sheet action. Yet, prominent glaciologists freely admit that drumlins are most difficult-to-explain. It is certainly hard to imagine awesome masses of moving ice both carving bedrock drumlins and deftly shaping drift drumlins, with nearly the same shapes, in the same drumlin fields. The other drumlin anomalies just make these tear-drop-shaped features all the more perplexing. Rating: **2.**

Possible Explanations. The favored theory of glacial action (employing abrasion and accretion) has been modified by several geologists. Variations in pore water pressure and the injection of drift material from below have been suggested. In some ways, drumlins "seem" to be water- rather than ice-sculpted; could they be the result of sheet-flooding?

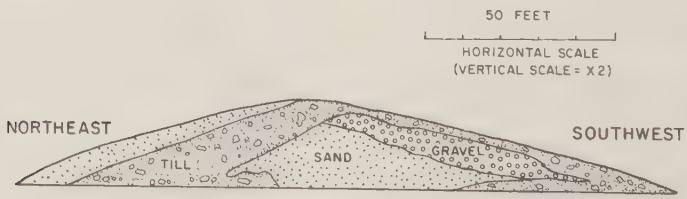
Similar and Related Phenomena. Eskers (ETR2); potholes (ETB2); anomalous sandhills (ETM7); pingos (ETM10).

Examples

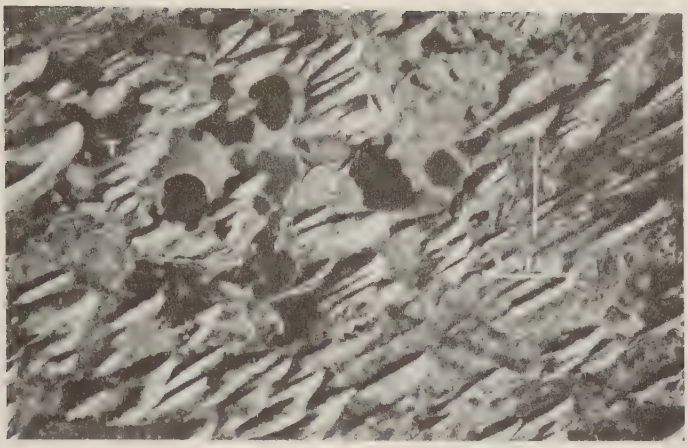
X1. General observations. First an encyclopedia description that gives little hint that drumlins might be anomalous.

Drumlin. "A hill of glacial drift or bedrock having a half-ellipsoidal streamline form like the inverted bowl of a spoon, with its long axis paralleling the direction of movement of the glacier that fashioned it. The 'upstream' end is higher and steeper than the tail, which tapers in the 'downstream' direction. Most drumlins are 5-50m high, 400-600m wide. Drumlins grade from 100% bedrock, through individuals consisting of a bedrock core covered with till, into 100% drift, without change in the typical streamline form. They are made by glacial abrasion, glacial accretion (a plastering-on process), or both. In the mainly accretional forms the constituent till is rich in clay. Drumlins occur in families or in larger fields." (R2)

Some amplification by R. F. Flint. "Drumlins are widely distributed in both North America and Europe and, though conspicuous forms constitute rather distinct fields, less ideally shaped drumlins are present in intervening districts where they have escaped attention. Among the conspicuous fields in North America are those in central-western New York (about 10,000 drumlins), east-central Wisconsin (about 5000), south-central New England (about 3000, many of which consist of rock), and southwestern Nova Scotia (2300). Large groups of remarkably long narrow forms occur in various parts of the Great Plains in Canada and northern United States. Some are chiefly bedrock; others chiefly drift. Possibly such forms outnumber 'conventional' drumlins.



Cross section of a typical drumlin. (X1)



Drumlin field near Snare Lake, Saskatchewan. (D.E. Cox and Canadian Government) (X1)

.....

'Ideal' drumlins constitute a standard from which individual units depart widely. Proportions range from nearly circular to a length/width ratio of 50:1. Single isolated forms are rare; usually drumlins occur in groups of scores, hundreds, or even thousands, each group constituting a distinct field. In some places adjacent drumlins are separated from each other only indistinctly. They form 'double or triple ridges united at the steeper end with the tails only distinct; doublets en echelon, the tail of one rising from the flank of the other as an inclined terrace or shelf; small drumlins plastered on the side of larger ones, giving a grooving effect to the flanks of the latter; two-tiered drumlins...' Despite these variations, however, long axes still parallel the direction of flow. This is strikingly evident where radial flow occurred in the terminal part of a glacier lobe." (R1)

Conditions which must be satisfied by any theory of drumlins. In 1953, C.P. Gravenor set down ten drumlin characteristics which must be explained. I.J. Smalley and D.J. Unwin summarized these as follows, adding an eleventh of their own:

"1. Drumlins may consist of a variety of materials.

2. They may have layers of stratified materials which may be faulted or folded.

3. Rock and till drumlins have the same shapes and occur in the same fields.

4. Many glaciated areas do not have drumlins.

5. They occur in fields which are wider than most moraines and they rarely occur singly.

6. They have a streamlined shape with the blunt end pointing upstream.

7. Lamination may be present.

8. Some drumlins may have cores but most do not.

9. Drumlins are found behind end moraines.

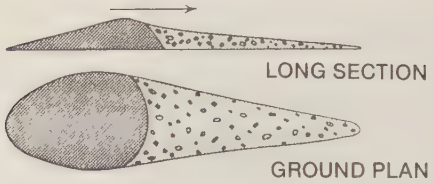
10. They are aligned parallel to the ice-flow direction.

11. They are formed beneath temperate glaciers." (R8)

A recent assessment of drumlin theory. "Drumlins remain a major problem in glacial geomorphology such that no satisfactory explanation to their mode of origin exists." (R3) Compare this statement with the encyclopedia "explanation" above. Indeed, geology textbooks usually treat drumlins as well-explained. (WRC)

X2. Drumlin associations with other geological features.

Shallow parallel grooves. "Abstract. Remarkably straight and parallel ridges, which are interpreted to be an elongated type of drumlin, trend southeasterly across an area of ground moraine in the vicinity of Velva in north-central North Dakota. The drumlins are paralleled by shallow grooves in the intervening



Some drumlins contain a rocky crag followed by a tail of drift. (X1)

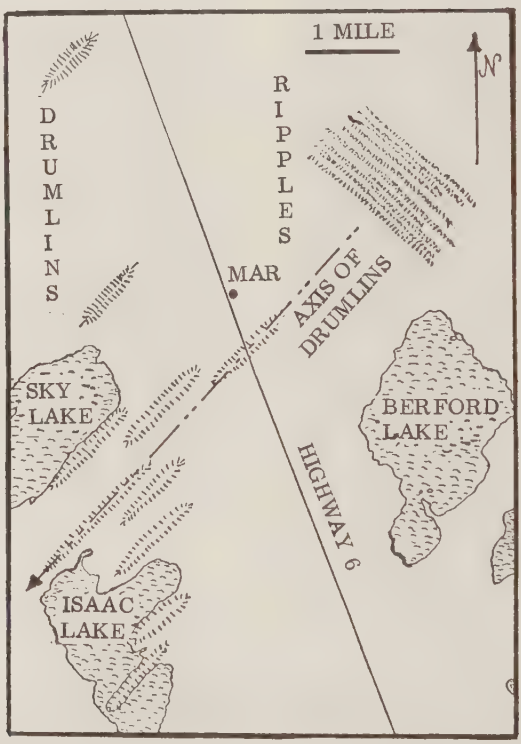
ground moraine; arcuate recessional washboard moraines lie transverse to them. The drumlins are commonly 1 to 3 miles long, 5 to 15 feet high, and have even crestlines. The longest, however, is 13½ miles long and 15 to 30 feet high. The higher and wider drumlins consist mostly of stratified sand and incorporated bodies of till; those less than 5 feet high consist almost entirely of till." (R7) The "giant ripple marks" described below resemble the "washboard moraine" transverse to the above linear drumlins. (WRC)

Giant ripple marks. "On the Bruce Peninsula in Ontario, a pattern of linear ridges is evident, which is a striking feature on topographic maps and aerial photographs. The ridges resemble giant ripple marks trending transverse to the axes of drumlins on the Bruce Peninsula.

A series of these ridges and troughs occurs northeast of the group of drumlins near Sky Lake, and exposures can be seen along highway 6 about 2 miles north of the village of Mar. The ridges are sinusoidal in section, crests are 12 to 20 feet in height, and the spacing between crests is about 250 feet." (R4) The significance here is that ripples are generally indicative of flowing water rather than ice. (WRC)

Terrain slope. "One of the most curious facts about patterns of drumlins is the uphill orientation in many areas, that shows flow of currents over hills, escarpments, and from out of the sea.

In north central New York the direction of flow was from out of the region of Lake On-



Map showing the relationship of drumlins and large ripples on the Bruce Peninsula, Ontario. (After D.E. Cox) (X2)

tario, uphill towards the Allegheny highlands to the south.

A group of drumlins east of Owen Sound, Ontario, shows that flow was from out of Georgian Bay, uphill towards the Niagara Escarpment. A fan shaped pattern of drumlins south of Green Bay, Wisconsin, shows a similar uphill flow." (R4)

X3. Drumlin features incompatible with theory. As stated in X1, glacial theory says that drumlins were formed by ice action involving abrasion, accretion, or both. But some drumlin characteristics are antagonistic to such a simplistic theory.

"1. Drift and bedrock would be eroded differently by an ice sheet, yet drumlins of both types may occur in the same drumlin fields, having similar form and orientation.

2. Cross stratified sand and gravel in drumlins is believed to have been deposited during the melting of the ice sheet, but if this were so, the ice sheet would no longer be available to shape the surface of the drift into drumlins.

3. The pattern of stratification in the sand and gravel in many drumlins has not been disturbed by the weight of a vast ice sheet scraping over it.

4. The direction of orientation of drumlins in some regions shows that the direction of flow was uphill. This is explained in the glacial theory as due to the greater thickness of ice at the rear, causing a lateral thrust of the ice sheet. But the drumlins at higher levels are more intricately streamlined and show a faster rate of flow, which could not occur if the ice sheet was being pushed against gravity.

5. Rock basins occur in some drumlinized areas, such as the Finger Lakes of New York. The excavation of deep rock basins probably could not be accomplished by ice erosion, and the concept is inconsistent with the ice simultaneously flowing over the drift without disturbing the patterns of stratification in sand and gravel.

6. The bedrock below the drift is striated but usually has not been streamlined. The striations are attributed to moving ice, but it seems inconsistent to believe the ice slid over both the surface of the drift, and the surface of the bedrock at the same place.

7. Drumlins in some regions have been modified by a change in the direction of the flow of the agent of streamlining. Crossing patterns of orientation also occur. Even a small change in the direction of motion of a glacier would most likely have obliterated previously formed drumlins.

8. The drumlin form seems inconsistent with ice erosion, which would tend to have a leveling effect rather than molding the country into streamlined hills.

9. There are no deposits of the ice sheet lying above the streamlined surface in drumlin fields, that could have been deposited during the melting of this last ice mass. Yet many drumlins are attributed to erosion by the ice sheet, which would tend to result in accumulation of debris in the glacier.

10. Existing ice sheets do not form drumlins. J.K. Charlesworth stated: 'An appeal to modern glaciers is unavailing, since drumlins in statu nascendi are unknown though accumulations somewhat resembling them have been described from time to time." (R4)

X4. Other theories of origin. Creationists tend to believe that drumlins and many other supposedly glacial features are the consequences of water action. (R4)

J. Menzies suggests that drumlin formation is controlled by variation in pore water pressure in the glacial till material. (R3, R5)

The Whittecar-Mickelson theory of drumlin formation depends upon two competing processes: material being injected into the drumlin from below and material being removed by erosion above. (R5)

C.P. Gravenor has presented a modified erosional theory. "The complete process of drumlin formation can be outlined as follows: (1) Masses of till and stratified materials would be deposited at the front of an advancing glacier if there was a temporary halt during the ice advance. (2) Ice riding over this drift would erode and shape it and thereby produce drumlins." (R6) Bedrock drumlins seem to be forgotten in this theory. (WRC)

I.J. Smalley and D.J. Unwin favor a theory of drumlin formation based upon a mechanical property of glacial till called "dilatancy." "Abstract. If glacial till contains more than a certain minimum boulder content, it is dilatant and requires a much larger stress to initiate shear deformation than to sustain it. If the stress level at the glacier-terrain interface drops below a certain critical level, or the till reaches its critical boulder-content density, then the till

beneath the glacier packs into stable obstructions. These are shaped into streamlined forms by the glacier and are found distributed at random in drumlin fields. Due to drumlin coalescence there is a normal distribution of drumlin axes about the direction of ice movement." (R9)

References

R1. Flint, Richard Foster; "Glacial Erosion and Transport," Glacial and Quaternary Geology, New York, 1971, p. 100. (X1)
R2. Flint, Richard F.; "Drumlin," McGraw-Hill Encyclopedia of Science and Technology, 4:313, 1977. (X1)
R3. Menzies, J.; "A Review of the Literature on the Formation and Location of Drumlins," Earth-Science Reviews, 14: 315, 1978/1979. (X1, X4)
R4. Cox, Douglas E.; "Drumlins and Diluvial Currents," Creation Research Society Quarterly, 16:154, 1979. (X2-X4)
R5. Smalley, Ian; "How to Make a Drumlin," Nature, 282:446, 1979. (X4)
R6. Gravenor, Conrad P.; "The Origin of Drumlins," American Journal of Science, 251:674, 1953. (X4)
R7. Lemke, Richard W.; "Narrow Linear Drumlins near Velva, North Dakota," American Journal of Science, 256:270. 1958. (X2)
R8. Millis, John; "What Caused the Drumlins?" Science, 34:60, 1911.
R9. Smalley, Ian J., and Unwin, David J.; "The Formation and Shape of Drumlins and Their Distribution and Orientation in Drumlin Fields," Journal of Glaciology, 7:388, 1968. (X1, X4)

ETM5 Mounds of the Missoula Flood Surfaces

Description. Small mounds geographically restricted (apparently) to the basalt surfaces swept nearly clean by the postulated Missoula (or Spokane) Flood in the Pleistocene. The mounds and generally 2-4 feet high and 10-30 feet across, slightly ellipsoidal in plan, and composed of debris that most investigators consider distinctly different from the basaltic surface. They occur mostly in groups and, occasionally, in lines. They differ from the Mima-type mounds in their location in eastern Washington and confinement to the basaltic surfaces. Most investigators claim that most mounds occur over depressions in the basalt.

Data Evaluation. Several studies of these mounds have been found; but many contradictions exist; viz., the presence or absence of depressions under the mounds, the nature of the mound material, and orientations of the major axes of the mounds. Rating: 2.

Anomaly Evaluation. Wind deposition and water erosion are the major competing theories of formation, with the former currently favored. With two reasonable, possible explanations at hand, the basalt-surface mounds can only be slightly anomalous. Rating: 3.

Possible Explanations. See above.

Similar and Related Phenomena. The Mima-type mounds (ETM1); drumlins (ETM4); the so-called Palouse topography created by the postulated Missoula Flood.

Examples

X1. General observations.

Early description and explanation. "The recent discussion of various types of mounds of uncertain origin leads me to call attention to a form common in Eastern Washington, which seems thus far to have escaped printed notice. Very conspicuous examples are found in the vicinities of Spangle and Medical Lake. Similar ones occur near Winona in the old bed of the Palouse River. Less striking examples are generally found along the crests of all the canyons hewn out by streams in the basalt, especially on the north walls. The general proportion of these mounds is about that of an upturned saucer, but occasionally more convex. The most conspicuous are about four feet high, about twice the height of the most usual ones. In diameter they vary from ten to twenty feet, or rarely more. The first generalization that forces itself upon one is that these mounds occur only where there has at one time been flowing

water. They are conspicuous enough even at the top of the Snake River canyon, though the river now flows on a bed two thousand feet below. Where these mounds occur along the crests of canyons there is usually but a single series of them. Where, on the other hand, they occupy the old beds of broad shallow streams, as at Medical Lake and near Spangle, there may be acres of them, rather evenly scattered, and often quite close together.

The soil of these mounds shows no appreciable difference from the surrounding soil of basaltic origin, and except in the rare cases where water stands about their bases, they do not support a vegetation more or less luxuriant than that of the surrounding soil. There is nothing, in short, in the structure of the ordinary mounds to give a clue to their origin." The author's guess was that these mounds were the result of decaying masses (caps) of basalt. (R1)

The discovery of depressions under the mounds. In 1926, O.W. Freeman remarked that the thousands of mounds found in the Channelled Scablands of eastern Washington were actually composed of material different from what would be formed from weathered basalt. Further, they occur only on bare basalt surfaces. Also: "We only find the mounds in places where the basalt's surface contains depressions. The mounds are found in the midst of level areas, on the sides of hills, at the edge of rock terraces and even on top of small isolated hills of basalt. They occur both in the timbered and treeless parts of the scablands. In fact, they may occur anywhere on the bare basaltic rock and never elsewhere in this region." Freeman's theory of origin centered around the depressions he found under the mounds. At the end of the great Spokane flood (see ETV5), the basaltic lava was left with a pitted surface. The pits served as collection foci for sediments, vegetation growth, and the subsequent accumulation of wind-blown sand. (R2) Note that the development of these mounds on bare rock eliminates the gopher theory for this class of mounds. (WRC)

Contradictory claims. In 1929, A.C. Waters and C.W. Flagler published a paper containing observations that contradicted those of Freeman. "Our own observations in the same area do not accord with Freeman's statement that the mounds almost invariably cover depressions. Certainly many of them lie on a basal floor that is practically level or has a uniform tilt down slope. Piper's studies (R1) in the same region apparently led him to believe that the mounds rest upon high places in the underlying basalt.

Also, in other areas of the plateau, the mounds definitely do not cover depressions. In the Maupin district the removal of hundreds of mounds to furnish material for the roadbeds of the newly constructed Sherman and Dalles-California highways has uncovered a surface that is simply a continuation of the flat-bottomed intermound areas.

We are also unable to agree with Freeman's statement that 'the mounds average practically circular'. Although circular mounds probably do occur, we believe that more than 90% are elongate. Of the thirty which we measured not one was circular and the average elongation was about eight feet. The mounds are uniformly elongated in the direction of slope. If the mounds are of wind origin, their direction of elongation should be dependent upon the direction of the prevailing wind. The individual mounds on the several sides of a low rounded hill about 2½ miles from Cheney are elongated to all points of the compass, but the elongation is invariably down slope." These authors favthe water-erosion hypothesis of origin. (R3) But the story continues.

Results of a more recent field study, 1963. "The Lake Missoula flood of the late Pleistocene stripped a deep covering of loess from hundreds of square miles of the Columbia lava plateau, leaving surfaces of bare basalt or of coarse till material. Most of the soil removal took place within that part of eastern Washington bounded by the Spokane, Columbia, and Snake rivers.

An arresting feature of the newer surfaces, herein called Missoula Flood surfaces, is the presence of small natural mounds. Most of these measure 10-30 feet across and 2-4 feet in height. They resemble in shape the sections which might be struck from the sides of melons, symmetric, with their high points at their centers. They are most common in groups and on surfaces of less than two per cent of slope. They are composed of a fine silt which contrasts sharply with the solid rock or coarse gravel on which they rest."

.....

In a summary of his observations at five typical sites, the first four items recapitulated the above introductory paragraph. The list continues as follows:

"(5) They occur above depressions in the base surfaces.

(6) They are, in shape, segments of ellipsoids.

(7) The mounds slope 20-40 degrees where they meet inter-mound surfaces in sharp margins.

(8) Inter-mound areas are almost free of fine soil.

(9) Major axes of the mounds are from 1.1 to 1.5 times as long as minor axes.

(10) Major axes are aligned with the prevailing wind."

In essence, the present author supports Freeman (R2) and contradicts Water and Flagler (R3) on the matter of depressions under the mounds. It is no surprise when it is concluded that the mounds are of aeolian origin. (R4) Obviously, there has been strong disagreements among the various field studies, especially regarding the presence of depressions and circularity of the mounds. (WRC)

References

R1. Piper, C.V.; "The Basalt Mounds of the Columbia Lava," Science, 21:824, 1905. (X1)

R2. Freeman, O.W.; "Scabland Mounds of Eastern Washington," Science, 64:450, 1926. (X1)

R3. Waters, Aaron Clement, and Flagler, Charles W.; "Origin of the Small Mounds on the Columbia River Plateau," Ameri-Journal of Science, 218:209, 1929. (X1)

R4. Olmsted, Robert K.; "Silt Mounds of Missoula Flood Surfaces," Geological Society of America, Bulletin, 74:47, 1963. (X1)

ETM6 Fluid-Vent Mounds

Description. Mounds of sand, mud, coal and/or other materials brough to the surface by expelled liquids and gases. Some are only a few inches high; others reach 20-30 feet and more. Many have vents on their tops. The mound-forming fluids are forced to the surface by earthquakes, hydrothermal activity, and pressures accumulating in petroleum reservoirs.

Data Evaluation. The literature, especially that dealing with large quakes and hydrothermal activity, contains copious examples of fluid-vent mounds. No attempt has been made here to bring together all of these reports. Rating: 1.

Anomaly Evaluation. The formation of fluid-vent mounds is well-understood. Brief descriptions are included for background only. No anomaly exists. Rating: 4.

Possible Explanations. Simple deposition by upwelling fluids.

Similar and Related Phenomena. Mud craters, which are often perched on mounds (ETB3); volcanos; cinder cones; hot-spring deposits; mudlumps (ETM3).

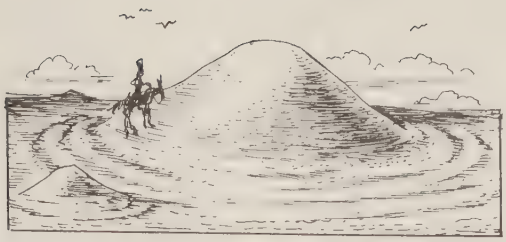
Examples

X1. Mud crater cones. Mud craters appear in category ETB3, where examples from India and Peru are described. These craters are located on the tops of rather large mounds. For details see ETB3. (R1)

The Minbu (India) salses and other mud cones. "Many mud volcanoes owe their activity to the high temperature of the subsurface layers of the earth's crust, which supplied steam to raise the mud and eject it with violence. The Minbu mud volcanoes of India are of a different type and have a special interest for the present study because they indicate that the petroleum beneath the mounds of the Gulf Plain may well have played a part in their formation. According to Cadel:

> The Minbu salses, for such they are in reality, are due to the escape of carbureted hydrogen from the oil-bearing strata on the top of the anticline, which rises through the clay beds mixed with a little water and oil and slowly bubbles up at certain spots. As the gas and water rises, it brings up a little gray mud, which, on exposure to the air, dries and hardens when the water evaporates, producing first a low crater basin with a dry rim of mud, then a cone with a crater on the top, in the center of which the gas finds vent.

It will be noted that we have here an evolution of topographic forms identical with those illustrated by the sand phenomena of earthquakes as above outlined. Other petroleum mud cones occur upon the Apennines at Sassnolo and San Venanzio, at Tanan and Baku in the Caucasus, and upon the Island of Trinidad, while Macaluba in Sicily rests upon



A mud volcano formed at Chemakha during the 1902 earthquake. (X2)

beds of clay containing gypsum, salt, sulphur, bituminous matter, etc. of much the same mixture as that to be found beneath the gulf mounds. The smell of sulphur which accompanies the eruptions of Macaluba is of interest because it offers a possible explanation of the sulphurous odors with which the air was charged during the great New Madrid earthquake of 1811-12." (R2)

Trinidad. Southern Trinidad is occupied by an extensive oil field and Pitch Lake. As noted above, this region includes many mud volcanoes. An interesting eruptive phenomenon has also been reported here:

"On November 3 (1911) an islet began to rise out of the sea about two miles S. of a district called Chatham, on the southern coast of this island. The islet is at present about 200 yards by 150 yards, and its highest part is not more than 15 ft. abobe the water. It has come up at or near a spot previously occupied by a mudbank situated on the Southern Anticline. A fisherman reports that he passed the mudbank on the 4th. inst., and did not notice anything unusual. Another account has it that a mound appeared above water on the 3rd. inst. A small party rowed across to investigate during the afternoon of the 4th. inst; but as the water in the vicinity of the mound of mud was found bubbling actively, it was decided to abandon the idea of landing. The party had just time to get back to the shore, when, at 5.45 p.m., a violent explosion occurred on the newly risen ground. The flame is stated to have shot up to a height of 100 ft. to 300 ft. At any rate, it was plainly seen from the seafront at Port of Spain, 43 miles distant as the crow flies. This was followed by the emission of dense smoke and vapour, lasting throughout the night and well on into the next day, the 5th. inst., when, late in the afternoon, it was possible for a party from the city to effect a landing. There were two craters, each a few feet in diameter. A gurgling sound could be heard within them, and they were emitting vapour of a bituminous odour. The surface was of honeycombed mud, which was very soft near the edge of the water, and made landing difficult." (R3) A similar phenomenon is reported in ETM3 near Trinidad, but this 1964 "mudlump" was considered to be of tectonic origin rather than due to the pressures of gases and liquids. (WRC)

X2. Sand and mud cones associated with earthquakes. The great earthquakes often expel from the ground large quantities of fluids---gases, liquids, and fluidized solids. These phenomena are not considered anomalous. We offer here only a generalized account.

"The object of the present article is to draw attention to the fact that the region (the Gulf Plain) is one of notable seismicity, and to point out that sand and water fountains, as well as mud volcanoes, with their products, 'sand' or 'mud' cones and 'craterlets,' are almost universally produced in connection with great earthquakes. The derangement of the ground water at such times results in: (1) local ejection of sand and water (sand blows and mud cones), (2) draining through vertical pipes of swamps or ponds ('funnels' and 'craterlets'), (3) in draining following upon an ejection of sand, mud and water (pitted cones), or (4) squeezing out following the sudden draining of the district. The best descriptions of such phenomena have perhaps been given

in connection with the earthquakes of Calabria, 1783; New Madrid, 1811-12; Iceland, 1896; India, 1897; and Chemakha, Turkestan, 1902.

The mounds referred to in the above mentioned examples generally consisted of sand mixed with small quantities of various other substances (mica, lignite, etc.) generally foreign to the surface layers of the soil, and it reached the surface borne by large volumes of water which left the material so charged with water as to resemble a quicksand. During the Indian earthquake of 1897 material of this nature spread out from many openings and blanketed large tracts of country with quicksand." (R2)

X3. Mounds at hydrothermal vents. Here again the literature is large; and, since no anomalies are involved in mound geology, a short description will suffice.

East Pacific Rise. "In contrast to the biology-dominated Galapagos-type vents, the sulfide mound hot-water vents are most notable for their geological attributes. In these, the water flows out through a limited number of discrete chimneys or stacks, which are superposed on basal mounds built directly on fresh basalt pillows or flows. The basal structures, similar to the CYAMEX sulfide mounds, are oxidized to Halloween colors of ocher, orange, and black and have overall lateral dimensions up to 15 by 30 m." (R4)

X4. Fossil gas vents. "Dome-shaped fossil gas vents occur on top of one of the Hopi Buttes, the Dilkon diatreme, 3.2 km (2 miles) west and 1.6 km north of Dilkon Trading Post." These fossil mounds are in Arizona. (R5)

References

R1. Stiffe, A.W.; "On the Mud-Craters and Geological Structure of the Mekran Coast," Geological Society of London, Quarterly Journal, 30:50, 1874. (X1)

R2. Hobbs, Wm. H.; "Some Topographic Features Formed at the Time of Earthquakes and the Origin of Mounds in the Gulf Plain," American Journal of Science, 4:23:245, 1907. (X1, X2)

R3. Campariolo, P. Clem.; "An Eruptive Phenomenon," English Mechanic, 94:421, 1911. (X1)

R4. RISE Project Group; "East Pacific Rise: Hot Springs and Geophysical Experiments," Science, 207:1421, 1980. (X3)

R5. Laidley, Richard A., and DuBois, Robert L.; "Dome-Shaped Volcanic Gas Vents in Arizona," Science, 145:153, 1964. (X4)

ETM7 Sandhills and Anomalous Dunes

Description. Mounds or hills---larger than Mima-type mounds---composed primarily of sand and possessing features that contradict eolian origins. Sandhills are more than 20 feet high and are often admixed with sand ridges and loess deposits. Very large tracts of country are covered by such deposits, even when conventional deserts are excluded. Undersea fields of sand dunes have also been discovered recently.

Background. The deserts of the world display a large variety of true sand dunes. Some of these, like the "star dunes", have bizarre shapes. Nevertheless, scientists have found good explanations for all types of dunes. Therefore, ordinary dunes, despite their admittedly strange configurations, are excluded from this Catalog.

Data Evaluation. Very little has been found in the scientific literature concerning any of the examples presented below. Most of the anomalous features have been delineated by one person, who also has a competing and controversial theory of origin. Rating: 3.

Anomaly Evaluation. Since geologists are fiercely adamant that all terrestrial sandhills and "dunes" are of eolian origin, the anomalous aspects reported here, weak though they are, are at the same time highly anomalous, because they support a marine-flooding origin. In addition, the "dune" fields discovered on the ocean floors have no reasonable theory of origin

that we can find. Rating: 1.

Possible Explanations. Since the sandhills and anomalous dunes are too large to be explained by gopher action and most other Mima mound hypotheses, the only surviving theories are those of eolian and water-deposition.

Similar and Related Phenomena. Sand dunes; anomalous ridges (ETR); Mima mounds (ETM1); loess deposits (ES).

Examples

X1. The Nebraska sandhills. These hills are part of an extensive deposit of loess/sand. Many mound-like formations occur, although there are also many ridges, too.

R. F. Flint's description. "The largest single area of dunes in North America is the Nebraska Sand Hills in northern Nebraska. Eolian sand there covers an aggregate area of ~ 35,000 km^2 to an average thickness of about 8 m. The dunes constitute at least three groups, of different though unknown late-Pleistocene ages, consisting of at least three morphological kinds. The oldest group indicates N winds; the others NW like the effective winds of today." (R1) The Nebraska sandhills are always described in this context of eolian deposition.

A.O. Kelly's demurrer. Kelly, a lone voice in the wilderness, objects to the eolian hypothesis on four counts: (1) The sand supposedly blown south from the Canadian Shield actually extends to northwest Texas, eastern Colorado, and Wyoming, covering an area of more than 200,000 square miles. The total quantity of sand and its geographical extent militate, in Kelly's view, against an eolian origin; (2) "Another physical feature pointing to water as the carrier and depositer of this fantastic amount of material is the fact that the loess thins out and overlaps the eastern side of the sandhills. If the medium of transportation had been wind, the lighter material, the loess, would have been carried farthest and deposited on or against the mountains"; (3) The thickness of the deposit is greater the lower the elevation, suggestive of water-deposited sediments; and (4) The tops of the sand hills are very level (concordant), which is an indicator of deep-water deposition rather than eolian origin. (R2)

X2. The Temecula Valley sandhills, California. "At the western end and on the high corner of the plateau, there is an area of about 50 acres of sand hills that have no possible stream source. Nor are they of eolian origin for these sand hills contain rocks up to fist size. These sand hills are more like large mima mounds, averaging about 150 feet in diameter and about 10 feet high. Their elevation is about 3,800 feet above sea level." (R2)

X3. The Imperial Valley sandhills and sand dunes. Geologists have always considered the well-known Imperial Valley sandhills to be the work of the wind blowing down the Valley. This immense deposit of fine sand, arranged in hills and ridges perpendicular to the Valley axis, stretches for about 70 miles. The Valley itself is 70-80 miles wide. Often, the sandhills are several hundred feet high. A.O. Kelly objects to the eolian theory on two grounds: (1) No reasonable sand source exists; and (2) Today's winds are not strong enough to create the deposit. Although some true sand dunes exist in the Valley, the sandhills themselves are not active dunes. (R2)

X4. Seafloor sandhills and "dunes". Results from the British ship Farnella, while engaged in exploring the Gulf of Mexico. "Farnella's crew discovered large sand dune fields in 3,000 meters of water---similar to dunes found in the Pacific last summer. 'There's something going on in deep water that people just aren't aware of,' says G. Hill." (R3) See also megaripples (ETR3).

References

R1. Flint, Richard Foster; "Drainage: Eolian Features," Glacial and Quaternary Geology, New York, 1964, p. 247. (X1)

R2. Kelly, Allan O.; Impact Geology, Encinitas, 1985, pp. 74, 83, 91. (X1-X3)

R3. "A Systematic Sounding of the Sea Floors," Science News, 128:191, 1985. (X4)

ETM8 Doughnut-Shaped Mounds

Description. Large mounds of glacial till and silt, averaging 300 feet in diameter and 15 feet in height. Although this type of mound may be more widespread, examples have been found only in Alberta and, possibly, Saskatchewan.

Data Evaluation. So far, the literature examined has yielded only one study of these mounds. It seems, however, a careful and thorough bit of research. Rating: 2.

Anomaly Evaluation. Considering the location of the known mounds and their constitution, we almost certainly have a glacial or periglacial phenomenon here. The range of topographical phenomena; such as drumlins, kames, patterned ground, etc.; blamed on glacial and periglacial action is so great that almost any geometry can be explained. Although we can only guess at the precise mode of origin, the guesses are reasonable, and no basic geological tenets seem at risk. Rating: 2.

Possible Explanations. The mounds were deposited when stagnant glaciers melted, dropping the contents of debris-filled pits. (The origin of the pits in the glacier also needs explanation.) The mounds may also be a phenomenon of frozen-ground or periglacial action.

Similar and Related Phenomena. Patterned ground (ETP1); Mima Mounds (ETM1); pingos and palsa mounds (ETM10); rock doughnuts (ETB5). In later volumes of the Catalog, the glacial theory will be challenged frequently.

Examples

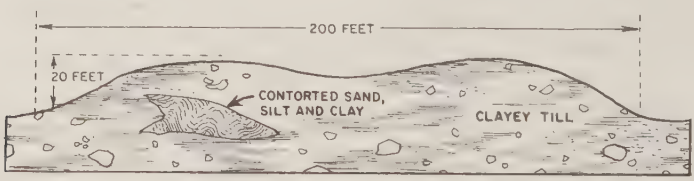
X1. East-central Alberta, Canada. Description of the Mounds. Aerial views of prairie mounds show that they are nearly circular and in most cases have a central depression. The mounds average 300 feet in diameter and 15 feet in height. The central depression is generally 3 to 4 feet lower than the elevation of the outer rim of the mounds.

For the most part the mounds are composed of clayey till. An exception to this general rule is found, however, in the mounds which exist on the southwestern border of the Viking moraine. At this location several mounds were found which are formed primarily of till but contain masses of contorted and slumped stratified silts and clays. It is significant to note that similar inclusions of stratified sediments have not been found in the ground moraine adjacent to the mound fields.

The intermound trenches are quite flat except where the mounds occur on the edges of, or in areas of, recessional moraine. Drilling operations in the mound field east of Hemaruka showed that the mounds and the intermound trenches are underlain by a minimum of 40 feet of clayey till. With the exception of a 3-foot layer of silty till cover on the rim of the mounds, there was no difference noted between the till in the mounds and the till in the intermound trenches.

In some places the intermound trenches are covered with a thin layer of sand which contains a few pebbles and shows evidence of rude sorting. This veneer of sand is not confined to the mound areas but is found over much of the ground moraine of east-central Alberta.

The mounds in the Watino area of Alberta, described by Henderson, are only 5 to 10 feet in height, but the diameters



Section of a typical doughnut-shaped mound from the Canadian prairies. (X1)

are approximately the same as those found in east-central Alberta. The Watino mounds are composed largely of till, and the inter-mound spaces are covered with a layer of silt 2 to 3 feet in depth."

From the air, these prairie mounds resemble giant doughnuts. The author believes that the mounds originated as debris-filled pits on a stagnant ice surface, and that the melting of the ice deposited the pit contents as mounds. (R1)

References

R1. Gravenor, C.P.; "The Origin and Significance of Prairie Mounds," American Journal of Science, 253:475, 1955. (X1)

ETM9 Dirt Cones on Ice Caps and Snow

Description. Sharply defined cones of dirt, usually with cores of snow or ice, found on ice caps and snow fields. Cone heights may reach 12 feet or more. Often these structures are found in rows which, in some instances, follow crevasses. Although dirt cones exist by the thousands in Iceland, they have not been reported widely elsewhere.

Data Evaluation. Dirt cones have been carefully described and photographed in Iceland and, to a lesser extent, elsewhere. The extent of the phenomenon is not known at present. What is the geographical range? Rating: 2.

Anomaly Evaluation. The scenario related below is quite convincing. The big puzzle is why similar cones have not been reported from more debris-covered ice sheets. Why are the conditions in Iceland so unique? Rating: 3.

Possible Explanations. Wind-borne debris, possibly concentrated by water action, retards the melting of the snow or ice it covers. As the surrounding snow and ice melt, the debris layer collapses at its edges, ultimately forming a dirt cone with a snow/ice core.

Similar and Related Phenomena. The mounds on the basalt of the Missoula Flood plain (ETM5), which may have once been dirt cones.

Examples

X1. Vatnajokull, Iceland. "Dirt cones are the most arresting feature of the ice-cap surface on the northern margins of Vatnajokull. Their frequency increases towards the edge of the ice-cap in direct proportion to the abundance of superficial material. This applies particularly to the northwestern portions of Bruarjokull which are covered by tens of thousands of dirt cones. The bare surface of the Central Desert of Iceland here proves to be a bountiful source of wind-borne material. The paucity of references to dirt cones in literature does not lead one to expect this widespread occurrence.

.....

The cones generally range from a few inches up to eight or ten feet in height. Where most abundant they are usually aligned in sub-parallel series, broken at intervals by transverse lines, the pattern obviously conforming to crevasse systems and the largest cones being found at the intersection of two or more such systems. The individual cones are generally elongated in the direction of the series; their steeper slopes approach forty-five degrees and apparently do not face any particular direction. When isolated the cone shape is almost perfectly developed. They appear to be solid cones of black basaltic dust and sand, the mixture being of a consistency of a slightly sandy loam. Closer examination, however, reveals that only the outer few inches are of such material, the remainder being a solid core of ice or snow. The mantle of debris is often thickest at the top of the cone, particularly when this is not sharply pointed, and occasionally the ice beneath is replaced by a solid mass of frozen dirt.

Dirt cones appear wherever much superficial material covered the surface of the ice or neve. This material might have been wind-borne in the first instance, after which it was frequently concentrated by the action of sur-

face streams of melt-water. It may sludge down onto the side of a glacier, may be brought to the surface by overthrusting, or be concentrated by superficial melting. The second condition equally essential for their formation is that of very rapid ablation by direct sunlight, rain, or high air temperature." The author opines that the cones, which his photos show are often very sharply defined, start with deposits of wind- and water-borne debris. As the snow melts about these deposits, the debris layers collapse and ultimately take on a conical shape. (R1) One can surmise that when these dirt cones collapse entirely, due to the melting of their cores, mounds similar to those on Washington's Missoula Flood surface might result (ETM5). (WRC)

X2. Jan Mayen Island, Norway, in the Arctic Ocean. "During the early summer the lower ground of Jan Mayen Island bears numerous, rapidly dwindling patches of snow. The surfaces of many of these patches are raised in hundreds of small cones, each covered with the volcanic sand that is a ubiquitous feature of the island. Similar 'dirt cones' have been recorded on snow patches in Iceland but seldom from elsewhere. Dirt cones on ice, on the other hand, are known in a variety of forms from many regions, including Jan Mayen; but they differ in character and in origin from dirt cones on snow, and they are not considered here.

Dirt cones examined during June 1950 generally measured up to about 10 cm. high, and were distributed evenly but irregularly at intervals of a few decimetres. They typically had exactly the appearance of those figured for Iceland by Spethmann and Swithinbank. The dirt cover of each cone was some 1 to 3 cm. thick on top of the cone, but thinner (down to 0.3 cm.) on the sides. The snow surface between the cones bore only a very light sprinkling of dirt. The sides of the cones sloped at a rather constant angle of about 60 degrees with the horizontal, steeper than that recorded for dirt cones in Iceland." (R2)

The author gives his explanation for the dirt cones in the paper's abstract: "These striking accumulations of dirt, separated by virtually dirt-free snow, are produced by movement (both contraction and expansion) of the snow surface during ablation. Factors controlling this movement operate in such a way that local concentrations of dirt will be produced even when the initial deposition of the dirt is almost uniform." (R2) See ETP1 for "patterned ground," which has similar features and, possibly, modes of origin.

X3. New Zealand. Here, we have what might be termed "ash cones." "Abstract. Due to the abnormally warm summers of 1955 and 1956 the glaciers of Mount Ruapehu deteriorated to such an extent that the ash layer of the eruption of 1945 was exposed everywhere. This caused a development of ice cones similar to those occurring in Iceland. Various factors, especially heavy crevassing, which took place at the same time, are responsible for the different ways of development of dirt cones on Ruapehu." (R3)

References

R1. Lewis, W.V.; "Dirt Cones on the Northern Margins of Vatnajokull, Iceland," Journal of Geomorphology, 3:16, 1940. (X1)

R2. Wilson, J. Warren; "The Initiation of Dirt Cones on Snow," Journal of Glaciology, 2:281, 1953. (X2)

R3. Krenek, L.O.; "The Formation of Dirt Cones on Mount Ruapehu, New Zealand," Journal of Glaciology, 3:312, 1958. (X3)

ETM10 Ice-Cored Mounds in Arctic Climes

Description. Mounds of dirt, sand, organic matter, and other debris possessing cores of ice. In North America, where they are called pingos, these mounds may be more than 200 feet high. The Eurasian variety, termed pals or palsa mounds, are only about one-tenth the size of the pingos. Some underwater mounds off the coasts northwestern Canada and United

States may be pingos.

Data Evaluation. Only a few reports have appeared in the mainstream, English-language journals. Apparently, much more can be found in the specialized journals, particularly those in the northern European languages. Rating: 1.

Anomaly Evaluation. There is no shortage of theories to account for the ice-cored mounds. But, as with other arctic and periglacial geological phenomena, it is difficult to pick the correct hypothesis. In any case, these mound phenomena are more curious than paradigm-challenging. Rating: 3.

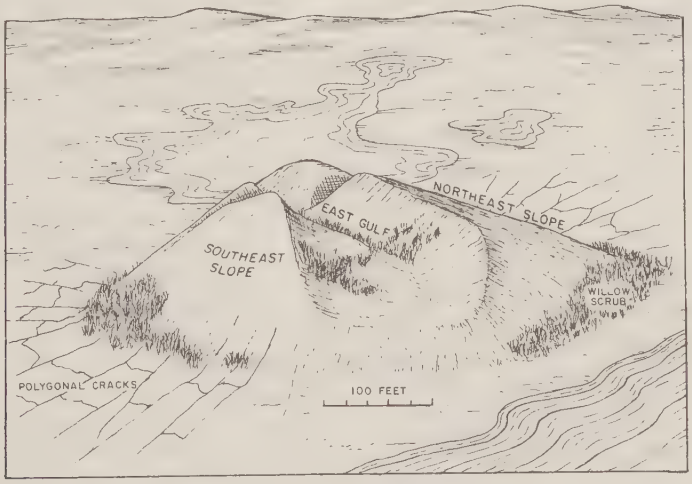
Possible Explanations. The two major theories involve the pressure exerted by artesian water and the freezing of water trapped between bedrock and frozen surface soil.

Similar and Related Phenomena. The Icelandic dirt cones (ETM9), which also have ice/snow cores.

Examples

X1. Pingos. These are roughly conical mounds with ice cores, ranging up to 200 feet in height. Pingos seem to be confined to North America.

General observations. "All travellers on the low coastal plain of northern Alaska between Point Barrow and the Mackenzie delta have noted the curious, isolated, more or less conical mounds that diversify the otherwise featureless plain. The Eskimos call such a mound a pingo. In a paper in the Geograhpical Review of January 1938, Mr. A.E. Porsild discusses the origin of pingos and other earth mounds in north-western America and Greenland. He agrees with E. de K. Leffingwell that the Alaskan mounds may be formed by hydrostatic pressure. This type is old and shows no signs of recent movement. The freezing of the surface layers over previously unfrozen strata produced conditions favourable to artesian wells. Where downward freezing checked the seaward flow of water, hydraulic pressure forced upwards the surface layers. A second type of mound, common in the Mackenzie delta, is found in level country or near the border of a lake or former lake basin. This type ranges from a few feet to more than two hundred feet in height and averages 40-75 ft. They often show a median rupture sometimes enlarged to a 'crater' and a well-defined stratification conforming to the slope of the surface. Mr. Porsild suggests that these mounds are formed by local upheaval, due to the expansion following downward freezing of a body of water enclosed between bed rock and



A pingo from the Mackenzie Delta, Northwest Territories, Canada. (Adapted from Geological Society of America, Bulletin, *67:1120, 1956.) (X1)*

frozen surface soil." (R2; R1)

A Mackenzie delta pingo. "The pingo is located at approximately 69°02' N. Lat. and 134°25' W. Long. It is a conical hill approximately 560 feet in diameter with its crater appreciably off center. Its summit is almost exactly 100 feet above the level of the surrounding ground. The sides of the pingo are relatively smooth, but the rim of the crater is broken so as to form four separate lips separated by sharply sloped guts approximately at right angles to one another.....

The crater is roughly circular with a diameter of about 30 feet. A pool of water in the crater at the time of the investigation was 10 feet wide, 30 feet long, 18 inches deep, and drained through the south gut." One core showed a layer of sand and decomposed organic matter 3 feet 8 inches thick, on top of a milky ice core. (R3) See the accompanying illustration.

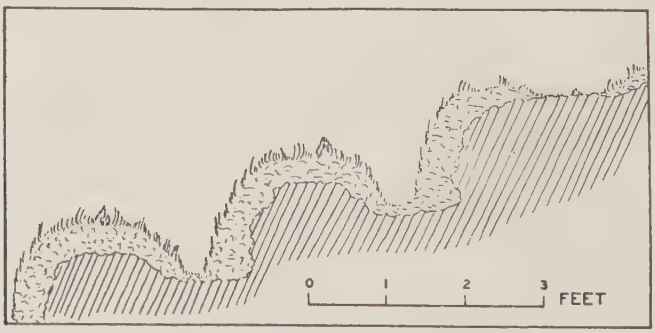
Pingo-like underwater mounds in the Beaufort Sea. In 1969, an icebreaker discovered a mound in the Beaufort Sea. Following this unexpected development, a Canadian survey ship found a total of 78 similar underwater mounds in a 5,000-square-kilometer area. "The mounds average about 400 meters in diameter and 30 meters high." These structures are thought to be pingos, which were formed during the last glacial period, when sealevel dropped 100-125 meters. (R4; R5)

X2. Pals or Palsa Mounds. Well-developed pingos are apparently restricted to North America, but much smaller mounds of similar character and, probably, origin, have long attracted attention.

General observations. "According to (A.) Hamberg mounds of a similar appearance but of much smaller size are found in sub-Arctic bogs of Europe and Asia. In Swedish literature they are known as pals. Hamberg dismisses theories explaining their formation advanced by earlier European writers and thinks that the pals are formed by a local upheaval caused by the lateral expansion of the surface soil in places that originally were slightly raised above the level of the bog owing to the absence of snow cover. By the suction caused by the resulting vacuum, liquid soil and peaty matter are slowly drawn from the adjacent subsoil." (R1; R6) Possibly relevant to the differences between pingos and palsa mounds is the fact that the latter occur where the land was once glaciated and is still frozen to great depths. Alaska, where the pingos exist, was never covered by the ice sheets, and the ground is not frozen very deeply. (R1)

Yukon Territory, Canada. Palsa mounds may be considered a variety of hummock, as described by R. P. Sharp. "Earth Hummocks. These are low rounded knobs of fine material covered by a tight mat of moss, grass, and scrubby plants. In this area hummocks are most abundant on slopes and flats covered by a thick growth of tundra-type vegetation, but closely related phenomena are also reported in bogs and swamps. Names applied to these features are numerous, but Palsen and Torfhugeln are two of the most widely used.

The Wolf Creek hummocks are 1 to 2 feet high with ground-plan dimensions of 1 to 5 feet. On flats or slopes of less than 5 degrees the hummocks are crudely hemispherical, but on steeper hillsides they develop an elongation across the slope. The



Cross section of soil hummocks and turf-banked terrace. A largely vegetative mat is superposed on earthy debris. Yukon Territory. (X2)

downhill side is higher and steeper than the uphill side, and in a few places the upper surface grades back into the hill slope without an intervening depression, thus forming a small terrace.

The hummocks consist of an earthen core with a 3- to 6-inch hull of humus, moss, and plant roots. The plants on top of the mounds are chiefly grass and small bushes with grass and moss predominant in the low damp areas between." The author considers hummocks to be formed when masses of fine material is squeezed up into small knobs under a vegetative cover through the action of differential freezing. (R7) As one can see from this and the preceding entry, no unanimity of opinion exists as to origin.

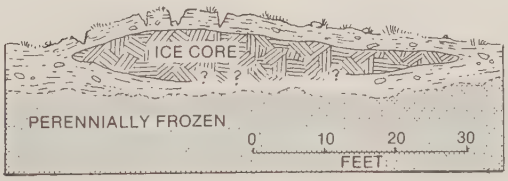
X3. Ground-ice mounds or hydrolaccoliths. This variety of mound resembles the pingo in many aspects, although it is much smaller. Its origin, too, is probably similar. It exists in many areas where there is tundra.

Yukon Territory, Canada. "The tundra in Arctic and sub-Arctic regions is irregular and rough in detail but relatively featureless in broader aspect. Low, scattered mounds that interrupt the monotony attract immediate attention. Although the mounds differ in size and shape, most of them are a few feet high, many tens of feet in circumference, and gently rounded or slightly asymmetrical in cross section. The large and well-developed mound of Figure 1 (not reproduced) is 60 feet long, 22 feet wide, and 6 feet high, with an egg-shaped ground plan and a slightly asymmetrical profile. This is one of the highest and largest mounds observed in the Wolf Creek area, and none appear to cover more than 1500 square feet. Mounds a foot or two high and of large area are barely discernible, and small mounds are hard to distinguish from other minor irregularities of the tundra. Roughly circular or elliptical ground plans prevail, usually with an elongation in a downslope direction. Profiles parallel to the slope have a steeper downslope side, but profiles transverse to the slope and those of the mounds in relatively flat areas are gently rounded.

The ground over most mounds of fairly large size is broken by tension cracks, the largest and deepest of which are near the crest of the upwarp and along its edges. In these places the mounds can be seen to consist of a core of clear ice mantled by a surficial hull, one to three feet thick, of gravel, sand, soil, and tundra vegetation. So far as could be determined, the lower surface of the ice core is essentially flat and the upper surface rounded in the shape of the mound. The ice is clean and fairly clear, containing a few bubbles without noticeable orientation. A crude vertical columnar structure is discernible as the ice melts or when it is broken by a pick.

.....

The hydrolaccoliths of the Siberian tundra, with their cores of ice and surficial fractures, closely resemble the Wolf Creek mounds in size, shape, and constitution. Larger mounds with cores of ice on the north coast of Alaska and Canada may also be comparable. Both the hydrolaccoliths and many of the Alaskan mounds are attributed to localized updoming by the hydraulic force of ground water, which freezes in the opening so formed." However,



Internal structure of a ground-ice mound, or hydrolaccolith, as observed in the Yukon Territory. (X3)

the author notes that hydraulic pressure cannot rise to a sufficiently high level in the permeable tundra. Rather, he postulates that these mounds are raised as bodies of ice grow in the thawed layer above perennially frozen ground. (R8)

X4. Moated ice mounds. These formations, though not considered anomalous, should be mentioned here. They are the result of the melting of "armored snowballs," which are formed when fragments of rocks break off cliffs and, in their descent, collect snow to create large snowballs. When the snowballs roll out over a beach of pebbles an "armor" of stones is picked up. When the armored snowballs come to rest on fiord ice and melt, the pebbles melt into the ice, forming a moat around the snow-ice core. The resulting ice mounds may be 4 feet high and 8 feet in diameter. (R9)

References

R1. Porsild, A.E.; "Earth Mounds in Unglaciated Arctic Northwestern America," Geographical Review, 28:46, 1938. (X1, X2)

R2. "Mounds of Arctic America," Nature, 141:252, 1938. (X1, X2)

R3. Pihlainen, J.A., et al; "Pingo in the Mackenzie Delta, Northwest Territories, Canada," Geological Society of America, Bulletin, 67:1119, 1956. (X1)

R4. "Underwater Mounds in the Beaufort Sea," Science News, 100:360, 1971. (X1)

R5. Shearer, J.M., et al; "Submarine Pingos in the Beaufort Sea," Science, 174: 816, 1971. (X1)

R6. "Origin of the Palsa Mounds," Nature, 246:64, 1973. (X2)

R7. Sharp, Robert P.; "Soil Structures in the St. Elias Range, Yukon Territory," Journal of Geomorphology, 5:274, 1942. (X2)

R8. Sharp, Robert P.; "Ground-Ice Mounds in Tundra," Geographical Review, 32:417, 1942. (X3)

R9. Ferguson, Laing; "'Armored Snowballs' and the Introduction of Coarse Terrigenous Material into Sea-Ice," Journal of Sedimentary Petrology, 40:1057, 1970. (X4)

ETM11 Large Blister-Like Structures

Description. Large circular and elliptical boil- or blister-like structures, which appear on aerial photos as if they are inverted meteor craters. Diameters are usually several miles; while heights reach nearly a thousand feet.

Data Evaluation. To date, only a brief mention of these structures has been located. Data are from aerial photographs; there has been no reported surface or seismic exploration of the phenomenon. Rating: 3.

Anomaly Evaluation. Magma pressure seems indicated, but the paucity of data makes this impossible confirm. Assuming this mode of origin, these blisters are not very anomalous. Rating: 4.

Possible Explanations. Magma pressure elevates the crust in the shape of a blister.

Similar and Related Phenomena. Laccoliths, especially hydrolaccoliths (ETM10-X3).

Examples

X1. Arctic Canada. "Several peculiar circular forms, looking like meteor craters in reverse or rocky boils on the skin of Mother Earth have been discovered on two Canadian islands in the Arctic Ocean.

One on Melville Island is four to four and a half miles in diameter and rises 739 feet above the surrounding flat country. There is another, about eight miles to the east, almost exactly like the first circular form.

Two smaller circular forms and two much

larger elliptical forms were found on Ellef Ringnes Island, about 200 miles to the northeast of Melville. All of the forms were discovered in Royal Canadian Air Force photos." The circular forms may be ring dikes, but the elliptical bulges were probably created by liquid rock that could not reach the surface. (R1)

References

R1. "Hot Rock Makes Strange Circles in Arctic Canada," Science News Letter, 60:344, 1951. (X1)

ETM12 Curious Columnar Structures

Description. Columns, pinnacles, and towers of snow, ice, sand, tufa, basalt and other materials. This is a catch-all entry.

Data Evaluation. Generally speaking, the structures described here have been little-studied. The few reports at hand are sometimes vague; others are merely the accounts of travellers. It is reasonable to assume that many similar phenomena have not yet been uncovered in the literature. Rating: 3.

Anomaly Evaluation. Most of the phenomena described below are mainly of curiosity value. Differential erosion, chemical precipitation, and magma action can probably account for most of them. Rating: 3.

Possible Explanations. Explanations are varied. See the entries below.

Similar and Related Phenomena. Naturally formed mineral dams (ETR5).

Examples

X1. Nieve penitentes: ice/snow columns.

General observations. "Nieve penitente is a fanciful name given to snow or ice pinnacles or other upward-projecting forms. The general cause of the phenomenon may be attributed to the action of heat in some manner or another upon neve and glacial surfaces, in which dense foci already exist; this melting away the softer portions and leaving the harder as standing or upward-projecting masses. From an extensive series of observations on nieve penitente found in great abundance under a variety of conditions during the summer of 1908, in the course of an exploring expedition to the Hispar glacier, on the Hunza-Nagar frontier of Northern India, and other localities in that region, Dr. Hunter arrives at conclusions which substantially confirm his former opinion of their origin. The preliminary condition essential for the development of the nieve penitente appears to be the striation in parallel ridges, separated by furrows, of the neve surface out of which they are evolved, such striation being caused by various agencies, such as the passage of avalanches, wind, the falling of rocky boulders upon the surface, the settling down of the neve on sharp slopes, etc. The ridges, however formed, run almost always in the same direction as the slope of the surface, and alter their trend in accordance with it. The first stage in the development of nieve pyramids from these simple ridges is "mammillation" in them, proving that some parts of the ridges are harder than others, containing foci of special density. The sun's heat melts away the softer portions, leaving, as aforesaid, the nieve forms as variously shaped projecting masses." (R3) Nieve penitentes frequently occur in regular rows which, in the Andes, run northwest-to-southeast. They also seem to be restricted to tropical latitudes, such as the high elevations of the Andes and the Himalayas. (R1, R2)

The Andes. "Penitents are spikes of old compact winter snow or of glacier ice, roughly ranged in an east-west direction, which in the Andes of Santiago, cover all the snow fields and glaciers between 4000 and 5200 m. in serried ranks. Lower down they progressively lose their sharp forms as will be described. At higher altitudes the snow re-

mains powdery too long to form penitents.

Since their first observation in 1835 by Charles Darwin at the Paso de los Piuquenes, the most fanciful theories on their origin have been proposed. Darwin attributed them to the wind, Brackebusch in 1893 to the cracks created by the descent of the snow on landslides, Conway in 1902 to the action of the sun on the snow from avalanches, Meyer in 1908 to melting by a warm west wind, Catalano in 1926 to the electromagnetic orientation of snow crystals, and Hess in 1933 to thermal eddies of the air and to the rain.

These theories ignored the fact that the penitents are found over all the snow fields of a climatic region and that they all lie in an east-west direction. The disturbances from this direction can be explained by non-symmetric insolation, due to cloudy evenings, or merely to the orientation. For instance in a steep couloir facing south-west, at 4550 m., there were at the end of January 1953 penitents 80 cm. high, whose direction was 75°, 255° instead of 90°, 270°."

The author gives his own theory succinctly in his abstract. "They are caused by the prolonged action of the sun in a dry and cold atmosphere. The sublimation of the snow or ice allows the crests to maintain their temperature below 0°C., while in the spaces or passages between the penitents, where radiation is concentrated and removal of water vapor not so easy, melting takes place. This hypothesis is justified by a brief study of the climate of the high Cordillera of Santiago...." (R12)

The Himalayas. "Large portions of the neve-covered surface of the Shafat glacier, from 16,000 to 18,500 feet, were thickly strewn with nieves penitentes. This was the first time we had met with them in five seasons of Himalayan exploration, and I am not aware that their existence in Himalaya has been mentioned by any other observer. For a time they were regarded as peculiar to the Andes, having been observed only by explorers of that chain, until Hans Meyer, and after him C. Uhlig, discovered them on Kilimandjaro. In the Andes they have been found from the equator to 35°4' lat. S., while those seen by us existed from 33°57' to 33° 59' lat. N.

They varied in height from 8 inches to 3 feet, and had the shape of wedges or pyramids flattened at the sides with curling fluted crests, all turned in the same direction.

They were arranged in parallel lines running diagonally to the axis of the glacier, the long diameter of each nieve being parallel to the long diameters of others in the system and coincident with the direction of the lines. They were composed of granular snow, hard frozen in the morning, but softening more or less under the heat of the sun. No ice was found in them. The central portion of each, even when softened by the sun, was much denser than the outer surface or the surrounding neve, offering even in the smallest decided resistance to the thrust of an ice-ax, while the two latter could often be scraped away with the fingers. The neve on which they stood sloped at angles of 30° to 40°.

From the foregoing, the conclusion may be drawn that the formation of nieves penitentes, certainly of such as were seen here, depends on two conditions: (1) the existence of a strong wind blowing constantly from the same direction, driving the snow into wavelets and ridges usually parallel to one another, and condensing it into compact masses at foci a little removed from one another; and (2) a prolonged period of fine weather following, during which the softer portions are melted away by the sun's heat both direct and reflected, leaving the denser parts standing in the well-known shapes." (R10)

"Giant" ice pinnacles (no dimensions given) have been reported on Mount Everest. They are said to be "enormously larger" than those in the Andes. (R11)

X2. Columnar tufa structures.

Searles Lake, California. "Towering like giant kings over a domain of blistering hot, salt encrusted wasteland, stand the tufa Pinnacles of Searles Lake, California---the strangest unsolved mystery of the American desert.....

At close range the Pinnacles appear to jut straight out of the ground like fingers pointing to the sky, some short, some two-hundred feet high. With our heads tipped back on our shoulders looking up to inspect the towering crags they assume as many different shapes as there are individual pinnacles. Their dirty white color with overtones of gray-purple stand out in sharp contrast to the deep blue of the clear desert air. On close inspection they prove to be porous and sound hollow if struck with a rock or pick." Exploration with a drill revealed a stem-like core of pure calcium carbonate or chalk. Speculations about the origin of the tufa columns focus on the former existence of several hundred feet of water in the Searles basin in the past. The tufa then might have precipitated out on seaweed or

other plant structures, as it does today in saline lakes. (R4)

More data have been found in a later scientific report. "Searles Lake is a playa or dry lake which occupies the central floor of Searles Basin, a northward-trending graben of the Basin and Range province in southeastern California. During pluvial periods of the Pleistocene epoch deep-water lakes filled Searles Basin, and in two of these lakes more than 500 pinnacled masses of calcareous tufa accumulated in an arm-like bay at the southwest end of the basin.

Pinnacles are tower-, tombstone-, and cone-shaped masses and large limestone ridges. Most of the pinnacles are 10 to 40 ft high, but a few reach heights between 100 and 140 ft. Basal diameters or widths range from about 10 ft to as much as 500 ft and average 20 to 30 ft. Seven varieties of tufa compose the pinnacles; one of these varieties is also found in lenticular bodies buried in the lacustrine sediments underlying the pinnacles at the northern end of the bay.

It is proposed that the pinnacles were precipitated by algae about the orifices of sublacustrine springs issuing along faults..." (R14)

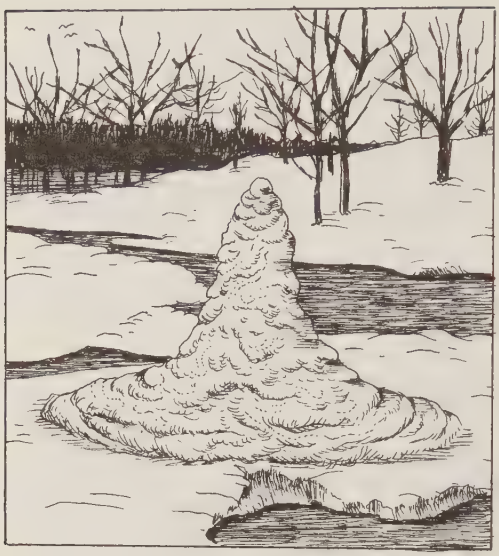
Mono Lake, California. Tufa mounds and towers also occur here. P. Cloud and K.R. Lajoie comment as follows on these tufa structures. "Sublacustrine deposits of calcareous tufa (sinter), which form pavements, mounds, and towers in alkaline lakes throughout the world, become exposed as evaporation reduces lake levels. Three modes of origin have been proposed for such tufa deposits: (i) physicochemical precipitation, (ii) biological precipitation by algae, and (iii) combined physicochemical and biological precipitation. Presently there is general agreement that the basic mechanism is physicochemical, with local algal activity influencing only form and surface texture." (R6) See X4 for more on Mono Lake structures.

X3. Ice pyramids in rivers.

The Bozenkill. New York. "Under certain weather conditions, usually in February or very early March, one may often see the building of volcanic peaks in replica at the foot of many of the cascades---volcanoes of creamy, frozen foam. They are a rare and beautiful spectacle. During a winter thaw the pulse of the stream which has for a long time been throbbing under a thick coat of ice, is suddenly quickened by a hundred invisible rivulets that find their way down through the hill meadows and wild pastures. Even before the thaw one can hear the muffled tinkling of the water as it slips over the ledges and hurries on from pool to pool. Then the activity is increased until the stream finds vent at the foot of some little fall where the ice is thinnest and where the observer may witness a real volcano, or sometimes a group of them in eruption.

The accumulated foam is tossed through this vent until a low mound is formed, frozen of course, for the cold wave that follows

Tufa towers at Mono Lake, California. (X2)



Pyramid of frozen foam on the Bozenkill, New York. (X3)

the thaw must assist at the building. Though the temperature falls, the mound continues to increase until just over the vent a hollow cone slowly rises, due to the agitation and pressure below. The live foam is constantly forced to the top where it spills over and freezes until a wonderful volcanic peak in miniature results, often five or six feet high, and more beautiful and symmetrical than the old pictures of south-polar volcanoes in the school geographies of our youth. To add to the similitude these volcanoes become extinct after a time, the internal action subsides or ceases, the final jet of foam is frozen, the peak is sealed at the top, and the geological likeness in complete." (R5)

X4. Columnar, concretionary sand structures. These are often associated with tufa structures. (See X2.)

Mono Lake, California. Abstract. "Associated locally with well-known tufa mounds and towers of Mono Lake, California, are subvertical, concretionary sand structures through which fresh calcium-containing artesian waters moved up to sites of calcium carbonate precipitation beneath and adjacent to the lake. The structures include closely spaced calcite-impregnated columns, tubes, and other configurations with subcylindrical to bizarre cross sections and predominantly vertical orientation in coarse, barely coherent pumice sands along the south shore of the lake. Many structures terminate upward in extensive calcareous layers of caliche and tufa. Locally they enter the bases of tufa mounds and towers." The sand towers are only a few feet high. (R6)

X5. Columnar solution pipes.

The Pinnacle Desert, Western Australia. In Namburg National Park, one may view thousands of calcified and silicified spires. Some of the columns reach 10-20 feet, and many take on bizarre shapes. They are thought to have formed when the region was covered with sand dunes. Rainwater sinking down through the sand absorbed minerals, which were later precipitated out deep in the sand. (R7)

X6. Undersea basaltic pillars and buttes.

East Pacific Rise. "The diameter of the approximately cylindrical pillars ranges from 0.5 to 2 m. Some pillars are made of multiple coalescent cylinders. The tops of the pillars are glassy, funnel-shaped and always widening upwards. The pillars were presumed to be hollow from several observations of gashes or openings in the vertical walls of the pillars. This was demonstrated during dive CY 78-19 to the south where a small pillar was toppled by CYANA and subsequent examination revealed a circular canal along the axis of the pillar. The outer surface of the pillars is marked by centimetre-thick glassy, subhorizontal ledges extending several centimetres from the outer vertical surface of the pillars.....Some pillars are inclined or slightly curved; others get narrower towards the base. The pillars are almost totally aphyric and have the same bulk composition as other lava types recovered in the axial zone of the East Pacific Rise at 21°N." The basalt pillars occur in a forest-like arrangement. They are believed to be the remnants of tubes through which lava flowed, filling a lava pool, which eventually drained away. When the solidified roof of the lava pool collapsed, the solidified tubes were left. (R8)

Columnar solution pipes in the Pinnacle Desert, Western Australia. (X5)

New England Seamounts. From the Alvin submersible, strange basaltic pillars were observed. See description in ETH3-X1. (R9)

Basalt pillars from the East Pacific Rise. See text for one theory of formation. (X6)

X7. Mud pillars.

Chilean Andes. "In the Chilean Andes of Tarapaca there exists in a certain place some remarkable series of pillars of earthy mud, formed by disintegrated rock. These strange pillars, which look like groups of statuary, often are of 10 to 30 feet in height, formed of material impregnated with sulfate of lime. During the day and under the heat of the sun they become soft and with a muddy-appearing surface, but at night become exceedingly hard, like frozen mud---the effect of temperature upon the sulfate of lime which they contain. The elevation is more than 14,000 feet. In the Peruvian Andes very remarkable gravel and conglomerate pillars are encountered at high elevations of the most weird forms, also due in some cases to action brought about by mineral impregnation." (R2)

X8. Columnar freaks of erosion. "Standing alone on a forested slope 55 miles east of Kamloops, British Columbia, is a remarkable, monument-like column of rocks known as The Pillar.

.....

You won't see The Pillar until you have climbed nearly to its rocky base---about 500 yards from the lake. Suddenly you will see the tall spire, like some stony totem pole. It looks manmade, its many sizes of rocks seemingly cemented together with a yellow-brown mortar. Actually, this column is all that is left of the load of rocks and sand once deposited here by an ancient river." The photograph accompanying this short travel note shows that the column is topped by a large flat rock, which has helped discipline the forces of erosion. (R13) Obviously there is nothing anomalous here. (WRC)

References

R1. "The Origin of 'Nieves Penitentes'," Geographical Journal, 26:91, 1905. (X1)
R2. Enock, C. Reginald; "Surface Forms in Western South America," Geographical Journal, 31:684, 1908. (X1, X7)
R3. "Nieve Penitente in the Himalayas," Geographical Journal, 34:570, 1909. (X1)
R4 Packard, Charles; "Mysterious Giants of the Desert," Rocks and Minerals, 23: 103, 1948. (X2)
R5. Christman, W.W.; "Volcanoes of Foam," Nature Magazine, 7:144, 1926. (X3)
R6. Cloud, Preston, and Lajoie, Kenneth R.; "Calcite-Impregnated Defluidization Structures in Littoral Sands of Mono Lake, California," Science, 210:1009, 1980. (X2, X4)
R7. Coate, Yvonne, and Coate, Kevin; "The Pinnacle Desert," booklet, no date. (X5)
R8. Francheteau, J., et al; "Basaltic Pillars in Collapsed Lava-Pools on the Deep-Ocean Floor," Nature, 281:209, 1979. (X6)
R9. Heirtzler, J.R., et al; "A Visit to the New England Seamounts," American Scientist, 65:466, 1977. (X6)
R10. Workman, William Hunter; "An Exploration of the Nunkun Mountain Group and Its Glaciers," Geographical Journal, 31:1, 1908. (X1)
R11. Odell, N.E.; "Observations of the Rocks and Glaciers of Mount Everest," Geographical Journal, 66:289, 1925. (X1)
R12. Lliboutry, Louis; "The Origin of Penitents," Journal of Glaciology, 2:331, 1954. (X1)
R13. "B.C. Curiosity...The Pillar," Sunset, 114:16, April 1955. (X8)
R14. Scholl, David W.; "Pleistocene Algal Pinnacles at Searles Lake, California," Journal of Sedimentary Petrology, 30: 414, 1960. (X2)

ETM13 The Andes Ice Islands

Description. Layered islands of freshwater ice that rise several meters above saline lakes. Known so far only from the Andes, these ice islands may be as long as a mile.

Data Evaluation. One scientific study of the ice islands is at hand, plus some more casual observations. Rating: 2.

Anomaly Evaluation. While some sort of freeze-thaw action seems a likely explanation of the ice islands, this remains surmise. No laboratory demonstrations have been attempted. It is not inconceivable that some unrecognized geological process is at work here. Rating: 2.

Possible Explanations. The freezing of fresh pore water in the lake sediments.

Similar and Related Phenomena. Islands of freshwater ice have been reported in the arctic. Of perhaps similar origin are hydrolaccoliths (ETM10) and some patterned ground (ETP1).

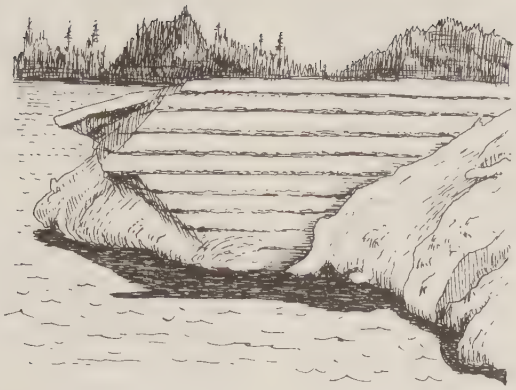
Examples

X1. Bolivia, Lake Colorada. "It must be one of the most unearthly places on Earth: a shallow salt-water lake with white shores in the Andes highlands, pierced by islands of freshwater ice nearly six metres tall and striped side to side as neatly as a stack of writing tablets." (R1)

X2. General observations. Lake Colorada's freshwater ice islands are not unique. At least ten saline lakes in southwest Bolivia and northeast Chile display similar ice islands. Those on Lake Colorada, however, are the most perfectly formed and show the layering best.

The Andes ice islands may be up to 1.5 kilometers long, and rise to 7 meters above the water surface. They may extend out under the unfrozen lake sediments for tens of meters. The tops of the ice islands are covered with dry, white sediments, mostly aragonite or calcite. The strata of nearly pure fresh water are up to 12 centimeters thick and alternate with strata 10-35 centimeters thick that contain frozen sediments in a lattice of pure-ice partitions.

One theory has the ice islands forming by the freezing of fresh pore water of lake



Sketch of a layered ice island, Lake Colorada, in the Bolivian Andes. (X1)

sediments during the "little ice age." (R2)

It is stated that islands of unlayered freshwater ice have been found in the Arctic waters; but no further information is given. (R1)

References

R1. "Who Made the Andes Islands of Ice?" New Scientist, 96:272, 1982. (X1, X2)

R2. Hurlbert, Stuart H., and Chang, Cecily C.; "Ancient Ice Islands in Salt Lakes of the Central Andes," Science, 224:302, 1984. (X2)

ETM14 Natural Beach Pyramids

Description. Three-sided pyramids of beach pebbles or sand arranged in a row along a beach. The pyramids may be a couple of feet high and 30 feet across.

Data Evaluation. Only one example of this curious phenomenon has been recorded---from the South Pacific. There is no information, so far, as to how often and how widely this phenomenon occurs. Rating: 3.

Anomaly Evaluation. Ordinarily, beach sculpturing by the sea is not included in this Catalog, but the New Hebrides pyramids are so different and delightful that an exception is made. The precise type of water action responsible for a long row of fair-sized pyramids is not known, but there is certainly no great mystery here. Rating: 4.

Possible Explanations. Some unrecognized combination of waves and currents.

Similar and Related Phenomena. The great variety of beach ripples.

Examples

X1. New Hebrides. "While engaged recently in biological research in the New Hebrides (in the Pacific Ocean) under the Percy Sladen Trust. I came across a curious geological phenomenon on the black sandy beach to the east of the mouth of the R. Yoro in Big Bay, Espiritu Santo. I have never heard of anything resembling it in any part of the world.....

All the way along the beach for three or four miles there extends a row of piles of pebbles. Most of these piles are a couple of feet high in the middle and a dozen paces

across. They are covered at high tide and wholly or nearly wholly exposed at low tide. The constituent pebbles, of black volcanic rock, are mostly oval in shape, somewhat flattened, and perhaps three or four inches long. Between each pile of pebbles and the next, there is in most cases an expanse of sand several paces across, which is almost bare of pebbles. There is a tendency for the piles to assume a definite shape, namely, the shape of a very low three-sided pyramid, inclined on the beach in such a way that the landward side of the pyramid is almost level. In some cases a second, smaller pyramid has been plastered on, as it were, to the seaward side of a large one. Each pile of pebbles rests on a similarly shaped accumulation of sand; and where there are no pebbles, the sand alone continues the succession of pyramids.

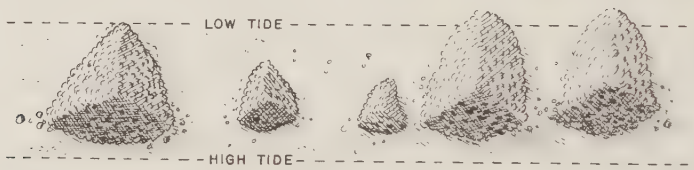
I erected sticks to mark the position of two adjacent well-formed pyramids, to see whether they would shift their position at all. Next day one of them was as before, while the other had shifted slightly, and a small one had risen between them. Two days later again the two marked pyramids had disappeared, one completely, the other so nearly completely that I should not have guessed of its previous existence had I not marked it before.

It is perhaps significant I noticed a strong current running in a westerly direction parallel to the shore.

This curious row of low pyramids extends along the beach to the west of the mouth of the river also; but here the phenomenon is less clearly defined, for the stones are much more numerous and the pyramids are not separated by bare areas. At Tasiriki, near the south-west corner of the same island, there is a somewhat similar row of piles of pebbles." (R1)

References

R1. Baker, John R.; "Natural Pyramids on a Beach in the New Hebrides," Nature, 122:843, 1928. (X1)



Naturally formed beach pyramids from the New Hebrides. (X1)

ETP PATTERNED GROUND, SOIL POLYGONS

Key to Phenomena

ETP0 Introduction

In the size range from a foot to several hundred feet, the anomalist finds a wide array of polygons, circles, and straight lines of loose materials, such as sand, gravel, and stone blocks. It is natural to ask how such loose materials came to be arranged in such satisfying geometrical shapes. Several physical forces are obviously at work: freezing and crystal growth (expansion), and thawing and desiccation (contraction). The rhythmic application of these forces tends to separate and geometrically arrange loose materials. The details of these separation and rearrangement processes are not well-understood, although no claim is made here that the phenomena are highly anomalous. Both patterned ground and desiccation polygons are easily brushed off as trivial probably long-ago-explained. In fact, we do not know all the details about how large-scale order is imposed on loose, structureless materials. Why do some soils have planes of weakness a hundred feet long, while adjacent soils have none? How do stone circles change into stone stripes? These are small problems, to be sure, but intriguing nonetheless.

Phenomena cataloged elsewhere in this volume are closely related. The Alaskan oriented lakes (ETB1) could represent a type of patterned ground. Gilgai soils (ETB4) could be considered patterned ground of a sort, even though we have classified it with "small depressions." Finally, desiccation polygons are probably generically related to joint patterns in sedimentary and igneous rocks, a subject treated in a forthcoming volume.

ETP1 Patterned Ground in Cold Climates

Description. Geometrically organized accumulations of stones, sand, gravel, and soil. The most common patterns are circles, nets, polygons, steps, and stripes. The geometrical figures are created by the natural separation of coarse from fine material and/or the elevation of elements of the design.

Data Evaluation. Patterned ground has always had a special fascination for scientists, perhaps because of the naturally generated geometrical figures. The literature here is large, and we present a small, but hopefully representative, sample. Rating: 1.

Anomaly Evaluation. Patterned ground theories abound. (See below.) The theoretical situation is similar to that for the Mima Mounds. Since most patterned ground is found in polar and subpolar regions, it is tempting to blame everything on freeze-thaw cycles and ice action. It is not this simple, because some patterned ground occurs in much milder climes. Also, the observed rapid formation and dissolution of patterned ground---in the space of weeks or months---adds to the theorists' problems. The unsolved origin of patterned ground is not one of geology's major problems; it is simply one of those niggling puzzles that no one has bothered to solve. Rating: 2.

Possible Explanations. Freeze-thaw cycling; mass heaving; local differential heaving; frost-generated hydrostatic pressure; ice-thrusting; thaw contraction; contraction due to drying; frost wedging; etc.

Similar and Related Phenomena. Gilgai topography (ETB4 and ETM2); block fields (ETP2); giant drying cracks (ETP3); polygonal fracturing and jointing of rock.

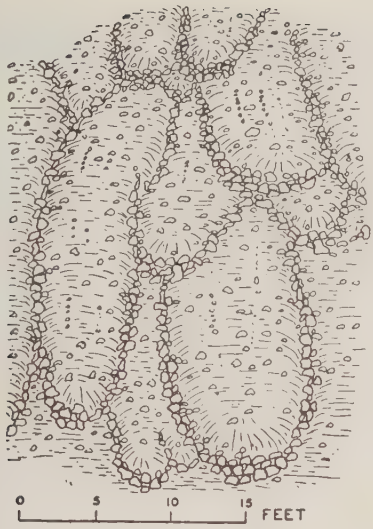
Examples

X1. General observations.

By C. S. Elton. From his introduction to Spitzbergen patterned ground. " In order that the reader may appreciate the bearing of the facts recorded later on in this paper, it is necessary to give a brief summary of our general state of knowledge of polygonal soil-markings in Spitzbergen. The first point is that in Arctic and in many Alpine countries mixed materials containing stones and mud, which may be derived from various sources (weathering rocks, marine or freshwater deposits, etc.) instead of remaining as a heterogeneous mixture, often tend to become sorted out in definite ways, the stones being segregated from the mud. On flat or slightly sloping ground this arrangement usually takes the form of isolated circles of stones surrounding mud-centres, or more commonly a polygonal network of stone borders with mud occupying the rest of the ground. The area of each circle or polygon varies from 2 to about 30 feet, 6 to 8 feet being frequently found. On steeper slopes the stone borders take the form of parallel strips with mud in between them. The regions of the world where this differential arrangement occurs have a cold climate, and the ground is permanently frozen except for a thin surface-layer, a few feet in thickness, which thaws during the short summer. It is reasonable to suppose that this circumstance is in some way connected with the differential arrangement. Various theories have been proposed to explain the phenomena, none of which carries conviction by itself. " (R3)

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

The origin of patterned ground is far from satisfactorily explained. Hypotheses are reviewed and summarized according to dominant processes as follows: (1) ejection of stones from fines by multigelation (often-repeated freezing and thawing), (2) mass heaving, (3) local differential heaving, (4) cryostatic movement (movement by frost-generated hydrostatic pressure, (5) circulation due to ice thrusting, (6) frost wedging, (7) absorption of water by colloids, (8) weathering, (9) contraction due to drying, (10) contraction due to low temperature, (11) contraction due to thawing, (12) convection due to temperature controlled density differences, (13) convection due to



Sorted steps in glacial till. (X1)

moisture-controlled changes in intergranular pressure, (15) differential thawing and eluviation, (16) vibration, (17) artesian flow, (18) rillwork (for stripes), (19) solifluction in combination with one or more of the above processes (for stripes).

Conclusions regarding origin are that: (1) the origin of most forms of patterned ground is uncertain; (2) patterned ground is polygenetic; (3) some forms may be combination products in a continuous system having different processes as end members; (4) climatic and terrain interpretation of patterned ground, both active and 'fossil', is limited by lack of reliable data about formative processes." (R7)

X2. Circles. "Sorted circles are patterned ground whose mesh is dominantly circular and has a sorted appearance commonly due to a border of stones surrounding finer material.....Debris islands are sorted circles occurring amid blocks or boulders. ....Sorted circles form singly or in groups and where crowded closely together may be difficult to distinguish from sorted polygons. ....In Svalbard where sorted circles are classically developed they vary in diameter from 0.8 to over 3 m. Miniature sorted circles within larger sorted forms have been described.....Nonsorted circles are patterned ground whose mesh is dominantly circular and has a nonsorted appearance due to the absence of a border of stones such as that characterizing sorted circles." The normal gilgai of Australia resemble nonsorted circles. (R7) In this Catalog, gilgai topography is covered in ETB4. Note that gilgai country is definitely not polar or alpine.

Spitzbergen. This island north of Norway is home to large numbers of almost perfect sorted circles about 2 meters in diameter. "The features, generally round though not perfect circles, consist of gravel and large stones that lie in protective rings around mounds of soil. In between the stone rings and the soil is a distinct depression, or trough, that remains relatively clean." (R16; R15)

Idaho. On the western Snake River plain, one can find small circular areas of soil from 3 to 10 feet in diameter. These closely resemble the debris islands of sorted circles. (R10)

X3. Nets. "A sorted net is patterned ground whose mesh is intermediate between that of a sorted circle and a sorted polygon and has a sorted appearance commonly due to a border of stones surrounding finer material....Earth hummocks are a particular type of nonsorted net with a mesh characterized by a three-dimensional knoblike shape and cover of vegetation....Earth hummocks form in groups rather than singly. Earth hummocks in Iceland are 25-50 cm high and 1-2 m in diameter." Hummocks are almost certainly related to frost action. (R7) See also ETM10-X2.

Washington: Puget Sound region. A nonpolar example of rather typical patterned ground. "In the Arctic and sub-Arctic lands and also in the high mountains intensive frost action produces distinctive structures in the surface soil. These 'retriculated' or 'cellular' soils have been described from many localities by me and by many other observers. The published discussion of this subject by Bryan and a recent conversation with him have recalled to my attention observations made some years ago in the Puget Sound region. Here on the prairies in the vicinity of American Lake, southwest of Olympia, Washington, are gravel outwash plains of the earlier ice advance. These localities were outside the border of the last (Wisconsin) ice and, therefore, must have endured a periglacial climate. The most significant features are segregations of gravel and soil that have a retriculated pattern. Over large areas the surface is divided into approximately equidimensional patches of soil

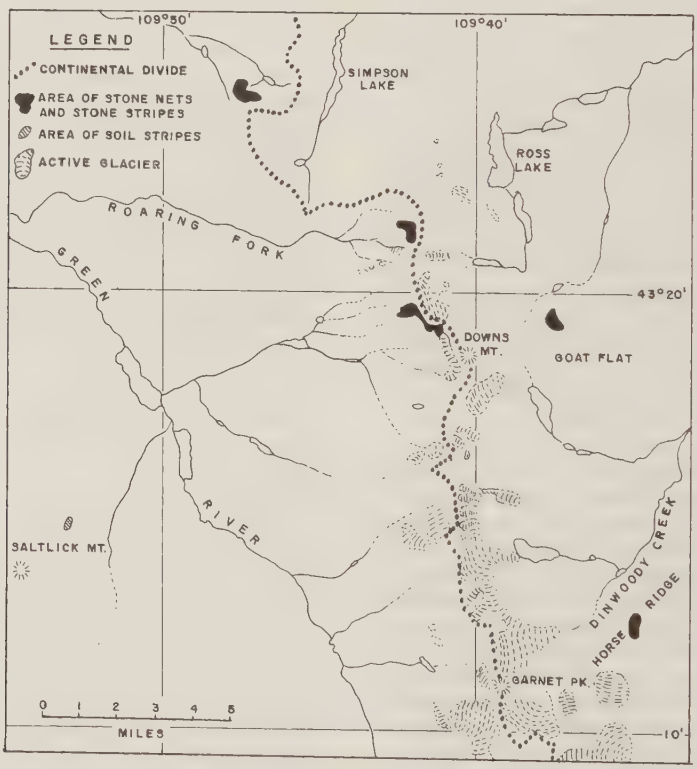
nearly clear of stones that are separated from each other by narrow strips of gravel and boulders having an open texture and little or no interstitial soil. As a general rule the soil patches stand higher than the boulder septae. In many places the margins of the boulder septae are higher than their centers. Major lines of boulder concentrations persist for long distances and branch up slope in characteristic drainage arrangement. In other words, one accustomed to the Far North finds here, under a present genial climate, a thoroughly familiar set of features, identical in every respect with the products of sub-Arctic frost rearrangement of mixed alluvial materials." (R4)

South Dakota. Rather typical nets and stripes are forming today in South Dakota soils. A strong resemblance to Australian gilgai soils exists. (R12)

Wyoming. G.M. Richmond has described more nonpolar nets in the Wind River country. "The stone nets in the Wind River Mountains are polygonal structures which form a regular netlike arrangement over areas as much as a mile in extent. They occur on slopes of 4° or less; and, as the slope steepens, they gradually lose their polygonal shape and become elongated until they merge into stone stripes.

The stone nets have from four to six sides and are 5-7 feet in diameter. Each structure consists of a central mass, herein referred to as the 'center', which is 2-4 feet across and which contains fine angular gravel, sand, and silt, with a little clay and a scattering of larger rock fragments. Around the center is a channel-like border, 18 inches to 2 feet wide, which is filled with angular rock fragments, 4 inches to 2 feet in diameter. The fragments are loosely packed in an unstable position and in many cases are oriented with their longer axes vertical." (R9)

X4. Polygons. "Sorted polygons are patterned ground whose mesh is dominantly polygonal and has a sorted appearance commonly due to a border of stones surrounding finer ma-



Map of patterned ground occurrences in the Wind River Mountains, Wyoming. (X3)

terial....In contrast to circles, sorted polygons apparently never develop singly. As with sorted circles, vegetation if present does not in most places emphasize the pattern as strongly as it does in nonsorted forms of patterned ground. According to Steche sorted polygons range in size from a few centimeters in diameter to large forms 10 meters across, with the size tending to increase with increasing severity of climate and availability of water; however, miniature forms may occur in vegetation-free central areas of large forms as well as independently. ....Sorted polygons are characteristic of polar, subpolar, and alpine environments. They are much more widespread than sorted circles....A peculiar sorted polygonal form from Christmas Island in the Pacific Ocean and sorted polygonal patterns from the Libyan Desert illustrate the fact that sorted polygonal patterns are not confined to polar, subpolar, or alpine environments....Ice-wedge polygons are nonsorted polygons characterized by bordering ice wedges....Ice-wedge polygons are typically large. Although diameters as small as 1-3 m have been reported, and 4.6 m (15 feet) is not uncommon, the average size is larger. Steche cited a diameter range of 10-40 m and Troll a range of 15-20 m. Black has given maximum diameters of 100 m or more. The pattern tends to be tetragonal, but pentagonal and hexagonal forms occur also. ....The fallacy of assuming that the formation of all forms of patterned ground, especially nonsorted polygons, is confined to polar, subpolar, or alpine regions is demonstrated by desiccation polygons in temperate and arid regions, by Lang's and Knechtel's description of nonsorted polygons 24.5-27-7 m in diameter in Animas Valley, New Mexico (ETP3), and by the recent formation in Poland of nonsorted polygons 1.5-3 m in diameter, attributed to desiccation, which are very similar to arctic forms." (R7)

Alaska. The ice wedge polygons observed here may be related to the Alaskan oriented lakes. (ETB1) "One of the surface forms of the coastal plain visible to the air traveller is the nearly ubiquitous ice-wedge polygon. Indeed, ice-wedge polygons are the most conspicuous features over thousands of square kilometers of Alaska.

The polygonal nature of the patterns results from the intersection of numerous shallow troughs which occur on the tundra surface. These troughs in turn are the surface manifestation of vertical wedges of ice which form a complicated honeycomb network beneath the ground.

.....

It is only in the upper seven to ten metres of the permafrost that ice wedges form. The size, spacing and growth rate of these wedges depend on the texture, strength and water content of surface materials, the nature of the snow cover and temperature variability.

There have been many theories to explain the formation of ice wedges. However, the thermal contraction theory which was first discussed in detail as early as 1915 by F. de K. Leffingwell is accepted by most workers today. During winter, thermal contraction causes vertical fractures in the frozen ground. These cracks, although very narrow, are likely to be two or three metres deep. The combination of snow, meltwater and hoarfrost which fills these cracks forms a more-or-less pure ice vein upon freezing. The next season's fracture occurs in this ice vein which is now a linear zone of weakness in the terrain. Each year the frost crack occurs, additional growth of the vein results. In time, up to several thousand years, this more or less annual increment produces a wedge which may grow to more than five metres in width.

Such ice wedges intersect each other to form a subterranean honeycomb pattern. There is not always evidence for this on the surface, but when there is it takes the form of a several sided, roughly equidimensional figure. The number of sides usually varies from three to six. The size of the polygons, which ranges from a few metres to more than thirty metres, depends on the variation in the nature of the ground material and the thermal stress resulting from lowering temperature during autumn and winter.... In many places on the North Slope frost cracks may parallel one another for great distances. Subsequent cracking results in polygons that are four-sided." (R14) Many of the Alaskan oriented lakes are rectangular, although the lakes are usually much larger than the polygons just mentioned. (See ETB1.) No satisfactory explanation has been found for the geometrical forms created by ice wedges. The same sort of question arises with desiccation polygons (ETP3).

The U.S. Appalachians. "Abstract. Sorted stripes, nets, and polygons in the Appalachians of Pennsylvania, West Virginia, and Virginia display patterns and stone orientations visibly similar to those of ground patterned under current cold climates. Larger forms appear inactive or fossil and may provide data on the paleoclimate and slope stability." (R13) The authors do not claim that patterned ground

is currently being formed in the Appalachians. However, see the next item. (WRC)

Maine. "The authors have found modern stone nets and stone stripes on Cadillac Mountain and on Jordan Mountain, and Professor Edward H. Perkins, of Colby College, has found them on Sargent Mountain, Mount Desert Island, Maine. On Cadillac Mountain they were observed as low as 1,300 feet and on Jordan Mountain as low as 1,100 feet, which makes these the lowest described Polygonboden in the United States. The nets and stripes on Jordan Mountain are embryonic and vague but rather numerous. Those on Cadillac Mountain are in many cases well formed, as well formed as any the authors have seen on Mount Washington, besides being much more numerous. These structures are found in the small barren patches or more or less modified glacial till, sometimes admixed with disintegrated granite, which is still preserved in places. The average diameter of the nets is one to two feet and the stripes are from four to five feet long. These are undoubtedly being formed at the present time and are similar to the modern stone nets and stone stripes which Antevs has described. These structures are undoubtedly present on other peaks of Mt. Desert Island..." (R5)

Spitzbergen. Besides the stone circles described above, Spitzbergen is also host to "mud polygons." These occur on the Reindeer Peninsula in a thin sheet of boulder-clay containing shells and rounded stones. "On the middle and end of the peninsula the boulder clay contains comparatively few, usually small, stones, and presents in many places the appearance of having been thrown up into hummocks, which occur at regular intervals of 2 or 3 yards. The channels which delimit the hummocks are polygonal in plan, sometimes showing a clear hexagonal arrangement, and form a continuous network between them. On one area, where the boulder clay was about 5 to 10 feet thick (as seen from exposures on the shore), this hummocking of the ground was very regular, the polygons being about 5 to 8 feet in diameter, and 6 to 12 inches in height. The well-marked convex domes of the polygons are usually bare of plants, except for a few lichens; but in the channels there is nearly always a closed mat of plants---chiefly the Arctic willow (Salix polaris). The plants growing in the channels further emphasize the polygonal appearance of the ground, and they also have in fact an important influence on the polygons, by stabilizing the soil, as is shown later on. A good many stones up to about 5 inches in diameter occur scattered over the surface, and also down in the clay, but they show no differential arrangement." (R3) Interestingly enough, Spitzbergen's circles are well-sorted, but the mud polygons are not. (WRC)

New York. Shale polygons are found at Letchworth Park, bordering the Genesee River. "The stone-centered polygons consist of slabs of shale approximately 1 foot in diameter and 3-4 inches thick, around which are arranged fragments of fresh, dark-gray thin-bedded shale averaging 3 inches in length, somewhat less in width, and up to $\frac{1}{4}$ inch in thickness. Most of the fragments stand nearly vertical, but some lie flat. The pieces lie parallel to the sides of the large slabs, radiate as if from a center, or lack

Fissure polygons combined with stone polygons on Spitzbergen. (X4)

definite patterns. Usually they rise above the central block, but not markedly so. All are tightly packed and complexly interlocked. Excavation showed that the upright surface fragments meshed with others beneath, also in a vertical position. Usually less than the equivalent of two layers was present." (R6) This is a most interesting variation of the sorted polygons---and in warm latitudes, too. (WRC)

Washington. Stone polygons 8-9 feet across have been observed in the Menastash Ridge area, in central Washington. Mounds are also abundant here. (R18)

England. "The site is on the west side of the River Avon, 1/2 mile west of Abbot's Salford and four miles north-north-east of Evesham, map reference SP 060501, Latitude 52°9' N., Longitude 1°55' W. It was photographed in late July, 1958, and the differential ripening of the crops brings out a system of large polygonal markings which are clearly the result of some natural process modifying the permeability of the subsoil and not due to any human agency. The polygons vary in size, the smallest being about 25 feet across, the largest perhaps 80 or 100 feet." These patterns are considered to be relics of a much colder climate. (R19)

North Wales. Observations of the conversion of polygons into stripes. "This communication describes certain preliminary observations made on stone polygons in Snowdonia during the summer of 1957, observations which appear to reveal the impermanent character of these structures. The polygon area has been briefly described by Pearsall: it consists of several connected flat expanses of bare detritus, formed from the erosion of the Juncetum squarrosi occupying the broad ridge between Carnedd Llywelyn and Foel Grach summits in the Carneddau at 915-945 m. The area was casually examined several times during the summer of 1956, but no polygons were observed, the detritus being unsorted. In the course of field work during the first week of July 1957 well-defined stone polygons were noticed over the whole area; each polygon was 45-60 cm. in diameter, with a centre of fine gravelly detritus and a rim, 10-15 cm. wide, of coarse stone (3-10 cm.); these coarse stones extended downwards for 10-15 cm., finally merging into a matrix continuous with the polygon centres. Ten days later, after predominantly fine weather but with a few days of rain with a blustery north-east wind, it was noticed that a large proportion of the polygons had, by apparent obliteration of the cross-connexions, been converted into stone stripes 2-4 m. long, orientated more or less at right angles to the direction of the prevailing wind." Gradually, the polygons disappeared and the stripes shortened. (R8) Any theory of polygon origin must account for this ephemeral nature of some populations of these structures. However, many polygons are exceedingly stable. (WRC)

X5. Steps. "Sorted steps are patterned ground with a steplike form and a sorted appearance due to a downslope border of stones embanking an area of finer material upslope.....Sorted steps form in groups, rarely if ever singly. Vegetation if present does not generally emphasize the pattern as strongly as in the nonsorted forms. The steps described by Sharp are 1.2-2.4 m (4-8 feet) wide, parallel to the contour, and up to 7.6 m (25 feet) long in a downslope direction; the stone borders are most pronounced at the downslope end where they form distinct embankments." Nonsorted steps exist, and they seem closely related to hummocks. (R7) See ETM10-X2.

X6. Stripes. "Sorted stripes are patterned

Longitudinal section of sorted steps. (X5)

ground with a striped pattern and a sorted appearance due to parallel lines of stones and intervening strips of dominantly finer material oriented down the steepest available slope.... Sorted stripes never form singly; they are essentially parallel and may be sinuous.... The width of individual stony stripes ranges from a few centimeters to 1.5 meters (5 feet) or more, and the intervening stripes of finer material may be two to four times wider, according to Sharp. Sharp also reported that he was able to trace individual stripes continuously for several hundred feet." Nonsorted stripes resemble the wavy gilgai common in Australia. (R7) Stripes, sorted and unsorted, commonly accompany other types of patterned ground. But, as with the more complex forms, the origin of steps remains uncertain. (WRC)

Antarctica. Stripes or ripples of pebbles one foot high and about 5 feet crest-to-crest have been found on ice-free land. Many pebbles are a half inch long, a few are more than an inch long. They are thought to be windrows. (R11) If these ripples of pebbles are truly wind-arranged, they are out-of-place here, because wind plays little if any role in the formation of classical patterned ground. (WRC)

Utah. The following occurrence of stone stripes is worth mentioning because of the low altitude and lack of similar stripes in comparable localities, indicating special conditions of some sort. "Foothills of Tertiary Salt Lake group fanglomerate on the east side of Cache Valley at the Utah-Idaho line are marked by well-developed stone stripes. Associated with these are solifluction lines and terraces. Flow of coarse mantle from the foothill area has largely erased the shore lines of Lake Bonneville both at the Bonneville and Provo levels and produced a ramplike landform extending to the valley floor. Elevation of the locality is 4700-5700 feet." (R17)

X7. Striations on gravel bars. Long furrows or grooves occurring in gravel bars in subpolar climes are not usually considered to be patterned ground, since they undoubtedly have very different origins.

Alaska. "The presence of furrows in gravel bars of spreading and meandering streams in Alaska seems not to have been mentioned in the literature on Alaskan geology.

These channels may be seen on the extensive bars of the Yukon and of the Porcupine rivers throughout the Yukon Flats. The bars are remarkably well developed along the Porcupine for about a hundred miles above its union with the Yukon and in low water they are exposed as broad, gravelly, and sandy beaches from one to five miles in extent. These extensive bars give excellent opportunity to observe the striations. An uprooted tree is often seen lodged on a bar with a channel marking its trail." The striations are often multiple and parallel. They are sometimes a foot or two wide and stretch for hundreds of yards. Ice and/or floating trees may gouge out these furrows. (R1)

References

R1. Barnett, V.H.; "Striations in Gravel Bars of the Yukon and Porcupine Rivers, Alaska," Journal of Geology, 16:76, 1908. (X1)

R2. Huxley, J.S., and Odell, N.E.; "Notes on Surface Markings in Spitzbergen," Geographical Journal, 63:207, 1924. (X4)

R3. Elton, Charles S.; "The Nature and Origin of Soil-Polygons in Spitzbergen," Geological Society of London, Quarterly Journal, 83:163, 1927. (X1, X4)

R4. Eakin, Henry M.; "Periglacial Phenomena in the Puget Sound Region," Science, 75:536, 1932. (X3)

R5. Nichols, Robert L., and Nichols, Frances; "Polygonboden on Mt. Desert Island, Maine," Science, 83:161, 1936. (X4, X6)

R6. Rozanski, George; "Stone-Centered Polygons," Journal of Geology, 51:330, 1943. (X4)

R7. Washburn, A.L.; "Classification of Patterned Ground and Review of Suggested Origins," Geological Society of America, Bulletin, 67:823, 1956. (X1-X6)

R8. Tallis, John H., and Kershaw, K.A.; "Stability of Stone Polygons in North Wales," Nature, 183:485, 1959. (X4, X6)

R9. Richmond, Gerald M.; "Stone Nets, Stone Stripes, and Soil Stripes in the Wind River Mountains, Wyoming," Journal of Geology, 57:143, 1959. (X3, X6)

R10. Malde, Harold E.; "Patterned Ground in the Western Snake River Plain, Idaho, and Its Possible Cold-Climate Origin," Geological Society of America, Bulletin, 75:191, 1964. (X2, X4, X6)

R11. "Strange Pebble Ripples Formed at South Pole," Science News Letter, 88: 324, 1965. (X6)

R12. White, Everett M., and Agnew, Allen F.; "Contemporary Formation of Pat-

terned Ground by Soils in South Dakota," Geological Society of America, Bulletin, 79:941, 1968. (X3, X6)
R13. Clark, G. Michael; "Sorted Patterned Ground: New Appalachian Localities South of the Glacial Border," Science, 161:355, 1968. (X4, X6)
R14. Walker, H.J., and Brewer, M.C.; "Patterns on the Alaskan Tundra," Geographical Magazine, 50:42, 1977. (X4)
R15. Weisburd, Stefi; "Halos of Stones," Science News, 127:42, 1985. (X2)
R16. Wick, Nancy; "Scientists Sort Out 'Sorted Circles' of Spitzbergen," The Oregonian, March 26, 1987. (X2) (Cr. R. Byrd)
R17. Williams, J. Stewart; "Stone Stripes at Low Altitudes, Northern Utah," Geological Society of America, Bulletin, 69:1749, 1958. (X6)
R18. Kaatz, Martin R.; "Patterned Ground in Central Washington: A Preliminary Report," Northwest Science, 33:145, 1959. (X4)
R19. Shotton, F.W.; "Large Scale Patterned Ground in the Valley of the Worcestershire Avon, "Geological Magazine, 97: 404, 1960. (X4)

ETP2 "Rock Cities" and Block Fields

Description. Large, squarish blocks of rock fractured and sculptured by natural forces so as to look like rude cities. Typically, the blocks are separated by regular "streets" at right angles to one another. The term "block field" is broader, designating large assemblages of stone blocks, but not necessarily with the geometrical regularity and sculpturing of the "rock cities."

Data Evaluation. Undoubtedly many more rock cities exist than we have found in the literature examined so far. Indeed, we have probably missed some well-known tourist attractions! The reality of the phenomenon is well-established but its extent is unknown. Geologists have in general paid little attention to "rock cities." Rating: 2.

Anomaly Evaluation. Many rock strata are characterized by regular jointing (a phenomenon to be treated in a later volume). Fracturing and eventual separation along these planes of weakness is to be expected in a periglacial environment. Likewise, the occasional sculpturing of rocks by erosion into forms resembling human works has little scientific significance. Thus, rock cities may have considerable popular appeal but present little that is anomalous. Rating: 4.

Possible Explanations. Ice wedging and erosion.

Similar and Related Phenomena. Rock rivers and boulder fields (ES); jointing in rocks (ES); large, lithified desiccation cracks in strata (ETP3-X3).

Examples

X1. Olean, New York. "The 'rock cities' near Olean and Salamanca, New York, consist of large blocks of massive conglomerate, ranging up to about 75 feet in length, separated by interconnecting passages along widened joint planes. The passages range up to several feet in width, and upwards of 10 feet in depth. Their walls are comparatively straight and approximately parallel, and follow a rectangular to angulate pattern. Adjoining the parent ledges, the blocks show no departure from bedrock either in dip or in level, but farther outward they display varying degrees of tilting and downward movement, grading into landslide masses. At present, the blocks appear to be immobile and undergoing gradual disintegration in place.

The enlargement of openings along joint planes without tilting or deleveling indicates a force acting only in a horizontal direction. Frost wedging is the one agency available to exert such a force to such a degree, and is believed to have pushed the blocks outward to the point at which gravitational forces introduced downward movement with accompanying disturbance. Conditions are no longer favorable for such processes, but must have been optimum during Wisconsin time,

when the ice front at successive times lay nearby to the north. The 'rock cities' are thus interpreted as a hitherto unrecognized species of periglacial phenomena." (R3; R1)

X2. Salamanca, New York. See X1. (R3)

X3. Southern Idaho. "In a basin of the Albion Range of southern Idaho, lies the extraordinary assemblage of natural forms known as 'Cassia City of Rocks.' Turrets and fortresses, towers and spires, mosques and monoliths, human and animal shapes, natural bridges and caves, 'bathtub' rocks, hollow boulders, and the like are carved from the granite outcrops. Nothing in North America matches this strange city, and Dr. Alfred L. Anderson, who describes it (Geology and Mineral Resources of Eastern Cassia County, Idaho, Idaho Bur. of Mines and Geol. Bull. No. 14, Moscow, Idaho, 1931) suggests that it even surpasses the fantastic Buffalo Rocks of Victoria, Australia....Dr. Anderson ascribes the formation of the rock city to "a complex set of factors involving deep granular disintegration and case-hardening under especially favorable climatic conditions, together with especially favorable structural features, not only the widely spaced sets of vertical and horizontal joints, but also the protective quartzite capping on the upper side of the basin and the flanking ridge on the lower side which has maintained a proper balance between erosion and weathering by not permitting too rapid removal of waste products such as would have occurred had erosion not been retarded by more resistant rocks." (R2) Although called a "rock city", it is not clear whether regular "streets" exist at Cassia. It may not be the sort of "block field" described in X1. (WRC)

X4. Blue Rocks, Pennsylvania. Abstract. "Blue Rocks (40°36'N., 75°55'W.) is a half-mile-long block field on the south slope of Blue Mountain, 3 miles northeast of Hamburg, Pennsylvania. The block field consists of angular blocks of Tuscarora Quartzite 4 inches to 20 feet long. The blocks were derived from strongly jointed quartzite cliffs on Blue Mountain and have been moved downslope over the Martinsburg Shale. On two sides of the field of open blocks are forested rubble deposits that contain boulders equivalent in size to those in the block field, but with fine material in the interstices. The rubble adjacent to the block field occurs as gently sloping, step-like terraces with fronts 10 to 30 feet high and slopes of 18° to 22°. The block field is separated from the source cliffs by about half a mile of rubble covered by mature forest." The authors believe that this block field was probably formed by solifluction or creep in the periglacial climate of the Wisconsin glaciation. (R4) Regular spacing of the blocks does not occur here, so that it can hardly be called a "rock city." (WRC)

X5. Baretown, Pennsylvania. A fascinating legend surrounds this rock city. It was supposedly built in ancient times by a force of 5,000 Indians, who had been enslaved by an even older race of white men! As with the New York cities (X1, X2), the rock involved is a conglomerate. Here follows an excerpt from W. M. Stapler's personal account of his investigation.

"Ascending the steep slope, the huge sandstone conglomerates looked like giant stepping stones jutting from the hillside. The crest, which is 200 ft. above the road level, and 650 ft. above Wallace Run in the gorge below, levels off to form a plateau. The northern end is a rocky rise, and all around you are the impressive remains of this fabled citadel. There is no underbrush. Only tall and healthy hardwoods shelter the scene. In this parklike setting the visibility was excellent and unhampered in all directions. Mother Nature was co-operating in setting the stage.

The boulders were so close now that there appeared to be avenues between, and avenues would open to courtyards or squares. There were overhanging shelves or balconies, there were dark defiles or cavernous depths below. Even if you had never read the fable of Henry Shoemaker, you would feel that there was something very unnatural about this place." (R5)

X6. The Front Range, Alberta. Abstract. "A rock labyrinth, a regular arrangement of large, joint-bounded chert blocks, separated by streets up to 15 m wide occurs on a dip slope of Upper Palaeozoic rocks in the Front Range of the Rocky Mountains, adjacent to the Red Deer River in Alberta. It is believed

to be caused by the development of ice wedges under earlier, periglacial conditions and to have been disturbed by later creep along weak units in the sedimentary succession. Labyrinth development may be a typical response of gentle dip slopes in cohesive rock units to periglacial conditions, particularly if systematic jointing exists perpendicular to the slope." (R6)

References

R1. Grahame, Wilder; "A Rock City," Scientific American, 67:100, 1892. (X1)
R2. "Cassia City of Rocks," Geographical Review, 23:488, 1933. (X3)
R3. Smith, H.T.U.; "Periglacial Frost Wedging in the 'Rock Cities' of Southwestern New York," Geological Society of America, Bulletin, 64:1474, 1953. (X1, X2)
R4. Potter, Noel, Jr., and Moss, John H.; "Origin of the Blue Rocks Block Field and Adjacent Deposits, Berks County, Pennsylvania," Geological Society of America, Bulletin, 79:255, 1968. (X4)
R5. Stapler, W. Mead; "Baretown---A Pennsylvania Legend," NEARA Newsletter, 7: 10, 1972. (X5) (NEARA = New England Antiquities Research Association)
R6. Simmons, J.V., and Cruden, D.M.; "A Rock Labyrinth in the Front Ranges of the Rockies, Alberta," Canadian Journal of Earth Sciences, 17:1300, 1980. (X6)

ETP3 Giant Expansion and Contraction Polygons

Description. Polygonal patterns of large size on arid playas, valley floors, and other surfaces. Polygon dimensions are often greater than 100 feet; fissures may be 15 feet deep and several feet across. The sides of most giant polygons are usually created during contraction of the soil due to desiccation, but at least in one case they formed by folds in expanding soils.

Data Evaluation. Dozens of sites display giant desiccation polygons. Aerial and ground reconnaisance has been carried out by several teams of researchers. The large extant literature is only sampled here. Rating: 1.

Anomaly Evaluation. Small networks of mud cracks, with cells measured in inches or fractions thereof, are within everyone's realm of experience. It is therefore tempting to assume that the polygonal fracturing of drying surfaces is well understood. This does not seem to be true, at least for the giant polygons considered here. Why some soils display these giant geometrical figures and others do not is not known. Certainly, the makeup of the soil, the climate, and other factors are important; but why do some soils crack so deeply along such long straight lines? How do these long range planes of weakness develop? Interesting though such questions may be, the answers will doubtless come with further research. No vital geological laws are at risk here, and the anomaly level is low. Rating: 3.

Possible Explanations. The basic causes of polygon formation are surface contraction or expansion. Although the soils involved seem structureless superficially, they obviously possess long planes of weakness, just as crystals have tiny planes of cleavage. Crack patterns have been explained in terms of the "principle of least work," which requires the polygons in drying soils or cooling solids (such as lava) to have maximum areas. (R7)

Similar and Related Phenomena. Patterned ground (ETP1); gilgai soils (ETB4); regular jointing in sedimentary rocks (ES, in a later volume); the so-called "rock cities (ETP2).

Examples

X1. Desiccation polygons. Such polygons are formed due to the contraction of the surface due to drying.

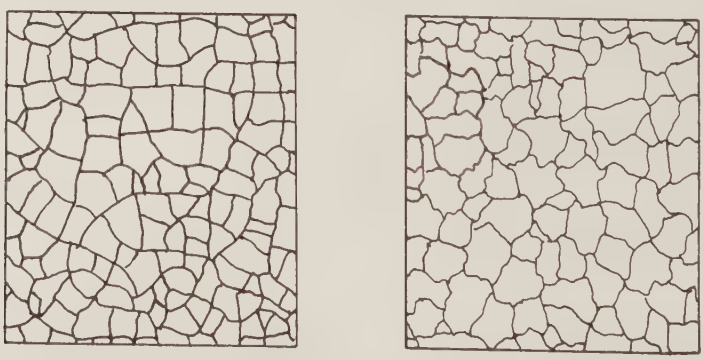
General observations. "Abstract. Several previous investigators have recognized giant polygonal fissure patterns in 6 playas of the Basin and Range Physiographic Province (Great Basin). This paper extends the study to 39 playas in Oregon, Nevada, California, Arizona, and New Mexico, with observations on the physical and mineralogical features of fissured and nonfissured areas.

Fissures are often 5 m deep and the polygons may attain a width of 300 m. These giant mud cracks develop in clay playas and are attributed to desiccation phenomena. As dehydration proceeds from the surface downward and penetrates the capillary fringe above the water table, shrinkage occurs, which ultimately results in rupture at depth that extends upward to the surface.

The mineral constituents of sediments in both the fissured and nonfissured areas are predominantly clay minerals, carbonates, salines, and analcite, with fine grains of quartz, feldspar, and ferro-magnesian silicates. Fissured playas possess significantly greater quantities of clay and carbonate minerals as compared to nonfissured playas. The clay minerals, carbonates, and analcite are primarily present in $< 2\mu$ size fraction. This colloidal aggregate is believed to exert a major influence on the physical behavior of the sediments which contain the giant polygons. In particular, the dehydration to an almost dry condition of a clay mass, in which the water content may exceed the mineral content, results in a major loss of volume. The shrinkage leads to rupture with the formation of fissures. The fissures form orthogonal polygons characteristic of volume change in a largely uniform horizontal mass with one surface exposed." (R5) Reiterating, the soil in which the giant polygons appear is different in composition. (WRC)

Several references discuss the mechanics of shinkage crack development, but they are customarily rather vague, in physical terms, about just how and why large orthogonal patterns emerge. Take, for example, the following: "Mechanism of Crack Formation. Shrinkage cracks form within muddy sediments (whether exposed or buried) in response to tension(s) within the sediment by volumetric decrease. This decrease is induced by loss of water from the sediment induced by variations in salinity of the depositing medium, sediment compaction, and/or temperature. According to Lachenbruch, within any medium subjected to a volumetric decrease one of two crack systems can be generated, depending on the homogeneity and plasticity of the medium. Within inhomogeneous, plastic media an 'orthogonal system' of cracking develops (i.e., cracks intersect at 90^{o} angles). In such a system cracks form at loci of low strength or high stress concentrations but they are not propagated simultaneously. In 'nonorthogonal systems,' however, very homogeneous, relatively non-plastic media are involved, with the cracks propagating laterally until a limiting velocity is reached at which time crack bifurcation occurs at obtuse angles. Unlike the orthogonal system, all elements of nonorthogonal intersections are generated virtually simultaneously." (R8) This is really a description of what happens, not an explanation. (WRC)

Animas Valley, New Mexico. "Some years ago there was brought to my attention a strange-looking polygonal pattern resembling drying cracks that appeared on aerial photographs of the playa of Animas Valley in southwestern New Mexico. Esimates made from the photographs of the probable size of the polygons gave such surprisingly large results as to raise doubt that they could be drying cracks. The writer requested the Army Air Force to photograph the area to provide additional material for study. This



Orthogonal polygon shapes, as often seen on playas. Left, regular random; right, irregular random types. (X1)

they did most effectively and kindly furnished an abundant series of vertical and oblique pictures. It was evident from these pictures that the pattern was not transient and it was inferred that the dark boundaries surrounding the light-colored polygons must be some very substantial feature upon the surface of the playa.

Subsequently the writer made three brief, but in time, widely spaced (1937-1941) examinations of the surface of the playa where the pictures indicated well-developed patterns. The first attempt proved disappointing and the investigation was partly hampered by a sheet of water from recent rains which then covered the playa. Nothing remotely resembling the striking pattern seen on the aerial photographs could be found on the playa at that time. The second visit proved more fruitful. By precisely locating a position on the ground with reference to its counterpart on the picture a faint trace was discovered which when followed through proved to be the margin of a polygon. The polygons thus identified were of enormous size averaging 80 to 90 feet in diameter. An uninformed person walking upon the playa would never suspect their presence; the only physical mark upon the surface is a broad faint depression more or less straight and trench-like, averaging 3 feet wide and perhaps an inch or more deep in the middle. Each side of a polygon is a line of fracture and fill which could not be recognized from the air were it not for a concentration of vegetation along these faint grooves. Here, either because of better-growing conditions or the more abundant lodgment of seeds, the plants Suaeda fruticosa Forsk., with fleshy leaves of a purplish color, and Atriplex acanthocarpa (Torr.) Wat., having fuzzy white leaves and bur-like fruits, are concentrated in greater numbers than upon the areas of the polygons and thus form the black borders which are so effective in outlining the polygons." (R1)

Black Rock Desert, Nevada. "Abstract. Open fissures, from 100 to several hundred feet apart, that have pronounced polygonal patterns on the Black Rock Desert, Nevada, are believed to be giant desiccation cracks resulting from a secular trend toward aridity in the last few decades." (R2) The aerial and ground-level photographs accompanying this article are very impressive. They show, however, that these particular desiccation polygons are very irregular. (WRC)

Indian Springs Playa, Nevada. An aerial view of this playa shows giant desiccation polygons grading into parallel stripes. (R4) Interestingly enough, patterned ground in polar and subpolar regions also displays this transition from polygons to stripes (ETP1).

X2. Fold-fracture polygons. Giant polygons also result when a surface expands.

Great Salt Lake Desert, Utah. "Abstract. Small folds and fractures (thrusts) up to 50 feet apart that have produced polygonal patterns in the Bonneville salt crust, western Utah, are believed to be caused by the annual expansion of the salt crust due to the growth of salt crystals within the salt layer plus the effect of increased summer temperature. It is suggested that these strain systems are caused by positive (compressional) isotropic planar stresses developed within the salt layers of the salt crust." (R3)

X3. Large sandstone polygons. When large desiccation polygons are lithified and later excavated by erosion, the result is an array of large polygonal blocks of rock. Such polygons should be be confused with normal jointing phenomena in rocks, although the basic forces causing the regular geometry may be the same.

San Juan County, Utah. On the southwest flank of the Boundary Butte anticline, the Carmel Formation, which is of Jurassic age, crops out "as a series of large, bedded, polygonal rock forms which resemble man-made stone corrals." The walls of these polygons are 1½-2 feet high and a maximum of 3 feet wide. The author hypothesizes that these polygons "were formed by eolian infilling of mud cracks with sand, followed by lithification and partial removal of the easily eroded siltstone 'mold.'" (R6)

References

R1. Lang, Walter B.; "Gigantic Drying Cracks in Animas Valley, New Mexico," Science, 98:583, 1943. (X1)

R2. Willden, Ronald, and Mabey, Don R,; "Giant Desiccation Fissures on the Black Rock and Smoke Rock Deserts, Nevada," Science, 133:1359, 1961. (X1)

R3. Christiansen, F.W.; "Polygonal Fracture and Fold Systems in the Salt Crust, Great Salt Lake Desert, Utah," Science,

139:607, 1963. (X2)

R4. Neal, James T.; "Polygonal Sandstone Features in Boundary Butte Anticline Area, San Juan County, Utah: Discussion," Geological Society of America, Bulletin, 77:1327, 1966.

R5. Neal, James T., et al; "Giant Desiccation Polygons of Great Basin Playas," Geological Society of America, Bulletin, 79:69, 1968. (X1)

R6. Tomkins, J.Q.; "Polygonal Sandstone Features in Boundary Butte Anticline Area, San Juan County, Utah," Geological Society of America, Bulletin, 76:1075, 1965. (X3)

R7. Hewes, L.I.; "A Theory of Surface Cracks in Mud and Lava and Resulting Geometrical Relations," American Journal of Science, 246:138, 1948.

R8. Plummer, P.S., and Gostin, V.A.; "Shrinkage Cracks: Desiccation or Synaeresis?" Journal of Sedimentary Petrology, 51:1147, 1981. (X1

ETR ANOMALOUS RIDGES, MEGARIPPLES, ESKERS

Key to Phenomena

ETR0 Introduction

Ridges are everywhere; anyone who has travelled at all can vouch for that! Tectonic forces wrinkle up the earth's surface; faulting and erosion create valleys and hills. And, of course, the Ice Ages deposited ridges of surficial debris called moraines. The point being made here is that a wide array of unmysterious terrestrial forces are available for ridge and ripple building. In this context, for any of the earth's multitudinous ridges, on land or under the ocean, to be classified as anomalous, the structure must be of doubtful origin or have characteristics suggestive of an origin that is at odds with current geological thinking.

To illustrate, the ripples or ridges buried within the continental margins are anomalous because we cannot ascertain their origin with certainty. On the other hand, megaripples on the sea floor are merely mildly anomalous due to their immense size and our lack of knowledge of bottom currents past and present. More obvious to the casual observer are the eskers, which all textbooks attribute to fluvial action on top of or underneath ice sheets. It appears, though, that eskers may not yield to such simplistic explanations. There are too many loose ends! Eskers and some other ridges of debris may, in fact, suggest catastrophic flooding, either from the sea or sudden melting of ice. Such conceptions do not, of course, fit well with current geological thinking.

A few ridge-type phenomena included here are primarily curiosities; but they are so intriguing that we make no apologies for them. Further, the mid-ocean ridge system, one of our planet's major topographical features, is a supporting pillar of the hypothesis of plate tectonics and, as such, is well-explained. Being nonanomalous, these ridges are omitted here.

ETR1 Ridges and Ripples in Glaciated Regions

Description. Systems of large ripples or ridges associated with Ice Age deposits. Such ripples generally have amplitudes of 10-20 feet, with crests a few hundred feet apart. They have been reported from the glaciated regions of North America and may possibly exist in northern Europe, too. Some larger ridges of glacial debris located in western Canada may have a different origin.

Data Evaluation. The so-called "washboard moraines" have been well-described in the literature. However, the same cannot be said for the ridges of drift in western Canada. Rating: 2.

Anomaly Evaluation. Ripples and ridges that have the characteristics of successive terminal moraines cannot be consider anomalous, because they are consistent with glacial theory. However, the prevelance and regularity of large ripple systems encourages the suspicion that they might be the consequence of massive, sheet-like flows of water. It is possible that rapid melting of the ice sheet could account for this type of ripple formation, but the occurrence of a transitory marine incursion should be considered, too. Our anomaly evaluation is based upon this latter possibility. Rating: 2.

Possible Explanations. The ripples might be successive terminal moraines of a sporadically retreating glacier or ice sheet. Large ripples may also be created by sheet-type water currents, say, from a rapidly melting ice sheet or the incursion of water from elsewhere.

Similar and Related Phenomena. Megaripples on the ocean floors (ETR3); drumlins (ETM4); eskers (ETR2).

Examples

X1. Interior plain of Western Canada. This region was not "officially" glaciated during the Ice Ages, but some drift nevertheless seems to occur there. "Perhaps the most remarkable feature of the region is that immense series of ridges of drift piled against an escarpment of Laramie and cretaceous rocks, at an elevation of about twenty-five hundred feet, and known as the 'Missouri coteau.' It is in some places thirty miles broad and a hundred and eighty feet in height above the plain at its foot, and extends north and south for a great distance; being, in fact, the northern extension of those great ridges of drift which have been traced south of the Great Lakes, and through Pennsylvania and New Jersey, and which figure on the geological maps as the edge of the continental glacier, ---an explanation obviously inapplicable in those western regions where they attain their greatest development." (R1) The author considers that these ridges of drift actually mark the western edge of a glacial sea. R1 is over a century old. No modern interpretations of these "drift" ridges have been found. (WRC)

X2. Iowa. "Abstract. Airplane photographs of the Wisconsin drift plain in Iowa disclose a pattern of light and dark streaks on the ground surface, suggestive of the changing outline of the ice lobe. The streaks are believed to reflect differences in soil composition and texture which probably developed as the result of the slight topographic inequalities of gentle swell and swale. Seasonal fluctuations of the glacial front are thought to have caused the arrangement of swells and swales in the described pattern." The amplitude of the ripples (swells and swales) is only about 10-15 feet. The area is roughly 10,000 square miles. Basically, the pattern is considered an array of recessional moraines. (R2) These Iowa ripples seem much like the till ridges reported next. (WRC)

X3. Manitoba. "Parallel, discontinuous, sandy-silty till ridges (washboard moraines) as high as 15 feet and as long as a mile are spaced 300 to 500 feet apart and form lobate patterns near Cartwright, Manitoba, Canada. Re-entrants between lobes contain 'dominant' eskers and outwash. Smaller 'subordinate' eskers cross the ridges at low points and commonly change direction or are offset at successive ridges. Till fabric studies show that they comprise mainly lodgment till, and the preferred orientation of cobbles conforms to the general direction of ice movement inferred from striated boulder pavements and other evidence, rather than to directions locally perpendicular to the ridges.

Probably these ridges were deposited sub-

glacially by lodgment of till at a line (zone) where the brittle upper ice extends down to the sole of the glacier, and where it thrusts against and over a marginal apron of stagnant ice. Subordinate eskers form in the stagnant ice, whereas the dominant eskers between lobes represent major glacier drainage where thinning was more rapid. Melting out of glacial debris furnished sediment for eskers and outwash and formed an insulating layer of ablation moraine that retarded melting of the stagnant ice.

The interval between ridges may represent retreat of the thrust zone and inward widening of the stagnant ice caused by annual glacier thinning; however, annual deposition is not proved. The discontinuity of the ridges may be due to irregularities in the subglacial floor and in amount of glacial debris transported." (R3)

X4. North Dakota. Narrow, linear "drumlins" 1-3 miles long and 5-15 feet high occur in the company of washboard moraines near Velva, North Dakota. See description in ETM4-X2. (R4)

Generally, drumlins are superficial to the drift under them, but these in North Dakota are parallel to grooves in the moraine. In contrast to the "washboard" moraines, the "drumlins" are parallel to the movement of the postulated ice sheet. (WRC)

X5. Sahara Desert. The ripples to be described next are now lithified. "One of the most extraordinary features of the sandstone lying above and to the north of the glacial moraines, was a belt where the sands had been swept by powerful currents into giant ripples ten feet or more from crest to crest, extending in a formation up to 100 feet thick and stretching out for several hundred miles. Giant ripples are formed in tidal currents in certain restricted areas today, such as the southern North Sea, the Celtic Sea, and in the Strait of Malacca. But the ripples in the Sahara are of vast dimensions. Could they represent the decanting of millions of tons of meltwater from the margin of the Ordovician glaciated region during the melt period? At such a time, the release of the ice pressure would have permitted the earth's crust to rise rapidly to its former position. A similar spillover occurred in the Baltic after the last glaciation and likewise in Hudson Bay." (R5)

X6. Ontario. Giant ripple marks on the Bruce Peninsula are transverse to drumlins. See a more complete description in ETM4-X2. (R6)

X7. Washington. The Channelled Scablands, mapped in great detail by J H. Bretz, were explained by him as the consequence of flood waters released by the breaking of an ice dam impounding Lake Missoula. "Bretz had presented no direct evidence for deep, surging water. Gouging might have preceeded sequentially, rather than all at once; anastomosis and hanging valleys might reflect filled coulees with gentle, rather than raging, flow. But when the first good aerial photographs of the scablands were taken, geologists noticed that several areas on the coulee floors are covered with giant stream-bed ripples, up to 22 feet high and 425 feet long. Bretz, like an ant on a Yale bladderball, had been working on the wrong scale. He had been walking over the ripples for decades but had been too close to see them. They are, he wrote quite correctly, 'difficult to identify at ground level under a cover of sagebrush.'" (R7) There are probably many more examples of such ripples, but no one has searched for them systematically. (WRC)

References

R1. Dawson, J.W.; "Some Unsolved Problems in Geology," Science, 2:190, 1883. (X1)

R2. Gwynne, Charles S.; "Swell and Swale Pattern of the Mankato Lobe of the Wisconsin Drift Plain in Iowa, "Journal of Geology, 50:200, 1942. (X2)

R3. Elson, John A.; "Origin of Washboard Moraines," Geological Society of America, Bulletin, 68:1721, 1957. (X3)

R4. Lemke, Richard W.; "Narrow Linear Drumlins near Velva, North Dakota," American Journal of Science, 256:270, 1958. (X4)

R5. Fairbridge, Rhodes W.; "The Sahara Desert Ice Cap," Natural History, 80:66, June-July 1971. (X5)

R6. Cox, Douglas E.; "Drumlins and Diluvial Currents," Creation Research Society Quarterly, 16:154, 1979. (X6)

R7. Gould, Stephen Jay; "When the Unorthodox Prevails," New Scientist, 79:942, 1978. (X7)

ETR2 Eskers

Description. Very long ridges of sand, clay, and rocky debris found chiefly in Europe and North America. Esker lengths, especially in Scandanavia, may exceed 100 miles. Although not all eskers are continuous, most are well-formed and remind one of a railroad embankment. Heights may be more than 120 feet; widths, more than 180 feet. Esker cores are usually covered with deposits of fine material, which may also contain marine shells.

Data Evaluation. Scandanavian geologists have paid considerable attention to eskers. The literature in English is also substantial, although the major contributions are almost a century old. Modern books on glaciology rarely mention the anomalous features of eskers, which were debated heatedly around the turn of the century. Rating: 1.

Anomaly Evaluation. As expressed in X0, below, geologists long ago reached a consensus that eskers were formed by rivers running across or underneath ice sheets. (R8) Catastrophic explanations seem to have been suppressed. Several esker features contradict the now-dominant fluvial origin. (See X1 below.) Since the Ice Age hypothesis is a crucial element is our scientific perspective, esker anomalies are very significant. Rating: 2.

Possible Explanations. Marine flooding, as championed by Howorth (X1), could account for the rounded stones and marine shells found in some eskers.

Similar and Related Phenomena. Drumlins (ETM4). In general, the so-called glacial drift, high-level gravel deposits, etc., all of which will be covered in a future volume (ES).

Examples

X0. Background. First, the prevailing wisdom concerning the nature and origin of eskers. "Eskers are elongate ridges of poorly stratified sand and gravel resulting from stream deposition in association with glaciers. They are known primarily from the Pleistocene record of North America and Europe, in which they seem to represent a concluding phase of glacial deposition for they occur on top of most other glacial detritus. From this fact and from study of the few modern eskers known, it has been concluded that eskers are formed near the margins of stagnant or retreating bodies of ice which front on ponded water or open seaways. Pleistocene eskers are recognized primarily by their geomorphic expression; most of those described are large and represent the last glacial phase. However, in regions of multiple advances and retreats, eskers must also have formed in the earlier phases, and we would accordingly expect that at least locally they would constitute part of a repeated till-outwash sequence.

Opinion is divided on the question of whether eskers are deposited in ice-roofed tunnels or ice-walled gorges and cracks in the ice. Judging from the evidence available it is possible that eskers have formed under both conditions.

Another problem relates to the formation of eskers in the subglacial regime: did the streams cut into the moraine or bedrock or are eskers directly depositional features built on underlying material? It is difficult to ascertain the relationships at the base of an esker, but Sharp describes portions of esker chains cut into bedrock; erosion of underlying moraine may have occurred during deposition of some of the structures described by Stone. A third problem concerns the possible genesis of eskers as deposits of englacial and superglacial streams. The most telling argument against this notion is the continuity and homogeneity of many esker deposits. If they had been let down from a position within or on top of a thick mass of ice, their identity would probably have been destroyed. Discontinuous esker deposits are not uncommon, however, and it is possible that they represent the disarticulated remains of englacial eskers situated near the glacier base." (R6)

Despite the confidence conveyed in the foregoing paragraphs, there exist many objections to a fluvial origin for eskers. See the comments of Howorth in X1 and those of Cox, which now follow. "Another enigmatic topic in the glacial theory is the origin of kames and eskers. According to the glacial theory the eskers were formerly river courses in the ice-sheets, and these may have been either surface rivers or rivers flowing in tunnels underneath the ice. The river beds became chock full of sand and gravel, that was deposited when the ice disappeared.

Kames are thought to be related structures,

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

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

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

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

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

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

However, the difficulty of the eskers following courses that go up and down hills is unexplained. It seems that for the common phenomenon of a sinuous ridge winding over the countryside many different theories are required, including (1) squeezing up of the drift by weight of ice on either side, (2) deposition of sediments in crevasses, (3) deposition from rivers flowing in tunnels underneath, (4) deposition from rivers flowing in tunnels within the glacier, and (5) dumping of debris at the glaciers' snout as it melted away. Eskers are actually enigmas in the glacial theory, as the variety of hypotheses proposed to account for them shows." (R7)

X1. Scandanavia. Eskers or asar (plural of as) reached the peak of their development in Scandanavia. The two accounts that follow are rather voluminous, but taken together thoroughly describe esker features.

P. Kropotkin." These observations on the asar, or eskers, of Finland were made in 1871. Many researches have been made since by Finnish geologists; but although the glacial origin of the asar is now firmly established, their mode of formation in connection with the ice-sheet remains uncertain.

The chief point which appears in regard to the asar of Finland and Sweden is that they follow the same lines as were followed by the ice-cap in its southward and south-eastward movement. While taking no heed of important orographical features, they take into account, like glacial striae, minor depressions and elevations, showing that the ice always followed the lines of least resistance.

The main Swedish asar descend from the highlands, they spread next upon an elevated plain, 100 to 200 feet high; then they descend to the Malar depression, cross it, and finally creep over the hilly tracks in the south of Lake Malar.

At the time of the author's visit to Sweden, the as of Upsala was cut through its whole width at Upsala, for making a new road. It consists of a core, made up of totally unstratified, unwashed, and unsorted gravel, composed of round, angular, and sub-angular stones, from a few inches to several feet in diameter, mixed with sand and finest mud. This gravel is exactly similar to the bottom moraine in the neighbourhood, only containing a slightly greater proportion of limestone

boulders brought from Gefle. This core is covered with a mantle of washed, stratified, and sorted gravels, sands (ripple-marks) and clays, with Baltic shells.

The asar of Finland, represented on an orographic map, all run N.W. to S.E.. One of them, the Pungaharju, was described, to show the orographic features of a big as. The Kangasala as, in West Finland, occupies a position which makes of it a sister as to the Swedish asar on the western shore of the Gulf of Bothnia. It is a typical as, ninety-five miles long (twenty-two miles explored). It has all the characters of a longitudinal moraine, partly destroyed by lakes and covered with sands and gravels which were washed by water and were deposited on the old shores of a lake which reached a higher level than is now reached by Lake Pajane. The moraine core consists of a typical kross-stensgrus, in which immense scratched boulders are scattered.

.....

The conclusions to be drawn from these facts, taken out of many others observed by the author, are:---A strict distinction must be made between the core of an as and its mantle. They are of distinct origin. The latter is always due to the action of water (rivers, lakes, or the sea), while the core, whenever access could be found to it, was invariably of moraine origin. Always it was found to consist of unwashed and unstratified till, and never of fluviatile deposits. This core is often buried under a thick sheet of water-deposits, and occasionally it lies even beneath the level of the surrounding plains. It must have the same origin as the drumlins, horse-backs, cames, &c., which are elongated hillocks formed in the bottom moraine, parallel to the motion of ice, and always accompany asar.

.....

We cannot say yet in which way these morainic ridges were formed, whether under, or within, or on the surface of, the ice-cap; but the asar can safely be taken as longitudinal moraines, superficially modified by water. It is also very possible that the main Swedish asar and the Kangasala as were side morainic deposits of the lobes of the ice cap. But it is equally possible that similar morainic ridges may arise under the ice-cap, or within it.

At any rate, it seems almost impossible to explain the formation of asar by river action. The cores of the Kangasala and Yvaskyla asar, with their immense scratched boulders, certainly have not been deposited by rivers. Nor the unstratified, unwashed, and unsorted core of the Upsala as. This latter, which runs from a level of 500 feet to 120 feet, next raises to a level of 207 feet, descends to Lake Malar in the level of the sea. Even under the ice a river would mine its channel in the line of least resistance (eastwards in this case), instead of running uphill. No river could, moreover, have so steady a channel, a few hundred feet wide, as to make such a ridge; it would have changed its channel in the course of time in the ice as well, just as it does in a rocky bed."(R1) Kropotkin has mentioned several esker features that receive scant attention in modern assessments: (1) the distinct natures of the core and mantle; (2) the presence of marine shells; and (3) the eskers that run uphill. (WRC)

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

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

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

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

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

Still another anomaly of the Swedish eskers is brought forth by Howorth: "There remains another element which we have not yet considered, namely, the large, sometimes portentiously large, angular and subangular blocks which occur in the surface layers of the asar, and sometimes in large numbers on their backs, the as near Gamla Upsala being a good example. Among the many boulders we noticed, there was one whose cubical contents must have been 36 yards. Similar subangular and angular blocks have occurred in the deposit containing marine shells at Upsala. How are we to explain these blocks and their occurrence where they are found, by any kind of fluvial action?"

Howorth goes on to dispose of the notions that eskers (asar) are : (1) moraine-like, and/or (2) fluvial deposits. He notes that the stones in eskers are rounded and water-worn, not at all like glacial stones. In addition, the sand and clay of the eskers are separated

from the stones and stratified, while the material of moraines is mixed up. The marine shells found in the upper layers of the eskers are never found in moraines.

Next, Howorth devotes several pages to discrediting the river-origin theory. The most telling fact against a fluvial origin is the observation that eskers sometimes run uphill. Some even cross one another. And, again, those marine shells would not be found in inland river deposits.

Howorth concludes his lengthy exposition by presenting his own theory: "The present evidence of the asar seems to me to completely support the view urged in previous papers from other facts and premises, namely, that Scandanavia was recently very largely submerged by the sea, which covered it for a long time, which smoothed and rounded its surface, and smoothed its myriads of boulders; and that this sea was eventually drained and discharged by some rapid and sudden upheaval of its bed, causing a perhaps unprecedented diluvial movement." (R3)

X2. Ireland. "Of the more recent geological phenomena none are more curious, and none have given rise to more speculation, not to say controversy, than the ridge-like accumulations, principally of sand or gravel, found throughout the midland district of Ireland.

Considering that geologists have very commonly associated these ridges---eskers as they are called in Ireland---with the products of glaciation, it appears to me not a little remarkable that they are confined to a comparatively narrow zone running through the flattest part of the island from Galway Bay to Dublin Bay. The remark would apply with almost equal force to the corresponding formations of Scotland and the Scandanavian peninsula. The kames are nearly confined to the valleys of the Clyde and Forth, as the asar of Sweden have their most striking development in the Lake Malar district. True, there are mounds of gravel in some of the northern counties of Ireland, but they are not to be confounded with the typical eskers of Galway, King's County, North Tipperary, Queen's County, Kildare, and Dublin; and in Scotland the term kame is applied to ridges and mounds 'of marine, lacustrine, fluviatile, and meteoric (wind-drived) drifts.

.....

The true esker, or ridge, when seen at a little distance bears a striking resemblance to a railway embankment, and, as Kinahan remarks, is sometimes so narrow at the top that people may almost shake hands across the width. This is, however, rather exceptional. I know well the Parsontown esker described by Jukes. It crosses the county road between Birr and Banagher---the road is, in fact, cut through 'The Ridge'; and the latter runs across the country in the direction of the Shannon, the top of it serving, for a considerable distance, as a bog-road or boreen. The Mayborough esker---also locally known as The Ridge---is said by the country people to extend 'all across Ireland'; it can indeed be traced, more or less continuously for many miles. Adjoining the town of Maryborough its slopes and top have until recently been used as a cemetery. Geike mentions certain kames in Scotland that have long been used for the same purpose.

So far we have been making approach to the interesting but perplexing question--- How came these eskers to be what they are? By what particular agency, or agencies, have sand, gravel, clay, and shingle been ridged up, and at the same time sorted and stratified as we find in the typical esker?

All who have attempted the solution begin by confessing the very great difficult of the question; and the admitted difficulty has given rise to a considerable amount of 'scientific' romancing." (R2)

X3. Maine. Marine shells have also been found in North American esker-like formations. "Abstract. Fossils have been discovered in an esker-like glacial ridge of sand and gravel. It is suggested that the deposit was formed as a crevasse filling, Since the fossils are mostly intact, many with both valves together in place, but slight transportation of the shell material is indicated. Probably a reentrant in the ice front was colonized, while stagnant ice still lingered in the region." The length of this "esker-like" ridge is given as 3,000 feet. It is called a "hillside esker", but it may not be a true esker. (R5)

Also in Maine, nature conducted an interesting experiment on March 15, 1936, near Bingham. Five inches of rain fell in 36 hours, turning streams into torrents, which cut through the snow cover. R. L. Nichols described one consequence of the deluge in the following manner: "A much smaller ravine and fan exist about a quarter of a mile upstream. A permanent stream flows

from the ravine across the fan. In the winter, this stream runs across the fan in a channel, cut in snow, 4 feet or 5 feet wide and as deep as the snow is thick. During the heavy rains of the week of March 15, 1936, this streamlet carried out, on its snow-covered fan, sand and gravel that filled its channel and covered the rest of the fan with from 1 to 2 feet of sand. When the snow melted, the sand deposited on the snow was lowered, the buried channel becoming an esker-like ridge, 200 feet long, 5 to 8 feet wide, and 1 to 2 feet high." (R4) Appealing though this tale is, real eskers may have radically different origin(s). (WRC)

References

R1. Kropotkin, P.; "On the Asar of Finland," Report of the British Association, 1897, p. 648. (X1)
R2. Fitzpatrick, Thomas; "The Eskers of Ireland," Natural Science, 13:172, 1898. (X2)
R3. Howorth, Henry H.; "The Surface Geology of the North of Europe, as Illustrated by the Asar or Osar of Scandanavia and Finland," Geological Magazine, 35:195, 1898. (X1)
R4. Nichols, Robert L.; "New Mechanism for the Formation of Kettle-Holes and Eskers," Geological Society of America, Proceedings, 1936, p. 403. (X3)
R5. Trefethen, Joseph M., and Harris, John N.; "A Fossiliferous Esker-Like Deposit," American Journal of Science, 238:408, 1940. (X3)
R6. Frakes, Lawrence A., et al; "Possible Fossil Eskers and Associated Features from the Parana Basin, Brazil," Journal of Sedimentary Petrology, 38:5, 1968. (X0)
R7. Cox, Douglas E.; "Problems in Glacial Theory," Creation Research Society Quarterly, 13:25, 1976. (X0)
R8. Crosby, W.O.; "Origin of Eskers," American Geologist, 30:1, 1902.

ETR3 Megaripples

Description. Immense ripples in the sandy deposits of marine basins and the continental shelves and slopes. Wavelengths vary from thousands of feet to ten miles or more; amplitudes from tens to hundreds of feet.

Background. The wavelengths and amplitudes of underwater sand ripples depend, as one would expect, upon current velocities and sand characteristics. Such ripples may have wavelengths measuring from inches to many miles. Generally speaking, the forces shaping small ripples are well-understood, and it is presumed that these theories can be extrapolated to the megaripples cataloged here.

Data Evaluation. Several reports of megaripples have been discovered in the literature examined so far. The dimensions of the ripples are well known, but bottom currents are not. Neither has confirmation been found that small-ripple theory extrapolates to megaripples. Rating: 2.

Anomaly Evaluation. Although they are of impressive size, it seems likely that megaripples form in the same ways as the ubiquitous ripples seen in streams and along the seashore. The only anomalous aspect may involve the sources of the formative currents (past and present). In the final analysis, megaripples are probably not anomalous; and they are included here because of the slim possibility that they are expressions of catastrophic movements of the oceans. Rating: 4.

Possible Explanations. Most likely, megaripples are contoured by bottom currents not far different from those observed today. In principle, though, they could be the consequences of great tsunamis or large meteor impacts.

Similar and Related Phenomena. Washboard moraine and large terrestrial ripples (ETR1), which are morphologically similar; eskers (ETR2), in the context of Howorth's minority view that they are the consequence of catastrophic marine action; undersea dunes (ETM7-X3).

Examples

X1. Britain's continental shelf. The large "sandwaves" located off the coast of Britain, although rather small, provide a good introduction to megaripples in general.

"Sand waves. Flume studies reveal that the form of a sand bed is dependent on the velocity of the current passing over it; hence the form gives an indication of the intensity of sediment transport. The familiar current ripples, with a steep lee-slope in the direction of advance, indicate low transport rates, and the much larger features of the same shape indicate higher transport rates. Simon & others showed that for sand with a median diameter of about 0.45 mm the change in dimensions took place abruptly when the speed of the current 3 ft above the floor was about half a knot. The crests of the ridges lie more or less normal to the current.

The large ridges have been recognized in rivers and are also formed by tidal currents. They are present on tidal flats; in estuaries, on and between off shore sandbanks, between islands, and on the open shelf. They are known by a variety of different names, including large sand ripples, transverse megaripples, dunes and in literature in the English language are commonly referred to as sand waves. The term sand waves will be used here.

The sand waves are shown in profile in Pl. 15b, in plan (with profile) in Pl. 16a, and their manner in interfingering with one another is illustrated by long crested waves in Pl. 16b. (Figures mentioned are not reproduced here.) Their heights can be up to 60 ft, wavelengths up to about 3000 ft, and crest lengths up to about forty times greater than their separation, although no group of features reaching all peak values at once has been found. Off the East Anglian coast the ridges are commonly about 15 ft high and some 450 ft apart; farther east larger ones are more common. The sand waves of largest wavelength occur near the edge of the continental shelf." (R1) The "small" sand waves just described are probably fully explicable in terms of present day bottom currents. (WRC)

X2. The Argentine Basin. Some early survey work of the Lamont Geological Observatory was described as follows: "To date they have looked at two areas in some detail. The first is the Argentine Basin in the South Atlantic where encroaching Antarctic currents have produced considerable areas of uniform giant ripples. They are too flat to be explained as the result of gravitational creep, according to (M.) Ewing, and optical tests on sediments in suspension suggest that they are a direct result of controlled deposition in which scouring plays little part.

Seismic profiling, which cuts a kind of section through the ripples, is especially revealing. Beneath the Argentine Basin is a hard layer, apparently of Cretaceous age and perhaps rather over a hundred million years old, which bounces back the seismic signal. Down to this depth stratification occurs which indicates that the ripple pattern has persisted for this great length of time." No ripple dimensions were given. The other site examined was the Madagascar Basin, which similar ripples occur. (R2) See X3.

X3. The Madagascar Basin. "In the Madagascar basin large undulations of the sea floor have been found, here called 'giant ripples' after similar features found in the Argentine basin. They cover an area of over 100,000 km^2. Their average wavelength and amplitude is 4 km and 50 meters, respectively. An extensive reflection survey utilizine satellite navigation was made which determined their continuity and trend. A trend of WNW-ESE was established, which is roughly transverse to the northward flowing bottom current in the basin. The sediments that, on the basis of surface samples, consist predominantly of lutite are found to consistently thicken on the northward downcurrent side of the ripple crests. The presence of these giant ripples here implies that a process of current-controlled deposition similar to that found in the Argentine basin is operating." (R3)

X4. Cape Hatteras continental rise. "A field of 'lower continental rise hills' situated on the seaward flank of the Hatteras Outer Ridge was investigated with a grid of bathymetric profiles, a continuous seismic reflection profile, and short (1.2 m) gravity cores.

Throughout the field investigated the lower continental rise hills are not isolated 'hills' but rather are linear waveforms with a fairly regular distribution and orientation. The waveform parameters are as follows:

trough-to-trough wavelength between 3 and 12 km, trough-to-peak amplitude between 10 and 100 m, crestal lengths of tens of kilometers trending NW-SE, symmetric with steeper limb facing SW. Core samples recovered from the hills contain lutite and clay. The NW-SE crestal orientation and morphological similarity of these linear lower continental rise hills to megaripples or dunes are evidence that their development is related to deposition controlled by the deep Western Boundary Undercurrent, which flows southwest over the continental rise." (R4)

X5. Off western Mexico. "A 45-km belt of large symmetrical sediment waves extends along the west coast of Mexico west of Manzanillo between depths of 320 and 770 m. They are thought to be the result of a strong subsurface current that changes seasonally from southeast to northwest." The ripple height averages 20 meters, with an average width of 400 meters. (R5)

References

R1. Stride, Arthur Harold; "Current-Swept Sea Floors near the Southern Half of Great Britain," Geological Society of London, Quarterly Journal, 119:175, 1963. (X1)

R2. "Giant Ripples Tell of Enduring Ocean Flow," New Scientist, 38:113, 1968. (X2)

R3. Ewing, Maurice, et al; "Giant Ripples in the Madagascar Basin," American Geophysical Union, Transactions, 49:218, 1968. (X3)

R4. Rona, Peter A.; "Linear 'Lower Continental Rise Hills' off Cape Hatteras," Journal of Sedimentary Petrology, 39: 1132, 1969. (X4)

R5. Shepard, F.P., et al; "Sediment Waves (Giant Ripples) Transverse to the West Coast of Mexico," Marine Geology, 20:1, 1976. (X5)

ETR4 Moving, Gravity-Created Ripples in Rock

Description. Rapidly forming ripples or waves in solid rock. Typical dimensions: hundreds of feet long; 20-30 feet high.

Data Evaluation. A single investigative report of good quality is at hand. The Culebra Cut ripples represented a serious engineering challenge; the paucity of reports in the scientific literature does not reflect the engineering effort made to understand what was happening. Rating: 2.

Anomaly Evaluation. The Culebra Cut ripples cannot be construed as anomalous. They are cataloged here because of their novelty and their possible bearing on the "mud-lump" phenomenon. Rating: 4.

Possible Explanations. Gravity waves in moisture-weakened rock induced by excavation.

Similar and Related Phenomena. Mud lumps and islands (ETM3), which are also thought to be "tectonically" created.

Examples

X1. Panama. The Culebra Cut, during the excavation of the Panama Canal, 1908-1912.

"From time to time during the last four years portions of the bottom, a few hundred feet long and perhaps as much as a hundred feet wide, have risen in a hump or weald often to a total height of 20 feet. The upheaval is rapid. In one case, it was 9 feet in an afternoon; in another it was 10 feet in ten minutes. The upheavals occur both in the dry and wet seasons. The upheaved rock comes up quite dry, and its surface is crevassed. The upheaval is accompanied or more often followed by a sudsidence of the bank some distance at the back of it, forming a concave depression with a crevassed surface. Between the crevassed convex upheaval and the crevassed concave subsidence the surface generally remains without deformation. It has happened that in such an

intermediate position a locomotive has remained without disturbance upon the rails of a construction track." (R1) Prior to the actual excavation, canal engineers had agreed that the rock walls of the Culebra cut were strong enough to support relatively steep sides. However, the removal of overburden admitted water to the rocks, causing some rotting of the rocks. Thus weakened, gravitational waves or ripples rose in the cut.

References

R1. Cornish, Vaughan; "On the Panama Canal, and the Formation of Gravitational Waves in the Culebra Cut," Geographical Journal, 41:239, 1913. (X1)

ETR5 Unusual Naturally Formed Dams

Description. Small river dams that form around obstructions due to the deposition of minerals contained in the water. Dam build-up can exceed a foot or two each year.

Data Evaluation. A rather popular account from Science is our only reference. No detailed scientific studies are available---but perhaps none is needed! Rating: 3.

Anomaly Evaluation. Natural dams represent a charming but hardly anomalous phenomenon. Rating: 4.

Possible Explanations. Natural mineral deposition.

Similar and Related Phenomena. Tufa columns and solution pipes (ETM12).

Examples

X1. Havasu Canyon, Arizona. This Canyon is part of Grand Canyon National Park.

"Emerging from the Supai formation, some 2700 ft. below the rim of the Grand Canyon, are a series of fresh water springs whose overflows join and flow down through Havasu Canyon. This creek, bearing the same name as the canyon, once had beautiful blue-green water. Hence, the Indians living there are called the Havasupais, which, translated, means 'the blue-green water people.'

In addition to its phenomenally colored water, Havasu Creek deposits spectacular mineral dams across parts of its course north of the Supai village. These dams sometimes build upward as much as 2 ft. a year. The local Indians give little thought to this until the water levels at the fords become so deep that their feet get wet when they are crossing them on horseback. When this annoying height is reached, the dams are breached with explosives until the water levels return to a convenient fording height.

Although they readily encrust any submerged twig or root, the minerals never seem to impregnate porous, dead bits of wood. Other than arching downstream, there is little consistency in the method of mineral deposition or in the structure of the dams. Anything resisting the flow of the creek tends to become encrusted with minerals and to initiate a dam. Analyses of mineral samples indicate that the subaqueous deposits are primarily calcite with some admixed clay. Remnants of older and higher deposits of minerals now visible along the lateral areas of Havasu Canyon contain layers of crystalline calcite, aragonite, and clay, as well as manganese oxide stains, on their weathered surfaces. Both old and recent deposits are rich sources of impressions of past and present vegetation in this region." (R1)

References

R1. Black, Donald M.; "Natural Dams of Havasu Canyon, Supai, Arizona," Science, 121:611, 1955. (X1)

ETR6 Lake Walls and Ramparts

Description. Walls of boulders, gravel, dirt, and other debris piled up around and along the shores of some lakes in cold climates. The phenomenon has been reported only from North America.

Data Evaluation. Very few accounts of lake walls have been found in the literature, although they should be rather common in frigid climes. No truly scientific study of lake walls has been discovered in our literature searching. Rating: 3.

Anomaly Evaluation. All observers of walled lakes conclude that ice expansion pushes shallow rocks of lake bottoms shoreward, bit by bit, over the years, until walls are built up on some shores. This all seems quite reasonable, but there are many likely spots where the phenomenon does not transpire. We should know more about this delightful phenomenon, and why it architectually so successful, in Iowa especially, and not elsewhere. Our anomaly evaluation is based on a subjective suspicion that the prevailing explanation, appealing though it is, may be a bit simplistic. Rating: 3.

Possible Explanation. Ice expansion, as described above and below.

Similar and Related Phenomena. Wind-blown boulders on playas (ER in a later volume).

Examples

X1. Iowa. "We will describe the case in Iowa, as it seems to be the most perfect of all that have come under our notice. The lake is in Wright County, situated in a large plain, covering an area of about 1,900 acres, and is from two to twenty-five feet deep, with a hard sandy bottom. Around the lake is a wall of heavy stone, in some places ten feet high, thirteen feet wide at the base, sloping up both sides to five feet wide at the top, and is entirely composed of boulders from fifty pounds to three tons in weight. In some places this rampart, with soil, forms a barrier preventing the meadows contiguous from overflow. The top of the wall is level, while the land is undulating, varying in height from two to ten feet for two miles in extent. The writer cautions his reader 'not to imagine that this wall is as regular and nice as the wall around the fountain in front of the City Hall, in New York City,' whence we conclude that there is a considerable irregularity to it." (R1)

"The questions whether the so-called 'walled lakes of Iowa' are the work of some extinct race or are natural formations, have periodically appeared for discussion. In his 'Geology of Iowa,' Prof. Charles A. White presents as a theory that in the shallow portions of the lakes the ice along the shores freezes fast to everything upon the bottom, whether sand, gravel, bowlders, or mud, and the expansive power of the water in freezing is exerted upon them, acting from the center of the lake in all directions toward its circumference. By this means whatever substances are frozen into the ice are pushed up upon the shores as far as the expansive force is exerted, and there left as the ice melts in the spring. By this means embankments have been formed, varying from 2 to 10 feet in width and from 5 to 20 or 30 feet across. The ice, during long ages, has brought these materials together in this manner, having in some instances moved large bowlders and piled them up with other materials.

In corrobation of this, a writer in the Sun states that he has 'seen the ice piled up on the shores of Walled Lake, in Wright County, pushed up along these embankments, and containing earthy materials of which the walls are made. Occasionally these walls were found along the old margin of some dried-up prairie slough, proving the existence of an open shallow lake in some time past." (R2)

X2. Vermont. Referring to the Iowa walled lakes, C. H. Hitchcock recalls similar formations in Vermont. "We had hardly thought of finding these phenomena in Vermont, till our attention was called to a ridge of this description on the north shore of Willoughby lake. For forty or fifty rods the shore is fringed by a ridge about a rod wide, and five or six feet high, of coarse gravel and boulders. The outer side is perpendicular, and the inside slopes gradually towards the water, having the shape of a rampart in a fort. Rev.

S.R. Hall, who was with us, stated that he had seen the same phenomena in other small lakes or ponds, and upon a map of the Surface Geology of Vermont he has marked six other cases; namely, on the north side of both Great and Little Averill ponds, in the town of Averill, in the north-east corner of the State; on the north shore of Island Pond; the east shore of a pond in Maidstone; the east shore of Lake Memphremagog, at its south end; and on the east, west, and north shore of Franklin pond. Mr. Hall states that the rampart on this latter pond is fifteen feet high. We have ourself noticed a rampart of this kind upon Woodford pond, in southern Vermont, and have data from which we think it probable that another example may be found in Tinmouth.

.....

In the cases mentioned, large stones were found to have been moved towards the shore of the pond, and by measurements the exact distance over which they were moved, in a single winter, for instance, was ascertained. One rock, weighing several tons, was removed three rods during one winter. Though several causes were proposed, none was so satisfactory as that which called in the expansive power of ice. If the ponds, or some parts of them, are rather shallow, and the bottom covered by boulders, the ice of the winter would enclose the stones, and the gravel of the bottom it may be, and, from its well-known property of expansion, it would force the fragments from the central parts of the lake towards the shore." (R1)

X3. Wisconsin. "Madison lately had a tremor which was not due to a social or other earthquake, nor yet to a dynamite explosion. A disturbance which shook the university buildings was caused by the expansion and contraction of ice in Lake Mendota. Under the influence of intense cold the ice had expanded until the shore could resist the pressure no longer, when the ice burst and doubled up about four hundred feet from the shore, and on a line parallel with it. The sudden release of the shores from pressure caused the tremor. This phenomenon of freezing upon bodies of water having low shores frequently results in the piling up of huge rocks on the edge and the overturning of trees. The shore line of lakes frequently consists of gravel mounds forced up during successive winters." (R3)

References

R1. Hitchcock, Charles H.; "Lake Ramparts in Vermont," American Association for the Advancement of Science, Proceedings, 13:335, 1859. (X1, X2)

R2. "The Walled Lakes of Iowa," Scientific American, 50:246, 1884. (X1)

R3. "An Icequake," Scientific American, 52:178, 1885. (X3)

ETR7 Buried Ridges within Continental Margins

Description. Long, ridge-like structures buried under various depths of sediments running parallel to the rims of many continents. Such ridges may rise 2-3 kilometers above adjacent sediment-filled troughs and extend for hundreds of kilometers. Seismic, gravitic, and magnetic surveys have outlined the locations of these buried structures.

Data Evaluation. The only report bearing on this phenomenon is from 1968. Given the extensive drilling along the continental margins in more recent years, it seems likely that additional data have yet to be found. If so, they will be incorporated in revisions of this volume. Rating: 3.

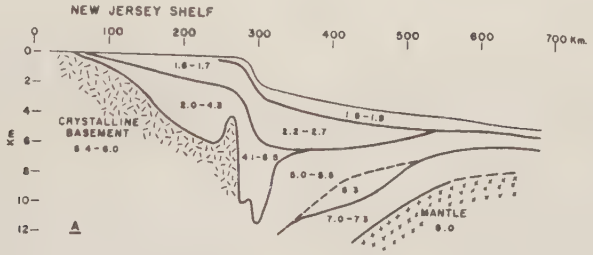
Anomaly Evaluation. As suggested, in X1 below, the prevalance of these buried ridges along the edges of the continents implies the existence of an unrecognized geological process. As of 1968, this process could not be singled out from among the many possibilities. Rating: 2.

Possible Explanations. A few of the many proposed mechanisms of ridge formation are: compressional folding, reef growth, plutonic intrusions, faulting, and continental accretion.

Similar and Related Phenomena. Island arcs (ETL2); the terranes apparently plastered against some continental margins (ES).

Examples

X1. Atlantic North America. "Probably the most important work discussing buried marginal ridges was the compilation and geophysical data by Drake, Ewing, and Sutton from the Atlantic seaboard of North America between Newfoundland and North Carolina. These workers clearly showed an apparently continuous basement ridge rising to heights of two to three kilometers above an adjacent, sediment-filled, landward trough within the continental shelf. The ridge lies approximately beneath or slightly seaward of the shelf-break throughout its extent, and it is bordered on the east by another sediment-filled trough beneath the lower continental slope and rise." (R1) The author also advances data indicating similar ridges along Atlantic South America and elsewhere.



Generalized structural section of the Atlantic margin of North America, showing the buried ridge. (X1)

X2. General observations. "Although buried ridges are not known from all continental margins, they appear to represent a major feature at the submerged edges of many continents. The development of many of these ridges appears to be in part the result of movement along normal faults. Differential subsidence of the landward basin appears to be especially important, regardless of other structural details, and arching and uplifting of the marginal ridge may also be a widespread characteristic. The growth of organic reefs may create or perpetuate a marginal ridge. None of these ridges can yet be attributed with confidence to compressional tectonics. Igneous rocks may yield refraction data which deceptively suggest a structural ridge; or they may be intrusive additions to a real structural ridge.

A significant problem which has not been discussed here is why these ridges should be where they are---at the outer edges of the continent, and parallel to the continental margin. This may depend upon the transition from continental to oceanic crust and to an inherent structural instability along this zone; or the location may be related to the normal history of marginal geosynclines; or possibly to the major fault systems which seem to parallel many continental edges. (Many of the local structural features have already been attributed indirectly to such major faulting.)

If further study shows these buried marginal ridges to be as widespread as the data now suggest, it seems likely that they must result from a common and fundamental cause regardless of how they are expressed." (R1)

References

R1. Burk, C.A.; "Buried Ridges within Continental Margins," New York Academy of Science, Transactions, 30:397, 1968. (X1, X2)

ETR8 Desert Ridges of Unknown Origin

Description. Long ridges of gravel in desert regions that are stabilized by covers of cobbles and pebbles. The only example on file is about 100 kilometers long, 1-2 kilometers wide, and 10-20 meters high.

Data Evaluation. Our data file consists only of one paragraph from a long article on desert morphology by a senior geologist. There seems to be no reason to question the existence of the phenomenon, although we would obviously like to know much more about it. Rating: 2.

Anomaly Evaluation. The explanation presented below represents only an educated guess---all that one can expect given so few facts. An anomaly evaluation here is guesswork, too. If the Wari'ah ridge is truly the remains of an old stream course, we would have no anomaly. On the chance that it could be something bizarre, such as the remains of an esker, we assign a modest anomaly rating. Rating: 3.

Possible Explanations. One speculation has the Wari'ah ridge the remains of an old stream course, the bed of which has been protected from erosion by its armor of cobbles and pebbles.

Similar and Related Phenomena. Eskers (ETR2), which bear an interesting resemblance to the Wari'ah ridge; megaripples (ETR3)

Examples

X1. Arabian Desert. From a review of desert morphology. "There is another gravel feature, the Wari'ah gravel ridge, which is quite a puzzle. This ridge is about 100 kilometers long and 1 to 2 kilometers wide and extends east and west, along the southern margin of ad-Dibdibba. It is protected from erosion by the heavy cover of coarse-to-medium cobbles and pebbles, and it stands about 10 to 20 meters above the surrounding plain. F.S. Vidal and I found a few crude rolled artifacts in the gravels in 1958. Wari'ah seems to be the remains of an old stream course heading east, but very little else is known of it." (R1)

References

R1. Holm, Donald August; "Desert Morphology in the Arabian Peninsula," Science, 132:1369, 1960. (X1)

ETS CREVICULAR CRUSTAL STRUCTURE

Key to Phenomena

ETS0 Introduction

Historically, the earth's crust below about 10,000 feet has been considered to be free of significant voids and crevices. Intense pressures were believed to close up any open spaces. Ground water was therefore thought to be confined to shallow rock formations. The direct detection of fluid-containing crevicular structure well below 10 kilometers has been reported by the Russians. Added to this unexpected discovery are hints from biological observations at ocean-floor sites and from earthquake distribution that the earth's crust is actually widely and deeply fractured and host to circulating fluids. Such a vision, if confirmed by future research, would necessitate a reevaluation of geological thinking.

ETS1 Biological Evidence for Geographically Widespread Crevicular Structures

Description. Caves, crevices, tunnels, and voids, existing over wide regions, that are now or once were interconnected, as inferred from life forms now present. This phenomenon will also be cataloged in the biology series of catalogs, but it must also be mentioned in the present context.

Data Evaluation. Blue holes, ocean-floor seeps, and similar structures have been described at great lenth in the literature. However, the important aspect of these structures in the present context is the similarity of their associated organisms. This characteristic has not been studied and reported in any detail so far. Such biological affinities are mentioned only in an offhand manner. Rating: 3.

Anomaly Evaluation. The appearance of the same or closely related species at widely separated locations implies that these places are now interconnected or were once in close prox-

imity. This reasoning applies, of course, only to those species that are unlikely to have dispersed great distances under prevailing ocean-floor conditions. The suggestion that the earth's upper crust is crevicular or grossly porous is not in consonance with current geological thinking. Rating: 2.

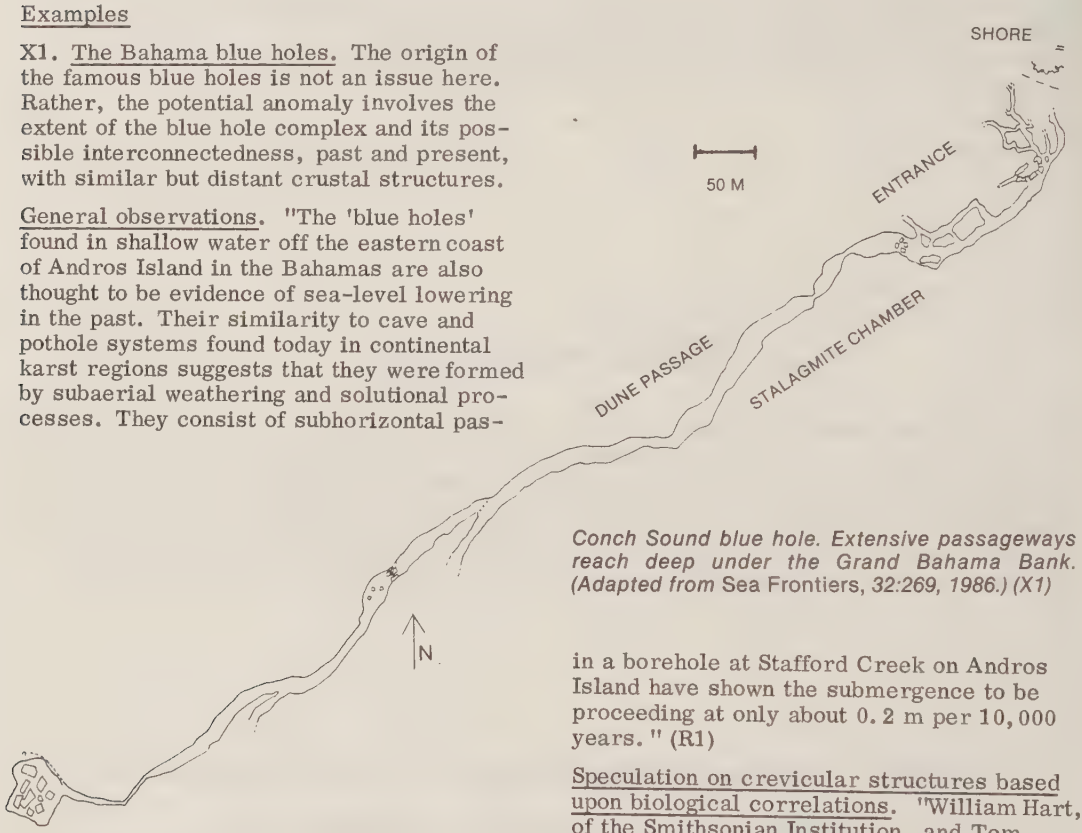
Possible Explanations. Crevicular life forms exist in and migrate through interconnected channels and voids in the earth's crust. The same life forms could have achieved their similarities through convergent evolution; or, they may have been dispersed in the distant past by continental drift.

Similar and Related Phenomena. Crevicular, fluid-filled structure at great depths (ETS2); seismic evidence of deep crevicular structure (ETS3).

Examples

X1. The Bahama blue holes. The origin of the famous blue holes is not an issue here. Rather, the potential anomaly involves the extent of the blue hole complex and its possible interconnectedness, past and present, with similar but distant crustal structures.

General observations. "The 'blue holes' found in shallow water off the eastern coast of Andros Island in the Bahamas are also thought to be evidence of sea-level lowering in the past. Their similarity to cave and pothole systems found today in continental karst regions suggests that they were formed by subaerial weathering and solutional processes. They consist of subhorizontal passageways and vertical pits extending to more than 100 m below sea level. Benjamin has located more than 100 blue holes in the Bahamas and has explored and mapped more than 60 of them. They cannot be simply explained in terms of a subaerial karst topography that is rapidly submerging as a result of tectonic processes, because correlations between depth and stratigraphic age



Conch Sound blue hole. Extensive passageways reach deep under the Grand Bahama Bank. (Adapted from Sea Frontiers, *32:269, 1986.) (X1)*

in a borehole at Stafford Creek on Andros Island have shown the submergence to be proceeding at only about 0.2 m per 10,000 years." (R1)

Speculation on crevicular structures based upon biological correlations. "William Hart, of the Smithsonian Institution, and Tom Iliffe, of the Bermuda Biological Station, believe that blue holes are one link in a chain of crevicular habitats---caves, fissures, rocks of the sea floor---that stretches from one side of the ocean to the other, from the Americas, across the sea floor and the Mid-Atlantic Ridge, to Africa and the Mediterranean. Related amphipods are not only found in Bahamian caves but in marine caves in Bermuda, the Pacific, and the Yucatan Peninsula." (R5; R4)

X2. Ocean-floor vents and seeps. These surface and near-surface manifestations of crevicular structure, like the blue holes, imply wide geographical distribution and, possibly, some degree of interconnectedness, based upon biological correlations.

Florida Escarpment. "Nine scientists set out last March with the research submarine Alvin to study the erosion process at the bottom of the Florida Escarpment, a range of underwater cliffs in the Gulf of Mexico that tower over the seafloor at heights greater than that of the Grand Canyon. 'Rather unexpectedly, we came across communities of abundant organisms. That's quite anomalous for what one would expect for abyssal (deep-sea) biological activity,' says Charles K. Paull, a graduate student at Scripps Institution of Oceanography in La Jolla, Calif. The scientists found bacterial mats, bivalves, crabs, fish, limpets and many other organisms similar to those that had been discovered thriving around hydrothermal vents along the East Pacific Rise."

(R2) The point being made here is that the widely separated deep-sea vents and seeps support the same, or very similar, unique organisms; suggesting, perhaps, geological interconnectedness. (WRC)

References

R1. Gascoyne, M., et al; "Sea-Level Lowering during the Illinoian Glaciation: Evidence from a Bahama 'Blue Hole'," Science, 205:806, 1979. (X1)

R2. Weisburd, S.; "There's Life among the Seeps, Too," Science News, 126:374, 1984. (X2)

R3. Palmer, Rob; "Life in a Sunless Sea," Sea Frontiers, 32:269, 1986.

R4. Palmer, Rob; "Ecology beneath the Bahama Banks," New Scientist, p. 44, May 8, 1986. (X1)

R5. Palmer, Robert; "In the Lair of the Lusca," Natural History, 96:42, January 1987. (X1)

ETS2 Fluid-Filled Crevicular Structures at Great Depths

Description. The discovery through deep drilling of crevicular structures containing abundant fluids.

Data Evaluation. Several rather popular accounts of the Soviet drilling program have been published, but they provide few details on the nature of the fluids discovered or the state of the rocks themselves. Rating: 3.

Anomaly Evaluation. As expressed in X1, the Kola discovery of deep voids and fluids were completely unexpected. Rating: 2.

Possible Explanations. None offered.

Similar and Related Phenomena. The biology of blue holes and ocean-floor vents (ETS1); geophysical evidence of deep, fluid-containing crevicular structure (ETS3).

Examples

X1. Kola Peninsula, USSR. "Deep drilling provides the most direct view of the earth's third and fourth dimensions. It provides only a shallow view, although Soviet scientists have shown that it can be a highly revealing one. The Soviet Union's exploratory drilling program includes the deepest hole drilled to date. Spudded in the Kola Peninsula east of Finland, the hole reportedly goes down 13 kilometers, 85 percent of the way to its targeted depth. Although the United States leads in deep-ocean and commercial drilling, its deepest hole on land, drilled by the United States oil industry, bottomed at 9.6 kilometers.

The Kola bore hole is one of a series being drilled to obtain both practical information and basic knowledge of the earth. Since its drill bit first chewed into rock in 1970, the Kola effort has been producing data that cast doubt on traditional theories of the structure of the continental crust, heat flow, and mineral formation.

.....

'What really surprised us about the Kola

hole results,' (J.) Oliver says, 'is that they found open fractures with fluids flowing through them at depths down to at least 11.5 kilometers. Many scientists expected that pressure would close all open space below three kilometers.'" (R2; R1, R3-R5)

The Russians also reported finding microscopic fossils at depths of 22,000 feet. (R1)

References

R1. "Journey to Earth's Center," San Diego Union, p. A-30, October 9, 1981. (X1)
R2. Cromie, William J.; "Windows to the Earth," Mosaic, 15:28, no. 6, 1984. (X1)
R3. Yardley, Bruce W.D.; "Is There Water in the Deep Continental Crust?" Nature, 323:111, 1986. (X1)
R4. Weisburd, S.; "Trickle-Down Theory of Eastern Quakes," Science News, 129:165, 1986. (X1)
R5. Rebeyrol, Yvonne; "Un Puits de 10 Kilomètres," Le Monde, p. 14, April 4, 1986. (X1) (Cr. C. Maugé)

ETS3 Seismic Evidence for Deep Crevicular Structure

Description. The occasional earthquakes experienced in eastern North America, which suggest a role of deep-circulating fluids.

Data Evaluation. Eastern North American earthquakes are a matter of historical record. Rating: 1.

Anomaly Evaluation. At issue here is not the seismicity itself but the implication that it may be a consequence of surface fluids, especially water, penetrating deep into the crust. Conventional geological wisdom holds that pressure should close all crevices and voids below about 3 kilometers. Rating: 2.

Possible Explanations. Quakes in eastern North America are triggered by surface rainfall descending deep into the crevicular crust.

Similar and Related Phenomena. See GQG2, in another volume of this Catalog, for additional data and comment on earthquakes in eastern North America.

Examples

X1. General Observations. Eastern North American earthquakes are diffusely dispersed and usually do not originate along known fault lines. J. Costain and his colleagues at Virginia Polytechnic Institute speculate that these quakes may be stimulated by rainfall that seeps deep into the crust through an extensive network of fractures.

"In building its model of hydroseismicity for the eastern United States, Costain's group draws on seismic reflection profiles and other studies indicating that the eastern crust is riddled with a diffuse network of near-vertical fractures extending down to about 20 km. According to the researchers, this fractured fabric was created during two rifting periods, starting about 200 million years ago when the North American continent was pulled apart from Africa and the Atlantic Ocean basin opened. In their model the researchers envision groundwater traveling down to 20 km along a network of connected fractures and then flowing back up to fill the rivers and lakes; somewhere during that journey, they propose, earthquakes can be triggered." (R1)

References

R1. Weisburd, S.; "Trickle-Down Theory of Eastern Quakes," Science News, 129:165, 1986. (X1)

ETV VALLEYS, CHANNELS, FURROWS

Key to Phenomena

ETV0 Introduction

Long linear and serpentine incisions in the earth's crust are ubiquitous. Most are easily explained by invoking the erosive characteristics of streams, turbidity currents, wind, and similar agents. In contrast, the ridges of ETR are usually the consequence of deposition rather than erosion, even though they have similar plan views. Exceptions exist, of course, such as rifts, grabens, and the crack along the mid-ocean ridges. However, the focus in this chapter centers on those valleys, channels, and furrows that do not seem to be well-accounted-for by applying the usual erosive mechanisms and conventional geological histories.

The science of geology has seen a protracted debate on the origin of the great submarine canyons. Even now, serious differences of opinion exist. The sea-floor channels, too, are not completely understood. These two major expressions of terrestrial topography must remain "anomalous" a bit longer. On land, we find that the Grand Canyon and the Channelled Scablands, both widely assumed to be well-understood, exhibit enough anomalies so that we cannot "close the book" on them---that is, we cannot if we look at all the facts and set up high standards for explanations.

Several unconventional and paradigm-challenging scenarios surface in this chapter: (1) Subaerial erosion during radically lower stands of sea level; (2) Catastrophic erosion due to sudden releases of impounded water or huge marine transgressions, resulting in sheet-flooding; (3) High-level erosion that implies high altitude inland impoundments of water or, again, marine incursions; and (4) Poorly understood deep-sea channels and furrows that seem to have been cut by unknown processes.

ETV1 Submarine Canyons

Description. Very long, very deep canyons incised in all continental slopes and shelves, the flanks of many island groups, and the edges of some inland sea basins. Submarine canyons number in the hundreds and constitute a major geological phenomenon. The salient features of submarine canyons are listed in X1, below. It is sufficient to say here that, as a class, submarine canyons are much larger than terrestrial canyons, which they closely resemble otherwise.

Data Evaluation. Submarine canyons have been studied intensively for almost a century. The literature is large, and reference is made to only a portion of it in this Catalog. Submarine canyons have been probed by sonar sounding and side-scanning, by dredge-sampling, and by first-hand reconnaissance by divers and manned submersibles. Rating: 1.

Anomaly Evaluation. It is a fact that most geologists and geophysicists consider the submarine canyon question to be closed. They hold that the canyons are almost entirely the work of turbidity currents. Unfortunately, we really know very little about turbidity currents and how effective they are in cutting hard, crystalline rock. The following pages will also detail some canyon features that are not consistent with a pure turbidity-current origin. It is safer to say that submarine canyons probably have a polygenetic origin; that is, several processes have been at work on most. From the anomalist's point of view, none of the forces thought to be active in a polygenetic origin is anomalous in itself. In fact, submarine canyons would be anomalous only if it could be shown that subaerial erosion has been dominant, and that sea levels, consequently, must have been much lower in the past. Since most canyons are very deep, sea level changes would have had to be measured in terms of a mile or two at least. Present data indicate that, although subaerial erosion has probably played an important role, we need not resort to immense sea-level changes. This situation could change, however, since other evidence also suggests large sea-level changes (ETE, ETH1) and catastrophic water-erosion events (ETR). It is too early to "close the book" on submarine canyons; some degree of anomalousness remains. Rating: 3.

Possible Explanations. Erosion by turbidity currents and slumping. Subaerial erosion by streams. Faulting. Chemical and biological action. See X17 for more details.

Similar and Related Phenomena. Sea-floor channels (ETV2); wind gaps (ETV3); furrows in the continental slopes (ETV8); Grand Canyon anomalies (ETV7); the Channelled Scablands (ETV5); sealevel changes of large magnitude (ETE); the guyots (ETH1).

Examples

X0. Introduction. It has been difficult to compress the voluminous descriptions and lengthy theorizing about submarine canyons into something of reasonable length. The following entries are divided into three parts: (1) A summary of the characteristics of submarine canyons (X1); (2) Descriptions of three of the most interesting of the submarine canyons (X2-X4); and (3) A historical journey through the literature with emphasis on new discoveries and changing theories (X5+). As is customary in these Catalogs, prominence is given to those features and implications that tend to contradict widely held theories.

X1. General characteristics of submarine canyons and special features requiring explanation. The primary source for the information provided below is R36.

Canyon length. Taken as a group, the lengths of submarine canyons average about 30 miles. The shortest are those off Hawaii, which average only 6.5 miles. The Bering Canyon runs for 230 miles. If associated fan valleys are included, the Congo Canyon holds the record at about 500 miles.

Depth of canyon head. On the average, submarine canyons head at a depth of 300 feet, but three Baja California canyons begin almost on the beach. All eastern North American canyons head at depths of more than 300 feet.

Depth of canyon termination. Again averaging, canyon terminations occur at about 7000 feet. The deepest is 15,580 feet for the Aviles Canyon off Spain. Of interest is the fact that many Mediterranean canyons terminate below

the depth of the sill at Gibraltar.

Nature of the coast near a canyon head. Of 77 canyons surveyed, 13 extended into estuaries, 25 were directly off bays, 26 were off straight beaches, and 13 began off relatively straight-cliffed coasts. Again taking the 77-canyon sample, 46 are located directly off river valleys, 11 show no valley relationship, and the rest begin too far at sea to classify. Some even begin on submarine ridges (viz., on the Honshu-Marianas ridge, 100 miles south of Japan (R62)). Submarine canyons exist off both stable and unstable coasts.

Canyon wall height. The average is about 3,000 feet, with the largest wall height being found near the lower end of the Grand Bahama Canyon at 14,060 feet. Canyon depths seem to show no relation to the type of rock.

Canyon transverse profile. Sixty in the sample of 77 canyons had V-shaped profiles; only 13 began as V-shaped canyons and changed to trough-shaped profiles at their lower ends; just two were entirely trough-shaped.

Nature of canyon wall. Data are limited here. Twenty-two canyons yielded crystalline rock (mostly granite); some 30 showed sedimentary rock only.

Nature of canyon termination. The data are incomplete here. Thirty-three canyons ended in fan-valleys; only 9 were without fan-valleys.

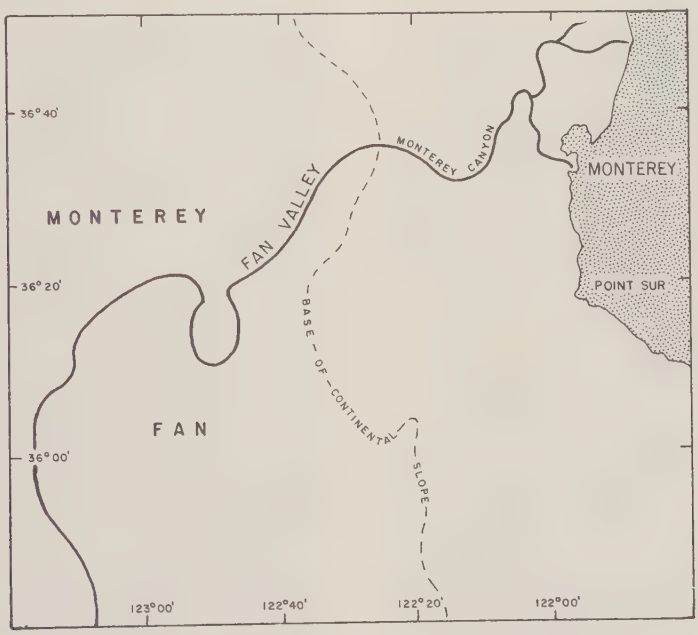
Nature of canyon course. Most submarine canyons possess winding courses; some may even be termed meandering.

Canyon tributaries. Tributaries are common, particularly near canyon heads. Many tributaries enter as canyon heads.

Canyon currents. Currents up to 0.5 knot have been observed. Ripple marks have been photographed as deep as 11,480 feet, indicating that currents persist at great depths.

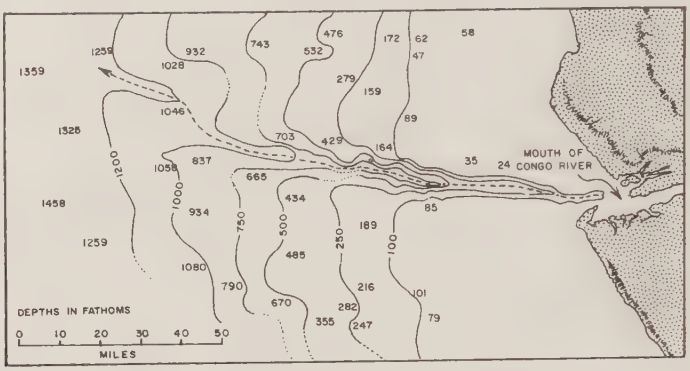
Canyon sediment transportation. Besides the near-shore transport of sand, gravel and even large boulders (some 3 feet in diameter), submarine canyons also carry shallow-water foraminifera to great depths.

The age of the submarine canyons. Many authorities contend that these canyons were cut during the low sealevel stands of the Pleistocene. Evidence does exist, however, that submarine canyon erosion continues today.



The Monterey submarine canyon meanders, like a mature river, as it crosses the Monterey Fan off the California coast. (X1)

X2. The Congo Canyon. We commence with an excerpt from one of the first important papers on submarine canyons. Obviously, much better data are available today, but J.W. Spencer's early interpretation is most interesting. Spencer begins with some speculations on canyon origin that reflect geological thinking circa 1903.



A 1903 map of the Congo submarine canyon. Modern surveys are, of course, much more precise and detailed. (X2)

"On the Origin of the Submarine Valleys. The origin of submarine valleys attaining a depth of even 1,000 or 2,000 feet in the continental shelf, and whose outer edge is submerged 300 or 400 feet, although implying a recent elevation of 2,000 or 3,000 feet, need scarcely be called into question. While these channels pass through canyons and descend abruptly into the deeper valleys which open out into embayments in the great continental slope to depths of 12,000 or 15,000 feet, it may seem difficult to explain these lower reaches by the hypothesis of atmospheric action during a period of emergence on account of the stupendous changes of level of land and sea required; yet the writer has ventured to adopt this hypothesis, in which he has been confirmed by many years of research. But from the broad standpoint the complex conditions doubtless qualify the simple hypothesis of the former elevation of the land with its consequent sculpturing by atmospheric agents. While some of the valleys may be attributed to tectonic or orogenic, or occasional ones to volcanic causes, no explanation based on these causes has been worked out in detail; consequently the author has been led, after presenting the facts given in this and other papers, to emphasize particularly the resemblances between these submarine valleys and land features, with the conclusion that the former were sculptured on the great continental slopes by atmospheric agents, which implies a greater change of level of land and sea than the 2,000 or 3,000 feet above mentioned. If it were a question of simple elevation, it would amount to 12,000 or 15,000 feet higher than at present along the border of the continent. This great elevation, however, may have been much reduced by an unequal bending down of the continental slope, or indeed to some extent by a shifting of the oceanic waters. Then also arises the question, What became of the waters, and also what were the causes of these great continental movements, about which we know nothing? The problem thus becomes so complex that the writer has to confine himself to the study of the resemblances above mentioned. While the features along the Atlantic coast are repeated on the eastern side of that basin and elsewhere, the author could not possibly imply a general drainage of the basins, but rather that there have been alternations, whereby great regions have been elevated while others have been depressed, as, for instance, the West Indian islands alternating in altitude with the lands of Central America. We know that in the epeirogenic movements the changes of level are unequal, with the rate of elevation or subsidence increasing or diminishing, and from the writer's observations such rates

increase on approaching mountain regions and diminish in the direction of the plains. This, extended to the great continental slopes, would favor the theory of their having been abnormally bent downward; consequently the land may not necessarily have stood 12,000 or 15,000 feet higher than now, although the bottom of the slopes had been emerged to that extent. Still the land stood very much higher than at present, probably sufficient to give rise to glacial conditions in the north.

When the amphitheaters, coves, or canyons indenting the edge of the submerged continental shelf are known to have a breadth increasing from 3 miles (that of the Hudson) to 5 or 10 miles, or where farther down the continental slopes the valleys open into embayments of 20 or 30 miles, even that breadth is no greater than can be seen in the lower reaches of many land valleys. It is seldom that we are able to restrict the channels to their actual breadth for want of closer soundings, such as have been made along a part of the Hudson valley and along the submerged extension of the Congo river, the last of which I may be permitted to refer to as a most detailed piece of work in revealing buried channels. Here the soundings were taken so as to obtain contours at given depths apart, which were often not more than half a mile. Thus Mr. J.Y. Buchanan found the depth of the river to be 900 feet at a distance of 20 miles above its mouth, where there is an obstructing bar. At 35 miles from the coast line the canyon has a breadth of 6 miles and a depth of 3,000 feet below the submerged plateau. The 6,000-foot contour of the continental slope recedes landward for 30 miles at this point. Beyond, Professor Edward Hull finds that the valley at over 7,500 feet indents the great slope for 20 miles landward. On account of the excellency of this study, the map of the Congo channel is here reproduced." (R2)

F.P. Shepard and R.F. Dill give a more recent portrait of this great canyon. "The river with the largest discharge in Africa, the Congo, debouches into a long deep estuary at the head of the Congo Canyon. This is amazing, because of the enormous sediment load in the Congo that tends to fill the estuary and because of the indication that this part of the African coast is stable, having few other estuaries and being bordered by a shelf of normal marginal depth. The head of the canyon, 15 miles up the estuary, has a depth of 70 ft (21 m) and the inner part has a gradient of 30 m/km, but within a mile this is lowered to approximately 10 m/km. This apparently continues at least out to depths of 2,000 ft (610 m). Beyond, the gradient is slightly lower. At the mouth of the estuary the depth is 500 ft (150 m). No new survey is available for the inner part of the canyon, but seaward of the shelf, Lamont scientists have run a series of echo-sounding lines across the canyon and the fan-valley that adjoins the canyon on the outside. According to the Lamont data and the earlier surveys, the canyon, after extending fairly straight across the shelf, curves slightly to the right and attains its greatest wall heights, 3,600 ft (1,100 m), at an axial depth of 6,000 ft (1,830 m). Here, it is still a V-shaped canyon with a width of 9 miles between the upper lip of its walls. About 15 miles beyond, natural levees are developed on both sides and the wall height decreases rapidly. It thus becomes a fan-valley. At a depth of about 8.700 ft (2,650 m) and 150 miles from the head, it turns about 90° to the left. From there on it crosses a large fan with a curving course and a depth below the surroundings of about 600 ft (180 m), gradually decreasing to about 100 ft (30 m). Some 250 miles from the head, the fan-valley bifurcates and it is difficult to tell which arm is the more pronounced. However, in the soundings of the Lamont ship Vema in 1963, a series of crossings were made starting 140 miles out beyond the last crossing of the southern arm, and a distinct fan-valley was found with natural levees on each side. Here, an axial depth of approximately 60 ft (18 m) exists below the surrounding fan." (R36) As a footnote, the Congo Canyon is the site of many cable ruptures, especially during periods of high water discharge. The implication is that turbidity currents and slumping occur at great depths. (WRC)

X3. The Bahama canyons. The following description is from Shepard-and-Dill's 1964 book.

"The principal canyon, called here Great Bahama Canyon, has two branches, both unique in that each heads in deep water adjacent to a flat-floored trough. The arm in the Tongue of the Ocean heads at a depth of 4,800 ft (1,460 m), north of the broad trough-shaped depression constituting the southern end of this inter-island passageway. This main branch extends north, passing west of New Providence Island, and then

swinging to the northeast where it extends out through Northeast Providence Channel, attaining a depth of at least 14,060 ft (4,290 m) in the strait between Great Abaco and Eleuthera islands. At this depth the transverse profile is V-shaped and the walls slope down continuously from the low islands on either side. Aside from the somewhat questionable depths in two western European canyons, this is the deepest canyon in the world and the walls are by far the highest, nearly 3 miles compared with 1 mile for the Grand Canyon of the Colorado. Fifteen miles farther seaward, a sounding line indicates that the V-shape has given way to two trough-shaped valleys at depths of 14,900 ft (4,540 m) and 14,850 ft (4,525 m), each with relatively flat floors. The total length of the canyon, measured from the Tongue of the Ocean head, is approximately 125 miles. In this distance the axis drops 9,600 ft (2,930 m) with an average gradient of only 13 m/km, almost comparable to the low gradient of Congo Canyon." (R36)

The so-called "Tongue of the Ocean", mentioned above is itself somewhat of a mystery. This flat-floored trough has mile-high walls and an oval tip some 40 miles across. (R58) If exposed and accessible, the Tongue of the Ocean would certainly be one of the natural wonders of the world. This trough is cut into the great limestone block that supports the Bahamas. Its origin is not clear. For the time being, it is classified with the submarine canyons.

More details about the Bahama canyons are related by J.E. Andrews et al, in their 1970 paper. "Abstract. Recent surveys and sampling of the V-shaped canyon that cuts into parts of the broad troughs separating the Bahama Banks have given a greatly improved picture of this gigantic valley and the processes operating to shape it. The canyon has two major branches, one following Northwest Providence Channel and the other the Tongue of the Ocean, which join 15 mi north of New Providence Island, and continue seaward as a submarine canyon with walls almost 3 mi high. These, so far as we know, are the world's highest canyon walls (either submarine or subaerial), and the canyon length, including the branch in Northwest Providence Channel, is at least 150 mi, exceeded only by two submarine canyons in the Bering Sea.

Bottom photographs from the outer portions of Northwest Branch and Tongue Branch show wall rock, rounded cobbles, and boulders along their axes, as well as ripple-marked sand to indicate the importance of currents moving along the canyon floor. Further evidence that erosion has at least kept the valleys open as the Bahama Banks grew comes from the winding courses and the numerous tributaries that descend the walls from the shallow Banks, particularly on the south side of Northwest Branch. The possibility that limestone solution has been important comes from the finding of more depressions along Northwest Branch than in other submarine canyons of the world, and the discovery of caverns along the walls by observers during deep dives into Tongue Branch in the Alvin and Aluminaut. It seems to us highly probable that the modern canyons are due primarily to submarine erosion, partly re-excavating old filled troughs." (R40)

X4. The Bering Sea Canyons. Again, we begin with a short description from Shepard-and-Dill's book.

"At the outer end of the wide Bering shelf, the large Bering Canyon heads at 450 ft (140 m) in a broad bowl north of Unimak Pass. It extends west-southwest along the Aleutian chain for 100 miles past Unalaska and Umnak islands, then swings northwest for an additional 105-mile course and finally bends west, terminating in about 11,000 ft (3,350 m) of water. The total length of about 230 miles is the longest in the world..... On the south side of the canyon, Bogoslov, an active volcano, is built up to the surface from time to time and then washed away by waves or destroyed by explosions. The canyon is about 20 miles wide near Bogoslov, with a section showing wall heights of 6,600 ft (2,000 m) on the south side and 3,500 ft (1,070 m) on the north side." Tributaries come into the canyon and are especially abundant on the south side. (R36)

The Pribilof Canyon heads near the broad shelf, like the Bering Canyon, and possesses a bowl-shaped head about 20 miles wide. It has wall heights of as much as 7,000 feet. (R36)

Further information about the Bering canyons may be gleaned from the following abstract: "Erosion of some of the largest known submarine canyons has removed more than 20,000 km^3 of former subduction margin between the Aleutian Islands and Cape Navarin, U.S.S.R. The canyons are incised as deeply as 2,400 m into Tertiary sedimentary and igneous rocks that make up the margin and attendant deep sedimentary basins

along the outer Bering shelf. Cutting of the seven major canyons probably occurred during low stands of sea level when the Bering Strait was exposed to a depth of about 135 m, which allowed the ancestral Anadyr, Yukon, and Kuskokwim rivers to carry large volumes of sediment to the outer shelf. Although their positions appear to be structurally influenced, the canyons apparently were cut by combinations of massive slumping and sliding of sediment deposited near the shelf edge and of scouring action of the resulting turbidity currents that carried debris to the abyssal sea floor, where deep-sea fans have formed. Other processes that affect the morphology and (or) sedimentation within these enormous canyons are: internal waves, as suggested by large sand waves in the canyon heads, burrowing of organisms, as shown by bioturbation of the sediment, large gyres within the prevailing slope and shelf currents, as revealed by suspended-sediment patterns, and the annual incursion of pack ice that covers at least the north half of the Bering Sea for a third of the year. Geophysical and sedimentological evidence indicates that all these processes are ongoing phenomena; their intensity has been variously affected throughout the Cenozoic by eustatic sea-level changes." (R49)

X5. 1902. California coast. An early assessment of submarine canyons.

"The mature Coast Ranges of California, taken as a whole, lie close to and parallel with the coast line, and the coastal topography is therefore rugged. As the larger stream courses follow the trend of the ranges and the coast for long distances, there are few coastal breaks of importance. Fringing this rugged coast and the coastal islands is a narrow submarine terrace or platform, the continental shelf, which has been formed mainly by marine erosion, and whose outer margin is marked approximately by the 100-fathom submarine contour. Its width ranges from a minimum of about a mile to a maximum of about thirty-two miles, the average being between five and ten miles. The submarine valleys (of which between twenty-five and thirty have been described along the Pacific

Topography of the Carmel Canyon, off the California coast. (Adapted from Submarine Canyons and Other Sea Valleys*)*

Coast of California and Lower California) notch this terrace and its outer escarpment. The valleys, for the most part, begin at or near the shore line and continue to depths ranging from about 400 feet to more than 3,000 feet, the majority descending to at least 2,000 feet. Most of the valleys follow a course roughly at right angles to the shore. Their forms are both simple and branched. Some of them head opposite the mouths of large valleys on the land, and some opposite abrupt and rugged portions of the coast, where there is no break in the Coast Ranges. The valleys in general are quite open, none of them being 'chasm,' as is frequently supposed. This may be easily seen in the cross sections of the valleys. While the general slope of their walls differs considerably, in any given case it is comparatively gentle, taken as a whole." (R1) The appearance of submarine canyons along rugged coasts, where there are no obvious sources of heavy runoff, is a significant point. (WRC)

X6. 1935. A reaction to the subaerial erosion hypothesis. "Certain examples of California submarine valleys are, I believe, beyond production by sub-aerial stream-erosion. They are shown on Davidson's chart of the coast off the Santa Monica Mountains which trend east-west not far west of Los Angeles, and which I have recently studied in another connection as will be told in a forthcoming article entitled 'The glacial epochs of the Santa Monica Mountains' in the bulletin of the Geological Society of America for 1933. It will be there shown that the mountain streams eroded valleys of moderate depth below present sea-level and for a moderate distance seaward from the present shore-line, while the ocean was lowered perhaps 50 fathoms during the last Glacial Epoch of the Glacial Period, but that the valleys were smoothly filled and obliterated during and since the Post-Glacial rise of the ocean to its actual level. Yet several much longer and deeper submarine valleys are found in the same district, for the excavation of which no sufficient emergence is indicated by the land-geology since the land and sea assumed their existing areal relations in this region. It is therefore illogical to insist on such emergence, because it is based on the tacit postulate that submarine valleys can have originated only in one way. Moreover, at least the heads of these deeper valleys should have been much aggraded during and since the lower stand of the ocean in the last Glacial Epoch while the adjacent shallower part of the sea-floor was being built up with terrigenous sediments, had there not been some submarine agency in operation by which they were kept open. Hence, inasmuch as their valley-like form cannot be reasonably accounted for by their having had a valley-like origin, I propose to call them 'mock-valleys.'" (R6)

X7. 1936. General observations on world-wide submarine canyons, plus an unusual hypothesis. "At least forty of these submerged valleys have been noted, and no doubt many more will be found when more soundings are taken on the continental slopes. They are known to occur in many parts of the world: off the coast of North America from Newfoundland south; off the coast of Europe from Ireland south; off Ecuador and Peru on the west coast of South America; off the coast of North America from Vancouver Island south; on the west side of the Pacific off Japan, Formosa and the East Indies; on the east coast of Africa off the Congo, Niger, Cape Verde and Gibraltar Straits; in the Indian Ocean off Ceylon; off the Indus and the Ganges and in the Arabian Gulf; and south of Zanzibar on the east coast of Africa.

Many of the valleys are known to extend to depths of thousands of feet, but very little information is available as to the maximum depths to which the valleys extend. The valley which may be the seaward extension of the Potomac River, recently surveyed by the U. S. Coast and Geodetic Survey, appears to reach 8,800 feet below sea level (latitude 37°). Several valleys in the Bahamas, investigated by reconnaissance buoy during the gravity measuring cruise of the U. S. submarine S-18, apparently reach 11,000 feet (latitude 26°). The English Channel valley, on the other hand, does not go down to a thousand fathoms (latitude 49°)." Hess and MacClintock, at this point in time, favored the subaerial erosion theory; proposing further that a change in the ellipticity of the ocean surface had exposed the canyon areas. This is why they correlated canyon depths and latitudes in the above quotation. (R7)

X8. 1939. The spring-sapping hypothesis. D. Johnson's suggestion that spring-sapping had eroded the submarine canyons is only of minor importance. It is, however, of

historical interest because of his book on the subject (R15) and his series of papers in the Journal of Geomorphology (R12). In addition, he maintained that spring sapping also helped form the Carolina Bays (ETB1).

X9. 1940. du Toit's orogenic hypothesis. A. L. du Toit, the great South African geologist and early proponent of continental drift, carefully reviewed the characteristics of submarine canyons and weighed in with his own hypothesis.

"It is universally admitted that, so far as is yet known, the canyons show in their detail all the peculiarities of normal terrestrial ravines, and such applies even more markedly to the associated furrowing. This is finely brought out in the charts by Veatch and Smith, although the particular type of topography there depicted is admitted by them to be not the only possible one, and more numerous and closer-set soundings may demand some modifications in contouring. These writers are nevertheless correct in emphasizing the stream-like erosion-pattern over the slope and also its terrestrial likeness. Such natural interpretation, which was indeed advocated for the Hudson Canyon so many years ago by Lindekohl and Dana, finds serious opposition, however, in the vast lowering of ocean-level that would be demanded, and with it the related problem---only one among other serious difficulties---of the temporary disposal of the displaced oceanic waters.

To evade such stupendous and rather improbable mechanism several hypotheses have been formulated that presume subaqueous erosion effected by currents, sapping, slumping, mud-sliding, etc. The small current velocities actually measured by Stetson along canyon-floors of George's Bank, southeast of Long Island---up to one-fourth of a mile per hour---would seem to rule out the first-named agency, though such speeds might yet be enough to keep the ravines free of silt. Whether the velocities would become sufficiently intensified by strong turbidity, as calculated by Daly and Kuenen, must await confirmation through further measurements, especially along the middle and lower reaches of the canyons. The discovery of ravines possessing steep walls of fairly consolidated materials such as sandstone, or even of crystalline rocks, as recorded by Shepard and Andrade, raises strong doubts concerning the ability of even heavily silt-charged currents to excavate such immense chasms beneath the ocean, and furthermore to such depths, where gradients have incidentally become much flatter.

Johnson has argued at length and almost convincingly for the importance of sapping through submarine springs and still more through the expulsion of the contained water from the porous sediments held to build the continental slope. If such sapping, or alternatively, if turbidity currents, were as potent as argued, such an action should also have operated in the past under more or less similar conditions. Now numerous cases of marine fringing-sediments of Mesozoic and Tertiary age, like those presumed to build the Atlantic Shelf and Slope, have been upheaved for inspection in various parts of the world. It is for stratigraphers to advise whether among such comparable profiles there is any clear example of an intensely dissected surface of dendritic pattern with high relief preserved beneath a younger, and preferably marine, covering.

While it is readily conceded that submarine agencies could have contributed materially to the development or maintenance of the ravines, the view that such agencies were primarily responsible for their initiation and excavation seems too large an order. Consequently, however improbable at first sight it might appear, we are thrown back upon the original suggestion, that of subaerial erosion. Even Johnson, protagonist of sapping processes, admits that a subaerial origin is still a working hypothesis. At the same time we shall have to rid our minds of the commonly expressed or implied idea that land, shelf and slope have throughout moved undeformed as a unit in relation to the ocean. On the contrary we shall be driven to recognize differential movements within the continental border. Movements of the kind producing Graben can generally be discounted, although in certain cases notching was definitely controlled by fault-systems trending normal or oblique to the shore, as detailed for the coast of Portugal by Andrade.

A scheme involving both faulting and warping with trends more or less parallel to the continental margin would appear more promising, as was suggested by the author in 1937, developed further when dealing with the presumed 'rift-basin' of the Atlantic-Arctic Ocean. This, the Orogenic Hypothesis, is elaborated below with proper recognition given to some of its weaknesses." (R17)

X10. 1951. Reevaluations. By 1951, considerable evidence had accumulated that turbidity currents have not only carried great volumes of debris far out into the oceans, but that they also might have contributed significantly to the cutting of the submarine canyons. (R24)

Also in 1951, F. P. Shepard, who had earlier considered subaerial erosion to be the only reasonable hypothesis, developed a new "composite" hypothesis of submarine canyon formations.

"A new composite hypothesis. New oceanographic information can now be combined with information from drill cores along the coasts and on islands to build a composite hypothesis that accounts for submarine canyons without appealing either to enormous movements of land or of sea level or to the excavation by powerful submarine currents for which there is no evidence. It now appears that many of the canyons have three divisions as follows:

1. Inner valley heads that extend into shallow water along many coasts and contain indications of having been cut at a relatively recent period.

2. Intermediate canyons that have rocky walls rising hundreds or even thousands of feet above their narrow, winding floors.

3. Outer valleys, only slightly incised into great masses of unconsolidated sediment, which can be traced out to the base of the oceanic slopes.

These three divisions are not clearly separated one from the other and apparently have had a composite and overlapping origin. The outer two divisions can be explained by a sequence of events that fits into a pattern well known to geologists who have investigated the history of depositional basins (geosynclines). The submergence of a geosyncline is known to alternate with reversals of movement. Similarly, the deep submergence of the continental margins, which is thoroughly established from well records along many of the present coasts, was probably interspersed with stages of uplift or preceded by an uplift. During uplifts, the exposed continental margin was trenched by stream erosion, thus forming the intermediate canyons. Outside these canyons deltas developed on the lower oceanic slopes.

Following the cutting of the canyons, the slopes were submerged. The canyons became a locus of intensive deposition, but wherever they had high gradients the sediment was carried outwards by submarine landslides such as are now well established as occurring in the canyons along the California coast. The soft sediments of the deltas are thought also to have undergone mass sliding movements, opening up cracks and scars on the delta fronts. One of the results of the slides was the development of turbidity (density) currents which transported the sediments down the canyon floors and, moving across the deformed deltas, sank into the landslide scars and cracks, gradually transforming them into valleylike features. These 'valleys' were eventually extended to the base of the continental slopes." (R25)

X11. 1953. Another composite theory. "Abstract. Submarine canyons have generally been lumped together and a common explanation of their origin has been sought. The author suggests that some, named submarine ravines, are drowned river valleys (Corsica). The other extreme, the New England type, is the result of glacial turbidity currents. Daly's explanation of the California type as drowned subaerial valleys, smothered by sediment, and excavated by glacial and recent turbidity currents is accepted with some change of emphasis. This type is thus tentatively ascribed to the same turbidity-current mechanism, but erosion has exhumed some buried valleys, cleaned out parts of others, laid bare parts of old mountain slopes, and has even developed new channels. Shepard's new hypothesis of drowned river valleys kept permanently open by submarine processes, comes near to this picture and is accepted for the submarine ravines, but it cannot account for the features that indicate submarine erosion in the recent past off New England and California. His main argument against erosion by turbidity currents is the absence of scour on lake-delta fronts, but conditions in lakes must be highly adverse to erosion and hence this objection is eliminated. On the other hand Ewing and his associates give convincing evidence for the great importance of turbidity flow in the oceans." (R28)

X12. 1953. The discovery of submarine canyons on the Arctic Slope. "Previous knowledge of the bathymetry of this region has come from a few scattered soundings which permitted only a general and often quite erroneous picture of the bottom topography.

Recently obtained continuous soundings and accurate means of location have permitted the recognition of many submarine canyons on the continental slope in this region. These were discovered in 1951 by a scientific expedition which included the author.

When the ship was directed essentially parallel to the 'strike' of the continental slope, that is, roughly parallel to the main trend of the contours, many large submarine canyons became evident on the fathograms taken in the Chukchi and western Beaufort Seas. These features average 2-4 miles in width and 200-350 fathoms (1,200-2,100 feet) in depth. Thus they resemble the submarine canyons found in many places in the world. .....With one exception, none of these large canyons crosses the shelf edge." (R29) The presence of submarine canyons around the edge of the Arctic Ocean strongly contradicts theories of origin which require subaerial erosion or turbidity currents during the Ice Ages, because this region is thought to have been covered by a thick sheet of ice during this period. (WRC)

X13. The Monterey Canyon delta and deep-sea channel. "The Monterey Canyon proper extends seaward for 50 miles from near the shore line in Monterey Bay to the base of the continental slope at 1700 fathoms. The topography of the canyon has been described in considerable detail by Shepard and Emery. In the 20 miles between the 1700- and 1800-fathom contours the canyon has a shallow U-shaped cross section. The gradient of the axis is low (30 feet per mile), so that the canyon appears to lose its identity as a valley form. However, a short distance beyond the 1800-fathom contour, a channel again notches the deep-sea floor. In the vicinity of the 1850-fathom contour, two 'distributary' channels break away from the main channel. All three channels assume courses roughly down the regional gradient of the delta. The western main channel has a maximum width of 2.8 miles and a maximum depth of 750 feet. Its length is unknown, but it has been traced for 40 miles. A leveelike ridge with a relief of 90 feet is present on the outside of the west channel where it turns south. The central channel has a maximum width of 1.2 miles, a maximum depth of 480 feet, and an established length of 20 miles. However, where traverses were made, it has no levee-like ridges. It is also slightly shallower than the west channel. The east channel is small; its presence is based on only one crossing, so its extent is unknown." (R31) See ETV2 for more on deep-sea channels.

X14. 1959. An anti-turbidity-current item. By 1959, geologists generally concurred that most submarine canyon erosion had been accomplished by turbidity currents. Still, a few problems prevented the unanimous acceptance of the turbidity-current hypothesis. For example, K.K. Landes pointed out that abundant fresh-water diatoms collected from the mid-Atlantic floor could hardly have been carried that far by turbidity currents, as stoutly maintained. Assuming that the fresh-water diatoms were carried there from Africa, a trip of 930 kilometers, over a 1000-meter hill would have been required. With this opening, K.K. Landes continues his dissent.

"Although fresh-water diatoms at the bottom of the sea may (or may not) be a freak occurrence, there is nothing freakish about the submarine canyons which are exact duplicates of subaerial canyons, but which a large segment of geologists prefer to blame onto submarine turbidity currents rather than onto rivers draining emergent sea floor. Figure 1 (not reproduced here) is a well-known and oft-used pair of cross sections (originally published by Shepard) showing the Monterey submarine canyon off the California coast and the Grand Canyon. Both are cut in part into granite. What role did the Colorado River (itself a turbidity current) play in the cutting of the Grand Canyon? It was merely the flushing agent. Decomposition and disintegration by subaerial weathering agents broke the rock down into fine enough particles to be flushed. Are the physical agents of disintegration, such as freezing and thawing, heating and cooling, active in Monterey Canyon? Decidedly not. What about the chemical agents of decomposition? The oxygen chemically combined with hydrogen is not available for oxidation. The percentage of dissolved oxygen in sea water, especially at depth, is insignificant compared with its percentage in the atmosphere. How was the submarine rock broken down so that it could be flushed?

Can we, as seekers of truth, shut our eyes any longer to the obvious fact that large areas of sea floor have sunk vertical distances measurable in miles? Why not accept this, and devote the cerebral horsepower now being wasted on futile attempts to explain away the truth to finding out the mechanism which produces these drastic sea-level changes?" (R33)

X15. 1968. Another explanation of the Monterey Canyon. Despite a few heretics, like Landes in X14, the turbidity-current theory remained dominant. But in 1968, it was proposed that the Monterey Canyon may well be an ancient subaerial canyon that was subsequently filled and then flushed out by submarine processes. The ancestral subaerial canyon was supposed to have been cut before the region underwent subsidence. (R39)

X16. 1973. The Mediterranean canyons. Deep drilling in the Mediterranean revealed the presence of many buried submarine canyons. Rather than attributing these canyons primarily to turbidity currents, the desiccation of the Mediterranean Sea was proposed---an interesting turnabout.

"A desiccated Mediterranean during the late Miocene dictates that the base level of erosion must then have been thousands of metres below the sea levels. Shelf seas should have withdrawn from continental areas, and coastal plains and newly exposed shelf should have been dissected by rejuvenated streams. They should have cut canyons of steep gradients hundreds of metres into a slightly older marine sediment, and should have left alluvial and terrestrial clastics in the channels. Such a stream system should have been drowned during the final submergence of the desiccated Mediterranean in the earliest Pliocene.

Such an important regression has indeed been deciphered from the available geological records on land. In southern France, for example, a marine sequence, ranging up to Upper Miocene Tortonian, has been cut by a deep channel system. The channels were filled with alluvial gravels, which in turn underlie marine Pliocene sediments. The event recorded by the channel cutting has been known to stratigraphers as the Pontian regression, but its cause was unknown until we formulated our model of Late Miocene desiccation.

Pontian regression has also been reported in Egypt, where the River Nile at Aswan cut a gorge 200 m below sea level. It should be recalled that Aswan is a long way upstream, some 1250 km from the coast; buried beneath the Marine Pliocene and Quaternary alluvial sediments of the Nile Delta area is a grand canyon comparable to the Grand Canyon of Colorado. Similar buried gorges have been found in Libya, Syria, Israel, and other Mediterranean lands." (R43)

The Russian drilling at the Aswan Dam site provided confirming evidence. "To the Russian's amazement they discovered a narrow, deep gorge under the Nile valley, cut 700 feet below the sea level into hard granite. The valley was drowned some 5.5 million years ago and filled with Pliocene marine muds, which are covered by the Nile alluvium. Aswan is 750 miles upstream from the Mediterranean Coast. In the Nile delta boreholes more than 1,000 feet deep were not able to reach the bottom of the old Nile canyon." (R42)

X17. 1981. General observations by F. P. Shepard. By 1981, new sonar techniques and extensive marine research had tempered extreme and single-origin theories.

From the Abstract. "In the past we have seen a great variety of hypotheses for explaining submarine canyons. Unfortunately almost all of these have been based on information from a small selection of the canyons, usually from one area. From the new information, it is evident that canyons are of composite origin and that many of the hypotheses suggested in the past were partly correct but did not appreciate that coordination of other processes was required. Thus there is growing evidence that, in the history of many canyons, there was a period in which subaerial erosion was an important precursor, but that present features are predominantly the result of marine erosion. Those advancing turbidity currents as the unique cause of canyons failed to appreciate that debris flows down the incipient valleys, as well as other types of landslides, could be an almost equally important factor in marine erosion. The great effect of biological activity on the rock walls of incipient canyons has been almost completely neglected in explanations, and various types of currents such as those of the tides have been left largely out of the picture. Perhaps the most important feature absent in these various hypotheses has been the realization that canyons may well be the result of a long period of formation, much longer than the short episodes of Pleistocene glacial sea-level lowering usually considered explanation enough of these giant features which commonly cut into hard crystalline rock. New information is showing that the

canyons may date back at least to the Cretaceous." (R44)

X18. 1985. Discovery of an unusual submarine canyon off western North America. Using advanced sonar instrumentation, named Gloria, scientists have discovered a huge underwater volcanic crater about 175 miles off San Francisco, beneath more than a mile of water. In size, the volcano was likened to Tambora, in Indonesia, which exploded in 1815.

"Near the underwater Tambora, Gloria kept the scientists riveted to the on-board computer by tracing the full extent of an enormous canyon. At first thought to be much smaller, it turned out to be comparable in size to the Grand Canyon. No one knows how it formed.

To add to the mystery, the chasm is associated with an underwater equivalent of an alluvian fan---but not in the usual way. On land, these features represent a kind of waste dump; they are formed of rock and gravel eroded from mountains and deposited by streams or rivers in a fan shape at the mouths of canyons or valleys. At sea, such fans are also found at canyon mouths and are thought to be composed of material eroded from the continent. The ocean fan, which encompasses an area about twice the size of Massachusetts, does not take shape at the giant canyon's outlet; instead, the canyon cuts down into the fan. How such a mass of material was deposited, and where it came from, remain a mystery." (R54) This submarine canyon---if that is what it really is ---does not originate close to the continent in shallow water. (WRC)

References

R1. Smith, W.S. Tangier; "The Submarine Valleys of the California Coast, "Science, 15:670, 1902. (X5)

R2. Spencer, J.W.; "Submarine Valleys off the American Coast and in the North Atlantic," Geological Society of America, Bulletin, 14:207, 1903. (X2)

R3. "Canyons in Ocean Bottom off New England," Science, 76:sup 8, 1932.

R4. Shepard, Francis P.; "Submarine Valleys," Geographical Review, 23:77, 1933.

R5. Davis, W.M.; "Submarine Mock Valleys," Geographical Review, 24:297, 1934.

R6. Davis, W.M.; "Submarine Mock-Valleys," American Geophysical Union, Transactions, 16:231, 1935. (X6)

R7. Hess, H.H., and MacClintock, Paul; "Submerged Valleys on Continental Slopes and Changes of Sea Level," Science, 83:332, 1936. (X7)

R8. Shepard, Francis P.; "The Underlying Causes of Submarine Canyons," Science, 83:484, 1936.

R9. Shepard, Francis P.; "The Underlying Causes of Submarine Canyons," National Academy of Sciences, Proceedings, 22: 496, 1936.

R10. Shepard, F.P.; "Submerged Valleys on Continental Slopes and Changes of Sea Level," Science, 83:620, 1936.

R11. "Submarine Canyons," Geographical Review, 27:681, 1937.

R12. Johnson, Douglas; "Origin of Submarine Canyons," Journal of Geomorphology, 1:111, 1938. First of a series of articles. (X8)

R13. Shepard, Francis P.; "The Enigma of the Submarine Canyons," Scientific American, 159:130, September 1938.

R14. Veatch, A.C., and Smith, P.A.; "Atlantic Submarine Valleys of the United States and the Congo Submarine Valley," Geological Society of America Special Paper, no. 7, 1939.

R15. Johnson, D.W.; The Origin of Submarine Canyons, New York, 1939.

R16. Shepard, F.P., and Stetson, H.C.; "Age of Excavation of North American Submarine Canyons," Geological Society of America, Bulletin, 50:1934, 1939.

R17. du Toit, Alex. L.; "An Hypothesis of Submarine Canyons," Geological Magazine, 77:395, 1940. (X9)

R18. Shepard, Francis P., and Bullard, E.C.; "Submarine Geology and Geophysics," Nature, 146:431, 1940.

R19. Fretz, A.H.; "Mechanics of a Hypothetical Hail Ring to Lower the Level of the Ocean," Geological Society of America, Bulletin, 52:2035, 1941.

R20. Shepard, Francis P.; "Imaginary Submarine Canyons," Science, 98:208, 1943.

R21. "Deep Submarine Canyons Found off New Guinea," Science News Letter, 53: 217, 1948.

R22. Shepard, Francis P.; "Submarine Canyons," Scientific American, 180:40, April 1949.

R23. von Engeln, O.D.; "Submarine Canyons and the Ice Age: A Discussion," Journal of Geology, 58:161, 1950.

R24. Ericson, D.B., et al; "Deep-Sea Sands and Submarine Canyons," Geological Society of America, Bulletin,

62:961, 1951.
R25. Shepard, Francis P.; "Submarine Canyons: A Joint Product of Rivers and Submarine Processes," Science, 114:7, 1951. (X10)
R26. Shepard, Francis P.; "Composite Origin of Submarine Canyons," Journal of Geology," 60:84, 1952.
R27. Landes, Kenneth K.; "Our Shrinking Globe," Geological Society of America, Bulletin, 63:225, 1952.
R28. Kuenen, Ph. H.; "Origin and Classification of Submarine Canyons," Geological Society of America, Bulletin, 64:1295, 1953. (X11)
R29. Carsola, Alfred J.; "Submarine Canyons on the Arctic Slope," Journal of Geology, 61:605, 1953. (X12)
R30. Kelly, Allan O., and Dachille, Frank; Target Earth, Carlsbad, 1953.
R31. Dill, Robert F., et al; "Deep-Sea Channels and Delta of the Monterey Submarine Canyon," Geological Society of America, Bulletin, 65:191, 1954. (X13)
R32. Heezen, Bruce C., et al; "Extending the Limits of the Congo Submarine Canyon," Geological Society of America, Bulletin, 68:1743, 1957.
R33. Landes, Kenneth K.; "Illogical Geology," Geotimes, 3:19, March 1959. (X14)
R34. Shepard, Francis P.; Submarine Geology, New York, 1963.
R35. Bartow, J. Alan; "Deep Submarine Channel in Upper Miocene, Orange County, California," Journal of Sedimentary Petrology, 36:700, 1966.
R36. Shepard, Francis P., and Dill, Robert F.; Submarine Canyons and Other Sea Valleys, Chicago, 1966. (X1-X4)
R37. Pratt, Richard M.; "The Seaward Extension of Submarine Canyons off the Northeast Coast of the United States," Deep-Sea Research, 14:409, 1967.
R38. Dietz, Robert S., et al; "Cayar Submarine Canyon," Geological Society of America, Bulletin, 79:1821, 1968.
R39. Starke, George W., and Howard, Arthur D.; "Polygenetic Origin of Monterey Submarine Canyon," Geological Society of America, Bulletin, 79:819, 1968. (X15)
R40. Andrews, James E., et al; "Great Bahama Canyon," Geological Society of America, Bulletin, 81:1061, 1970. (X3)
R41. Shepard, F.P.; "Submarine Canyons," Earth-Science Reviews, 8:1, 1972.
R42. Hsu, Kenneth J.; "When the Mediterranean Dried Up," Scientific American, 227:26, December 1972. (X16)
R43. Hsu, K.J., et al; "Late Miocene Desiccation of the Mediterranean," Nature, 242:240, 1973. (X16)
R44. Shepard, Francis P.; "Submarine Canyons: Multiple Causes and Long-Time Persistence," American Association of Petroleum Geologists, Bulletin, 65:1062, 1981. (X17)
R45. Smith, E.G. Walton; "When the Mediterranean Went Dry," Sea Frontiers, 28: 66, 1982.
R46. Stubblefield, W.L., et al; "Reconnaissance in DSRV Alvin of a 'Fluvial-Like' Meander System in Wilmington Canyon and Slump Features in South Wilmington Canyon," Geology, 10:31, 1982.
R47. McGregor, Bonnie, et al; "Wilmington Submarine Canyon: A Marine Fluvial-Like System," Geology, 10:27, 1982.
R48. Twichell, David C., and Roberts, David G.; "Morphology, Distribution, and Development of Submarine Canyons on the United States Atlantic Continental Slope between Hudson and Baltimore Canyons," Geology, 10:408, 1982.
R49. Carlson, Paul R., and Karl, Herman A.; "Ancient and Modern Processes in Gigantic Submarine Canyons, Bering Sea,' Eos, 64:1052, 1983. (X4)
R50. Hsu, Kenneth J.; The Mediterranean Was a Desert, Princeton, 1983.
R51. Hsu, Kenneth;"Lost Secrets of the Mediterranean," The Sciences, 23:44, September/October 1983.
R52. Dietz, Robert S., et al; "Bone-Dry?" The Sciences, 24:4, May/June 1984.
R53. McGregor, Bonnie A.; "The Submerged Continental Margin," American Scientist, 72:275, 1984.
R54. Yulsman, Tom; "Mapping the Sea Floor," Science Digest, 93:32, May 1985. (X18)
R55. Hess, Harry Hammond; "Submerged River-Valleys of the Bahamas," American Geophysical Union, Transactions, 14:168, 1933.
R56. Daly, Reginald A.; "Origin of Submarine 'Canyons'," American Journal of Science, 231:26, 1936.
R57. Kuenen, Ph. H.; "Density Currents in Connection with the Problem of Submarine Canyons," Geological Magazine, 75:241, 1938.
R58. Benjamin, George J.; "Diving into the Blue Holes of the Bahamas," National Geographic Magazine, 138:347, 1970. (X3)
R59. Bucher, Walter H.; "Submarine Valleys and Related Geologic Problems of the North Atlantic," Geological Society of America, Bulletin, 51:489, 1940.
R60. Kolbe, R.W.; "Fresh-Water Diatoms from Atlantic Deep-Sea Sediments," Science, 126:1053, 1957.
R61. Rigby, J. Keith, et al; "Turbidity Cur-

rents amd Displaced Fresh-Water Diatoms," Science, 127:1504, 1958.
R62. King, Lester; Morphology of the Earth, New York, 1967. (X1)

ETV2 Sea-Floor Channels

Description. Long, sometimes sinuous and meandering, shallow channels crossing deep-sea floors, possessing no certain associations with submarine canyons or terrestrial rivers. Lengths are measured in hundreds of miles; depths, in hundreds of feet; widths, one to several miles. These channels are generally found at great depths; i.e., about two miles. Natural levees are rather common. A tendency to parallel continental shelves has been noted.

Data Evaluation. Sea-floor channels are not as well researched as submarine canyons because of their great depths and shallow profiles. Still, good data are now available for several major sea-floor channels. However, information about current sources and strengths are sketchy. Rating: 1.

Anomaly Evaluation. The salient puzzle of the sea-floor channels is the source of the bottom currents that cut them and keep them cleaned out. Since the channels are not obviously associated with presently recognized current sources, such as terrestrial rivers and discharges from submarine canyons, it is thought that these currents are (or were) oceanic in origin, arising perhaps from the general migration of cold, dense water from the polar regions along the sea floors toward the Equator. Rather than placing at risk any hallowed geophysical principles, the sea-floor channels really represent a phenomenon where we do not know enough to generate detailed explanations. Rating: 3.

Possible Explanations. Sea-floor channels are the handiwork of cold, dense currents, including turbidity currents. Subaerial erosion seems improbable here.

Similar and Related Phenomena. Similar sea-floor channels are often extensions of recognized submarine canyons (ETV1). Large lakes, such as Lake Superior, display similar channels, which are believed to have been cut when the lake basins were nearly empty.

Examples

X1. General observations and possible mode of origin. Sea-floor channels have a much shorter scientific history than the submarine canyons. R.S. Dietz, a noted geophysicist and early researcher of sea-floor channels, describes the first explorations as follows: "In the last decade echo-sounding surveys of the ocean floor have disclosed the widespread presence of long river-like channels. This tardy discovery is ascribable to the fact that these channels, although comparable in dimensions with the largest river channels on land, are in cross-section relatively small sea floor features, likely to be lost in the general topographic roughness of the bottom.

Probably the first of these remarkable channels to be identified was that found in 1948 by H.W. Menard, E.C. Buffington, and myself, working from the US Navy Electronics Laboratory, on the gently sloping bottom of the San Diego Trough off southern California. (At about the same time similar channels were found off the United States Atlantic coast by B.C. Heezen and coworkers at the Lamont Geological Observatory.) Sounding profiles in the San Diego Trough showed a small U-shaped linear depression with raised sides---a most unusual topographic form which defied understanding as a structural geological feature. Additional surveying revealed that this depression was actually a long winding channel which tied into the mouth of the La Jolla Submarine Canyon. The curious raised rims or lips could only be interpreted as undersea natural levees.

.....

Although deep-sea channels are sometimes seaward extensions of submarine canyons, others are found far removed from the continental slopes and have no apparent connection to any canyon. It seems likely that some of these channels may owe their presence to

localized streams of dense water of high salinity and low temperature. Such density currents, as they flow along the bottom, would, of course, pick up a small amount of sediment which would add somewhat to their density, but the primary impelling force might still be the low temperature (contraction density) and high salinity (ionic density), rather than turbidity (solids-in-suspension density). It has long been theoretically established that the physical economy of the sea requires that waters in high latitudes descend from the surface and creep along the bottom toward the equator. In the absence of any precise data, such movements were presumed to be generalized and slow. However, following the lead of Dr. L. H. N. Cooper of the Plymouth Marine Biological Association Laboratory, many oceanographers now believe that the bottom water is formed at very selected spots and at irregular intervals. Hence, some deep-sea channels may well be formed in geographically and topographically favourable areas when high-density water masses cascade down to the abyssal floor and pour along it." (R3)

It should be added here that more recent deep-sea research has confirmed the scouring and eroding power of sea-floor currents. Indeed, the ocean floor seems to have its episodes of violent weather, just like the earth's surface. (R13)

X2. The Mid-Ocean Channel. "The longest known deep-sea channel is the Mid-Ocean Channel, delineated in the North Atlantic by the 1949 and 1952 Lamont Geological Observatory surveys. This runs for nearly 2,000 miles from a point between Iceland and Greenland to a deep basin in the west central North Atlantic, reaching the latitude of Washington, D. C. The channel is two to four miles wide and 25 to 100 fathoms deep. sand and gravel have been recovered from its axis. Trans-Atlantic cables crossing it have been snapped six times---presumably by turbidity currents. It seems probable that the flows along this channel have been at least initially triggered by freezing conditions off Greenland producing saline and cold heavy water." (R3; R8)

X3. Bay of Bengal Channel. "A deep-sea channel has been surveyed on the Ganges cone in the Indian Ocean. In a water depth of over 4000 meters the channel shows well-developed meanders repeating in a regular sinusoidal pattern, over a survey distance of 50 km along the channel axis. Levee heights above the channel floor reach 35 meters where the channel width is 3 km. A wide, flat terrace from 10 to 15 meters in height above the channel floor is observed on the inside of each meander bend. The bends have radii varying from 2 to 8 km, and the meanders are believed to persist along the major course of the channels across the large sedimentary cone. Photographs of the sea floor reveal the existence of weak bottom currents in the channel. The absence of massive graded silt or sand beds in the upper 1 meter of a core of silty lutite from the same location indicates that significant turbidity currents have not traveled through the channel during the last several thousand years." (R9; R1-R3, R7)

X4. Bay of Biscay Channel. "Abstract. A system of channels connecting the Biscay and Iberia plains was discovered in 1958. Two main channels cut through the sill and join after 20 miles. The total length between plains is 50 miles and the width of the channels varies from 2 to 10 miles. The change of level between plains occurs where the channel first leaves the upper plain. The channel shows a meader formation similar to a subaerial river. Cores show that turbidity currents have been active in the past. Small feeding channels on the Biscay plain converge on the interplain channels.

It is concluded that turbidity currents initiated on the continental shelves and flowing across the Biscay plain can be rejuvenated by the increase in gradient and lateral constriction, and flow through to the Iberia plain where they finally deposit their load." (R5; R8)

X5. The Brazil Channel. Abstract. "Most submarine canyons are furrows cut into the continental margin, but mid-ocean canyons have been found in the abyssal plains. A mid-ocean canyon is a steep-walled, flat-floored, persistent linear depression 1-5 miles wide and a few to more than 100 fathoms deep. Such features have been discovered in the northwest Atlantic east of Newfoundland, south of Nova Scotia, in the Gulf of Alaska, and easy of Ceylon in the Bay of Bengal. A new mid-ocean canyon

was discovered by the Research Vessel Vema of Fortaleza, Brazil, and traced for 350 miles. Unlike former mid-ocean canyons which occur in abyssal plains, this equatorial mid-ocean canyon runs southeast along the continental rise and parallels the the continental margin. Sounding lines have not revealed any connection between the westernmost end of the canyon and the nearest continental slope canyon. Cores taken from the floor contained sand and gravel, which indicates that the canyon, if not formed by turbidity currents, at least acted as a channel for them.

The parallelism of the Mid-Ocean Equatorian Canyon with the continental margin on one hand and the mid-oceanic ridge on the other suggests a tectonic control. However, the morphology of the canyon and its sediments suggest an origin through the action of turbidity currents." (R4; R8)

X6. The Cascadia Channel. "Another rather well-documented deep-sea channel is found between the two great fans that lie outside the continental slope off the Oregon and Washington coasts of the western United States. This channel was first discovered by Menard and later investigated in more detail by Hurley. It is very possible that this feature is simply a fan valley and represents a seaward continuation of Oregon and Washington submarine canyons. However, so far as can be ascertained from the Coast and Geodetic Survey soundings, neither Cascadia Channel nor its tributaries are definitely connected with any of the submarine canyons, and the much less conspicuous Astoria Channel to the east also fails to show any sure connections with a canyon. Furthermore, these channels extend much more to the south than would be expected for oceanward flow across the fans. This bend to the south has been called a 'left hook' by Menard and is explained by him as related to the Coriolis force causing more deposition on the right bank of fan-valleys. However, such a simple explanation does not seem entirely reasonable for the abrupt change in direction in Cascadia Channel at lat. 43°30' N. Nor is it evident why Astoria Channel should turn directly into the continental slope at 44° north. Both channels appear to have the same tendency to follow continental margins, as does the Mid-Ocean Channel in the Atlantic.

The gradient in Cascadia Channel is somewhat steeper than that of Mid-Ocean Channel. According to Hurley, it deepens 6,000 ft (1,830 m) in a distance of 1,300 nautical miles, giving it an average gradient of 0.85 m/km." (R8)

X7. The Aleutian Channel. "A vast channel in the sea floor, believed to have once connected the North American continent with the Aleutian Abyssal Plain, an area about one-half to two-thirds the size of Alaska some three miles below the surface of the North Pacific, is being charted by U.S. oceanographers.

When the Aleutian trench was being formed about 10 million to 15 million years ago, it apparently broke the channel, which once carried mud out to the plain from the main land. Since then, the only deposits received by the plain have been airborne dust and the remains of living organisms from the sea above it.

The channel is therefore regarded by scientists as a repository of evidence that may shed new light on the geological history of the area. The data gathered this spring on the 175-mile-long known portion of the sea channel, which is about four miles wide and 240 feet deep, are now being evaluated at the Environmental Science Services Administration." (R10; R4)

X8. The Maury Mid-Ocean Channel. "The Maury Mid-Ocean Channel transports sediment for distances as great as 2,250 kilometers from sources on Iceland and the Faeroe Islands. The channel follows the deepest axis of the northeast Atlantic, eventually emptying into the Biscay Abyssal Plain.

Seismic profiles, report Bruce F. Molnia of the University of South Carolina, and William F. Ruddiman of the Naval Research Laboratory, show that the channel is 5 to 15 kilometers wide and contains up to 400 meters of sediment---mostly coarse sand and gravel." (R12) One wonders whether turbidity or density currents could have cut the channel as deep as 400 meters. (WRC)

References

R1. Dietz, Robert S.; "Deep-Sea Channels," Geological Society of America, Bulletin, 63:1244, 1952. (X3)

R2. Dietz, Robert S.; "Possible Deep-Sea

Turbidity-Current Channels in the Indian Ocean," Geological Society of America, Bulletin, 64:375, 1953. (X3)
R3. Dietz, Robert S.; "The Channels on the Deep-Sea Floor," New Scientist, 4:946, 1958. (X1-X3)
R4. Heezen, Bruce C., et al; "Equatorial Atlantic Mid-Ocean Canyon," Geological Society of America, Bulletin, 71:1886, 1960. (X5)
R5. Laughton, A.S.; "An Interplain Deep-Sea Channel System," Deep-Sea Research, 7:75, 1960. (X4)
R6. Shepard, Francis P.; Submarine Geology, New York, 1963.
R7. "Gigantic Channels Found in Indian Ocean Floor," Science News Letter, 86: 88, 1964. (X3)
R8. Shepard, Francis P., and Dill, Robert F.; "Hybrid Types of Submarine Valleys," Submarine Canyons and Other Sea Valleys, Chicago, 1966, p. 275. (X2, X4-X6)
R9. Ryan, William B.F., et al; "A Meandering Deep-Sea Channel," American Geophysical Union, Transactions, 48:142, 1967. (X3)
R10. "Aleutian Sea Channel Mapped," Science News, 94:35, 1968. (X7)
R11. Grim, Paul J., and Naugler, Frederic P.; "Fossil Deep-Sea Channel on the Aleutian Abyssal Plain," Science, 163: 383, 1969. (X7)
R12. "Undersea Channel for Sediments," Science News, 100:328, 1971. (X8)
R13. Hollister, Charles D., et al; "The Dynamic Abyss," Scientific American, 250:42, March 1984. (X1)

ETV3 Wind Gaps

Description. Dry, V-shaped notches that occur in many mountain ranges. The name "wind gap" refers to the present-day flow of wind through the notches and not that wind created them. The more common water gaps generally have a U-shaped appearance.

Data Evaluation. So far, very little of any scientific consequence has been found on wind gaps in the scientific literature. Rating: 3.

Anomaly Evaluation. Wind gaps, like the high-level terraces in mountainous regions, may signify the existence of anomalously high water levels in the past. The water gaps are often explained in the context of high water levels created by ice dams during the Ice Ages, aided, perhaps by some glacial erosion. But wind gaps are higher than water gaps and, therefore, imply higher stands of water. If the high stands of water are simply due to ice dams, there is not much of an anomaly; but, the more radical possibility always exists that catastrophic flooding, perhaps of marine origin, may have occurred. Our rating is based on the former possibility. Rating: 3.

Possible Explanations. Water erosion due either to high water levels from ice-damming or marine flooding.

Similar and Related Phenomena. Water gaps; inland, high-level terraces (ETE4).

Examples

X1. Pennsylvania. The precise location of the "wind gap" described below by J.P. Lesley is not given.

"The Wind Gap is one of the strangest and most inexplicable features of the earth's surface...I am not aware that any serious attempt has been made to construct a satisfactory hypothesis of it origin...A long, straight, sharp-crested ridge, 1000 feet high on a base two miles wide, is here, not split by a fault, nor gapped by a stream, but worn smoothly through to half its altitude. The raggedness of the mountain crest ceases and smoothly rounded slopes descend to the smoothly rounded bottom of the gap which is lined with sand and gravel...It is evidently a deep cross-groove smoothly made and finished by some agent of erosion acting slowly and continuously---but an agent quite different from a river...I can see no serious objection to the supposition that the front of the ice-sheet may at one time have advanced

the necessary two miles and banked itself against the mountain at the Wind Gap... In any future investigation of the origin of the Wind Gap the fact that there extends southward from the level of the bottom of the Gap, a fan-shaped sloping plain of rounded boulder drift which has evidently all come through the Wind Gap, and has probably been brought through it by the agent which made the gap (although that cannot be taken for granted) must be taken into consideration.

Professor Lesley then repeats an explanation for the origin of the Wind Gap which he made in 1882, that it was due to the overflow of a vast lake which he supposed to cover a large part of Monroe and Carbon counties, which lake was due to a great ice-dam at the Lehigh Water Gap. But as this dam would have had to be 1100 feet high in order to deliver the water over the crest of the mountain when the Wind Gap was begun, and as the glacier did not cover the region about the Lehigh Gap, he grants that such a supposition is untenable." (R1) The context of this item is a paper reviewing evidence for glaciation south of the terminal moraine. Also, see ETE4 for high-level terraces in the Appalachians. (WRC)

X2. General observations. R.M. Daly, author of the following sketch and nephew of the reknowned geologist R.A. Daly, was a believer in a past, great, universal flood. He considers the many wind and water gaps in the Himalayas and other mountain ranges as evidence of such flooding.

"Dr. (E.W.) Shuler gives an interesting exposition of the remarkable manner in which several rivers have cut water gaps across the highest parts of the Appalachians, also of 'wind gaps' left as dried-up, V-shaped notches along the ridge crests. 'These are an interesting postscript,' he writes, 'to the story of these ridge-crossing rivers. There are left many memorials to those streams that tried to cross the hard ridges but failed! In addition to the water gaps across the Appalachian ridges, their even skylines are often marked with high V-shaped dry gaps for which the phrase 'wind gap' is well used locally, since winds rather than streams cross through them.'

.....

These dried-up 'wind gaps' cannot be explained by any theory of mountain uplifts, or by any other device that ingenuity can invent. Every mountain pass, excavated by water, is a proof that waters once flowed over the crest as the mountain range rose through the receding flood waters." (R2)

References

R1. Lewis, H. Carvill; "On the Supposed Glaciation in Pennsylvania South of the Terminal Moraine," American Journal of Science, 3:28:276, 1884. (X1)

R2. Daly, Reginald; "Origin of Sedimentary Mountains, Opposing Theories," Earth's Most Challenging Mysteries, Nutley, 1975, p. 294. (X2)

ETV4 Difference in Height of Opposite River Banks

Description. The tendency of one river bank to be obviously higher than the bank opposite.

Data Evaluation. The data uncovered so far are more or less casual observations in a few limited geographical locations. The information is so spotty that it is impossible to tell if a legitimate anomaly exists. Rating: 3.

Anomaly Evaluation. While the east-west effect of the Coriolis force is certainly not anomalous, its efficacy in altering the erosive capabilities of a stream has not been demonstrated theoretically or experimentally according to the literature surveyed so far. Further, the phenomenon has been reported for rivers flowing east-west, too. In view of this confusing situation, we relegate this phenomenon to the "curiosity" category. Rating: 3.

Possible Explanations. The Coriolis force, a consequence of the earth's rotation and north-south stream flow, causes preferential erosion of one bank. Perhaps more likely are local conditions, such as the effect of prevailing winds.

Similar and Related Phenomena. The well-known deflection of the courses of icebergs by the Coriolis force.

Examples

X1. General (rather old and innocent) observations. "It has been observed in Europe and Asia and in the lowlands of the Atlantic border of the United States, that the western banks of many rivers and streams are considerably higher than are their eastern banks respectively; especially is that the case where the rivers are large, the deposits earthy, and the pitch of the water small and in the direction of the stream. And, to account for this phenomenon, it is claimed that, owing to the eastward rotation of the earth, the western banks, in a sense, are pushed harder against the western sides of those rivers, etc., than is the case with their respective eastern sides: hence the greater steepness of the western over that of the eastern banks of rivers. etc.; because the waters cut more forcibly into them, the undermined deposits fall, and these banks, in consequence, are steeper than are the opposite ones. So some think." (R2) This article goes on to explain the phenomenon in terms of differences in solar attraction in the morning and evening!! However, it is an interesting early description of the phenomenon at hand.

X2. Long Island, New York. "During the summer of 1920 Mr. Henry Hicks, of Westbury, Long Island, pointed out to me the very interesting difference between the east and west banks of one of the short streams flowing across the almost flat southern slope of the island. Looking west across the almost imperceptibly sloping eastern bank of the stream-way one sees the western bank rising quite steeply and very much resembling a railroad embankment in height and steepness.

This peculiar situation has long been accepted rather generally by geologists and physiographers as due to the westerly deflection of streams by the earth's rotation. However, when one considers the weakness in flow of these streams, their very slight fall, and the fact that they are mostly less than ten miles long, serious doubts arise. To one who, like the writer, has studied the cumulative effects of wind and vegetation upon wind-borne materials, it appears very probable that the deflective effect is very slight as compared with the resultant effects of these other agencies." (R3)

The rotation-of-the-earth theory was proposed as early as 1855. (R1) However, a more thorough study of the Long Island valleys tends to discount earth-rotation and favor wind action, as suggested in the preceding quotation. "The only American streams used as evidence of erosion by rotative deflection are the creeks and brooks along the south side of Long Island. And this fact hints at the weakness of the theory.

In a belt about fifty miles long, with direction S.S.W. by E,N.E. some thirty weak streams with southerly flow, in sand and gravel, reach the Atlantic Ocean. The longest is less than ten miles. The valleys are shallow, few being twenty feet deep. The west banks of the shallow valleys are steeper than the east banks, as described by Lewis and by Fuller, and confirmed by Gilbert. The deeper valleys do not present the difference in the walls.

The claim for earth rotation as the cause of the difference in the slope of the valley walls has been made without any reference to other possible and more potent dynamic factors. Yet the most effective agency appears evident. Next to gravity the winds are the greatest force affecting water surfaces.

.....

The conclusion from this study is that the rotative deflective force, of vast effect on air currents and free-moving bodies, is so small in its effect on stream erosion, especially when masked by forceful agencies, that it is immeasurable and negligible." The author ventures, without calculation, that the winds' effect is a thousand times stronger than that of the earth's rotation. (R6)

X3. Siberia. The Yenisei River. "There is probably nowhere else in the world any other stream so favorable for the study of bank movement on a vast scale. This is for three reasons: This Siberian river is closely longitudinal; of great size; and so far north that a considerable section of it lies within the Arctic Circle. Dr. Fridjof Nansen, who has sailed up this river from its mouth in Yeniseisk---a distance of more than a thousand

miles---writes of the very pronounced con-contrast between the east and west banks. 'Every one going up the Yenisei must be struck with the remarkable difference between the east and west sides of the river. While the flat land on the east is comparatively high and falls abruptly with a steep bank to the river, a steeply sloping beach and relatively deep water outside, the land on the west is strikingly low. The steep river bank is not high, and the bare sandy beach slopes quite gently to the water, with a shelving bottom far beyond it, so that as a rule it is not easy to approach this shore in a ship or boat.' And again, 'It is striking how much higher and steeper the east bank is than the west everywhere along here." (R4) Note that the Yenisei flows north, whereas the Long Island streams flow south. The Coriolis force is thus reversed. (WRC)

X4. California. A.O. Kelly asserts that all of the rivers and streams along the California coast, where the streams run mostly east and west, show a strong cutting along the south bank. (R7)

X5. New Zealand. A.O. Kelly has personally noticed that on the west coast of South Island, New Zealand, the east-west streams cut strongly against their north banks. New Zealand, of course, is in the opposite hemisphere from California. (R7) Kelly attributes these effect, in X4 and X5, to oceanic flooding.

References

R1. Lewis, Elias, Jr.; "Certain Features of the Valleys or Water-Courses of Southern Long Island," American Journal of Science, 3:13:215, 1877. (X2)

R2. Hepburn, John; "Rivers with High Banks on One Side and Low Banks on the Other Side: What Is the Cause?" Scientific American Supplement, 12:4806, 1881. (X1)

R3. Jennings, O.E.; "Have the Streams of Long Island Been Deflected by the Earth's Rotation," Science, 55:291, 1922. (X2)

R4. Hayes, Ellen; "River-Bank Movements Due to the Earth's Rotation," Science, 55: 567, 1922. (X3)

R5. Russell, Richard Joel; "Significance of Baer's Law," Science, 75:584, 1932.

R6. Fairchild, Herman L.; "Earth Rotation and River Erosion," Science, 76:423, 1932. (X2)

R7. Kelly, Alan O.; Impact Geology, Encinitas, 1985, p. 58. (X4, X5)

ETV5 The Channelled Scablands

Description. A loess-covered area of eastern Washington dissected by many water-cut channels hundreds of feet deep. Many hills have been left uneroded, giving them the appearance of having once been islands in a huge braided river. The 2000-square-mile area also includes dry falls, carved-out basins, hanging valleys, and gigantic bars and ripples.

Background. J Harlen Bretz (no period after the J) began publishing his research on the Channelled Scablands right after World War I. Many years of field work in the region convinced him that the Channelled Scablands were the consequence of catastrophic releases of water rather than gradual, uniformitarian erosion. Such was heresy in those days. His theory was strongly resisted by the scientific establishment of the time. Early on, Bretz was unsure where the water for the floods originated. Eventually, he pinpointed the Ice Age Lake Missoula as the likely source. Impounded by an ice dam, which repeatedly ruptured, Lake Missoula discharged toward the Pacific. After an immense amount of confirming field work, Bretz's heresy has now become dogma. In fact, the debate over the Channelled Scabland is now held out as a model of how science really works!

Although all of the above is true, our purpose here is the presentation of new potential heresies. With apologies to Bretz, we now produce data that challenge his hypothesis.

Data Evaluation. J H. Bretz published his work widely, and many papers on the Channelled Scablands are to be found in the literature. We list only a few references here. However, papers challenging Bretz's theory and data supporting dissent are almost nonexistent. Thus,

from the anomalist's point of view, the data are poor. Rating: 3.

Anomaly Evaluation. The Lake Missoula ice dam theory is now so much a showcase of how science should work that any challenges must be considered strongly anomalous. Rating: 2.

Possible Explanations. In addition to the now-prevailing ice-dam hypothesis, catastrophic marine flooding has been proposed.

Similar and Related Phenomena. The Palouse topography of Idaho and Washington east of the Channelled Scablands. High-level gravels (ES); giant ripple marks (ETR3); labyrinth topography (ETV9).

Examples

X1. General observations. The main geological features of the Channelled Scablands have been nicely summarized by S. J. Gould.

"Flow basalts of volcanic origin blanket most of eastern Washington. These basalts are often covered by a thick layer of loess, a fine-grained, loosely packed sediment blown in by winds during the ice ages. In the area between Spokane and the Snake and Columbia rivers to the south and west, many spectacular, elongate, subparallel channelways are gouged through the loess and deeply into the hard basalt itself. These coulees, to use the local name, must have been conduits for glacial meltwaters, for they run down gradient from an area near the southern extent of the last glacier into the two major rivers of eastern Washington. The channelled scablands---as geologists designate the entire area---are puzzling as well as awesome, and for several reasons:

1. The channels connect across tall divides that once separated them. Since the channels are hundreds of feet deep, this extensive anastomosis indicates that a prodigious amount of water must once have flowed over the divides.

2. As another item favouring channels, filled to the brim with water, the sides of the coulees contain many hanging valleys where tributaries enter the main channels. (A hanging valley is a tributary channel that enters a main channel high above the main chennel's modern stream bed.)

3. The hard basalt of the coulees is deeply gouged and scoured. This pattern of erosion does not look like the work of a gentle river in the gradualist mode.

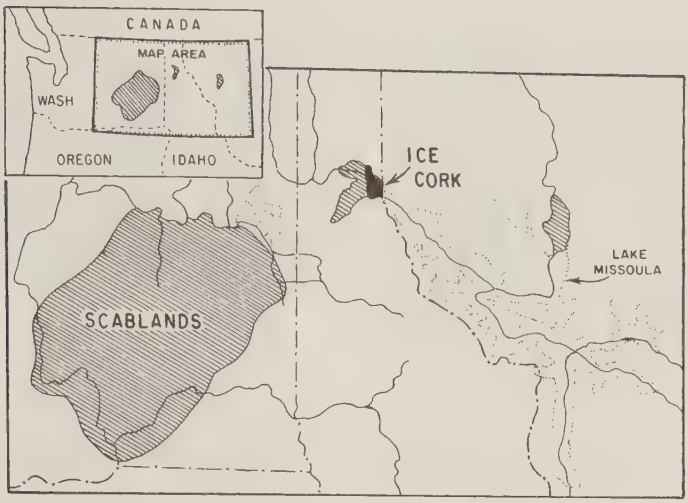
4. The coulees often contain a number of high-standing hills composed of loess that has not been stripped away. These are arranged as if they were once islands in a gigantic braided stream.

5. The coulees contain discontinuous deposits of basaltic stream gravel, often composed of rock foreign to the local area." (R6; R7)

X2. The Lake Missoula Hypothesis. J H. Bretz theorized that the Channelled Scablands are the consequence of the repeated breaking of an ice dam that impounded Lake Missoula during the Pleistocene. His reconstruction of the event is impressive.

"Although paleo-Indians were probably already in North America, no human ear heard the crashing tumult when the Lake Missoula glacial dam (the front of the Pend Oreille lobe of the Cordilleran ice sheet) burst and the nearly 2,000-foot head of impounded water was free to escape from the Clark Fork River valley system of western Montana and across northern Idaho. It catastrophically invaded the loess-covered Columbia Plateau in southeastern Washington and reached Pacific Ocean levels via the Columbia River, 430 miles or more from the glacial dam. So great a flood is unknown at present elsewhere in the world. It has been estimated to have run for 2 weeks. It was 800 feet deep through the Wallula Gap on the Oregon-Washington line.

On the Columbia Plateau in Washington, it transformed a dendritic preglacial drainage pattern into the amazing plexus of the Channelled Scabland. It flooded across stream divides of the plateau, some of which stood 300-400 feet above today's bounding valley bottoms. Closed basins as deep as 135 feet were bitten out of the underlying basalt. Dozens of short-lived cataracts and cascades were born, the greatest of which left a recessional gorge, Upper Grand Coulee, 25 miles long. The greatest cascade was 9 miles wide. The flood rolled boulders many feet in diameter for miles and, subsiding, left river bars now standing as mid-channel hills more than 100 feet high. Current ripples 10 feet and more in height diversify some bar surfaces. A gravel delta 200 square miles in



According to the accepted theory, the Channelled Scablands were created by catastrophic erosion when the ice dam impounding Lake Missoula broke. (X2)

area was built at the junction of Willamette and Columbia river valleys...Almost 2,000 square miles of the plateau's basaltic bedrock lost its preflood loessial cover which otherwise is on record in the 100 or more 'islands' 40 acres to 40 square miles in area---tracts that stood high enough above, or far enough from, main spillways to have escaped the tremendous erosional attack meted out to the plateau's preglacial valleys." Bretz believed that the Lake Missoula ice dam formed and burst at least seven times. (R3; R2)

X3. Discordant data that cast doubt on the Lake Missoula Hypothesis. C.W. Hunt has identified four facts that do not agree with the ice dam theory of Bretz. (1) Torrential flood deposits occur at or above the surface of Lake Missoula; (2) Lake Missoula beaches also occur "facing west over the Pend Oreille lake basin." The ice dam, therefore, must have been in the open valley of Lake Pend Oreille, rather than the assumed position at Clark Fork; (3) Many close-spaced beaches at the Lake Missoula site suggest that the lake waters were not discharged in great floods, but rather is many smaller releases (see also R1 here); (4) C.W. Hunt "rejects the suggestion that ice might have dammed Clark Fork so as to impound water to a depth of 2,100 ft (640 m). Having asserted in his study of 'Lake Calgary' that 1,200 ft (366 m) of water depth held by an ice dam is an impossibility, he must emphatically reiterate that assertion in the case of 'Lake Missoula.' When one considers that modern engineering employs bedrock grouting for securing the footings of 500-ft (150-m) dams, it must surely strike any reader as virtually frivolous to suggest that chance emplacement of glacial ice might have dammed Clark Fork across a 7-mile (11-km) span lacking in intermediate abutments, and then retained water at four times the pressure of modern engineered concrete dams! However, as previously said, the Clark Fork dam would not have been positioned so as to contain the lake that deposited silt north of Pend Oreille Lake. The dam in Pend Oreille valley would have had an unsupported length of approximately 50 mi (80 km) making a watertight abutment with the Bitteroot Mountains in order to retain 'Lake Missoula.' Any crack in the 50-mi (80-km) ice wall would have released a torrent." (R4) Hunt's own hypothesis is that the Channelled Scablands were carved out when an astronomical event, such as a meteor impact, caused a giant marine inundation of the west coast of North America.

References

R1. Eakins, Gilbert R., and Honkala, Fred S.; "Cenozoic History of Missoula Valley,

Missoula County, Montana," Geological Society of America, Bulletin, 63:1361, 1952. (X3)
R2. Bretz, J Harlen; "Channelled Scabland of Washington: New Data and Interpretations," Geological Society of America, Bulletin, 67:957, 1956. (X2)
R3. Bretz, J Harlen; "The Lake Missoula Floods and the Channelled Scabland," Journal of Geology, 77:505, 1969. (X2)
R4. Hunt, C. Warren; "Inundation Topography of the Columbia River System," Bulletin of Canadian Petroleum Geology, 25:468, 1977. (X3)
R5. Baker, Victor R.; "The Spokane Flood Controversy and the Martian Outflow Channels," Science, 202:1249, 1978.
R6. Gould, Stephen Jay; "When the Unorthodox Prevails," New Scientist, 79:942, 1978. (X1)
R7. Gould, Stephen Jay; "The Great Scablands Debate," Natural History, 87:12, August/September 1978. (X1)

ETV6 Apparently Youthful Rivers

Description. River ages of only a few thousand years, as measured by the apparent amount of erosive action and/or delta volume and their comparison with current rates of erosion and sediment deposition.

Background. The temptation to omit this putative anomaly is great, because the only modern discussions of it reside in the creationist and Velikovskian literature. But, even though these sources are prisoners of certain theories, there may be the germ of an important anomaly here.

Data Evaluation. The facts upon which this anomaly rest appear unreliable. Older estimates of river delta volume are questionable, as demonstrated by modern geophysical sounding methods. The use of present-day erosion rates of river gorges in estimating how long it has taken to cut gorges, over periods of thousands of years, is very risky. This unsatisfactory situation is underscored by the near-complete lack of reports on this subject in the modern, mainstream scientific literature. Rating: 3.

Anomaly Evaluation. Scientific creationists use this apparent youth of some rivers as evidence of a young earth, recently affected by a worldwide flood. To modern science, such implications are truly revolutionary. The claimed termination of the Ice Ages circa 4000 years ago is less challenging to our current outlook, but still unacceptable. Given the unsatisfactory nature of the basic data and the possibility that more conventional explanations may be adequate, it is difficult to gauge anomalousness. Nevertheless, anomalousness is measured in these Catalogs by the degree of challenge of the claim, not by the quality of the data supporting the claim. Rating: 1.

Possible Explanations. River gorge ages may be greatly underestimated because erosion rates may have differed greatly with time, because the rivers in question may have followed different routes as tilting affected drainage patterns, and because delta deposition may be greatly underestimated in terms of present volume and past removal to sea.

Similar and Related Phenomena. Grand Canyon anomalies (ETV7).

Examples

X1. The Niagara Gorge. Prior to the Ice Ages, Lake Erie is believed to have emptied into Lake Ontario, over the Niagara escarpment, through the so-called St. Davids channel. The St. Davids channel is now blocked with debris, and Lake Erie discharges through Niagara Gorge. According to conventional thinking, the erosion of the Niagara Gorge did not begin until the ice sheets had retreated northward.

Estimates of the erosion rate of Niagara Gorge are about 4-5 feet per year, based upon historical records. At this rate, the Gorge is only about 7000 years old. However, in the 1920s, the middle part of Whirlpool Rapids Gorge was found to contain a thick deposit of boulder clay, indicating that it had

been partially excavated before the Ice Ages.

The overall implication of the erosion of the Niagara Gorge is that the present river is young and that the Ice Ages terminated around 2000 BC, give or take a few centuries for changes in erosion rate. (R1, R3) This age figure is clearly at odds with the 10,000-15,000-year figures usually cited for the end of the Ice Ages. Naturally, the scientific creationists consider that their position is bolstered by such apparent youth. (WRC)

X2. The Mississippi River. A similar situation exists for the Mississippi River, at the Falls of St. Anthony at Minneapolis. Over a century ago, the geologist N. H. Winchell determined that these falls were retreating 2.44 feet per year. As a consequence, the Falls must have begun about 8000 years ago. Of course, the rate of erosion might have been higher during the melting of the ice sheets, making the Falls even younger. (R1) Some believe that the age of the Falls and the Mississippi River itself to be about the same. (WRC)

Many scientists have tried to estimate the age of the Mississippi from the size of its delta, which allows an estimate of the amount of sediment deposited. Using the current sediment-carrying figures for the River lead to an anomalously low figure---about 5000 years. (R2) However, the older estimates of delta volume are probably wildly incorrect. To illustrate, modern geophysical instrumentation has sketched out an immense buried valley filled with Pleistocene sediments below the present River. (R5, R6) Also, large volumes of sediment were doubtless carried via turbidity currents far out into the Gulf of Mexico. Gauging a river's age by delta size is risky business. (WRC)

X3. The Colorado River. "The Colorado River is so youthful that it has not had time to fill the Gulf of California with sediment. There is a small delta at the northern end of the gulf to represent the few thousand years of erosion since the flood." (R3)

In the foregoing quotation, fact must be separated from theory. The fact is that the Colorado had deposited little sediment in the Gulf of California (although no reference is given for this assertion). The theory is that a universal flood occurred only a few thousand years ago. In ETV7, the question of "where all the dirt went" will again be addressed. The material excavated from the Grand Canyon proper, as well as from upstream watersheds, has been reported as being deposited around Pierce Ferry, at the downstream end of the Canyon proper, not at the delta on the Gulf of California! This observation adds emphasis to the admonition about the dangers of using delta volumes as age indicators. (WRC)

References

R1. Velikovsky, Immanuel; "Thirty-Five Centuries Ago," Earth in Upheaval, New York, 1965. (X1, X2)

R2. Allen, Benjamin Franklin; "The Geologic Age of the Mississippi River," Creation Research Society Quarterly, 9:96, 1972. (X2)

R3. Daly, Reginald; "Niagara Falls before and after the Ice Age, "Earth's Most Challenging Mysteries, Nutley, 1975. (X1)

R4. Flint, Richard Foster; Glacial and Quaternary Geology, New York, 1971. (X1)

R5. Shepard, Francis P., and Dill, Robert F.; Submarine Canyons and Other Sea Valleys, Chicago, 1966. (X2)

R6. "Mississippi's 'Grand Canyon' Discovered," Science News Letter, 49:281, 1946. (X2)

ETV7 Grand Canyon Anomalies

Description. The questionable age and mode of formation of the Grand Canyon, as promulgated in standard texts. Regional geology and radiometric dating imply that the conventional explanation of canyon formation does not seem to apply; and, furthermore, that the Canyon may be much younger than customarily stated.

Data Evaluation. Considering that the Grand Canyon is a "showpiece" of modern geological

thought, it is rather startling to discover material seriously challenging long-taught explanations. The key article employed here appeared in Geographical Magazine. If Grand Canyon is really as anomalous as this article states, our survey of the geological literature should have yielded papers dealing with these anomalies. None was found. The data situation is, shall we say, unsatisfactory. Rating: 3.

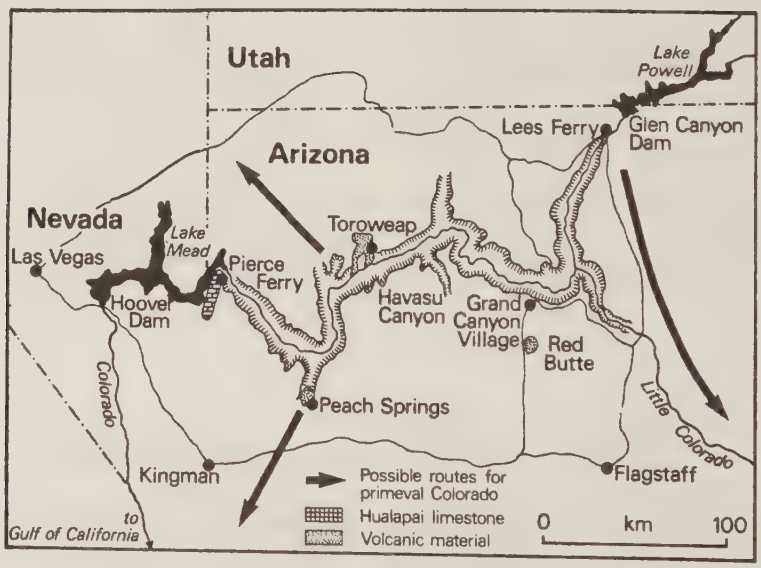
Anomaly Evaluation. The data supplied below portray a rather young canyon of debatable origin. Such directly contradict the prevailing scientific position on Canyon history. Rating: 1.

Possible Explanations. The regional geology could be misinterpreted and the radiometric dates incorrect. Otherwise, one is faced with a youthful canyon and the possibility of catastrophic erosion.

Similar and Related Phenomena. Apparently youthful rivers (ETV6). Grand Canyon's "missing" strata, unconformities, intertonguing strata, and other stratigraphic anomalies will be covered in a future volume of this Catalog (ES).

Examples

X1. Canyon origin enigma. The first problem emerges downstream from Red Butte at Pierce Ferry. There we find 200 meters of Hualapai limestone, which has been dated as 8.7 million years old using a thin layer of volcanic ash within the limestone. When this limestone was laid down, geology tells us that no large, sediment-carrying river existed in the vicinity; i.e., no Colorado River. Most geologists agree that the lower end of the Grand Canyon was not active around this time. No one knows where the Colorado River was flowing during this period. Some say it flowed southwest from Peach Springs; others point to a northwest route into Utah. All the likely alternatives face serious geological obstacles, such as lava barriers. What does seem certain is that the stock explanation of the formation of the Grand Canyon is incorrect. It was not steadily ground out, cutting ever deeper as the whole region was slowly elevated. Actually, geologists believe that the region stopped rising over 50 million years ago. Where, then, did the sediments from a 450-kilometer canyon and the wide expanses surrounding its rim go? The present exit of the Colorado near Pierce Ferry was blocked until fairly recently while the Hualapai limestone was being deposited, and other proposed routes do not seem promising. In sum, we do not



Map of the Grand Canyon of the Colorado. (Adapted from Geograhical Magazine, *55:288, 1983.) (X1)*

really know where the Colorado River was as recently as 8.7 million years ago, why it commenced its present course, and how it excavated the Grand Canyon and disposed of all the sediment. (R2)

X2. Contradiction of the popular explanation of Canyon origin. As mentioned in X1, the "accepted" theory of canyon formation, including the Grand Canyon, invokes the steady downcutting of a river as the land slowly rises. In the case of the Grand Canyon, the 8.7-million-year-old downstream limestone implies that Grand Canyon must be even younger; and, further, uplifting ceased about 50 million years ago. So, reiterating the point made in X1, the classical theory of canyon formation does not seem applicable here. (R2) The Grand Canyon, then, is rather young in geological terms, although not nearly as youthful as creationists would like in ETV6. (WRC)

X3. Undetermined disposition of sediment. "The average tourist looking from the visitor facilities at either the north or south rim sees only a small fraction of the canyon and may well fail to appreciate its overall dimensions. Measured along the river the canyon runs almost 450 km. To drive the shortest route between the visitor centres on the north and south rims involves a journey, if going upstream via Lees Ferry, of 345 km, and if going downstream via the Hoover dam, of more than 800 km. A simple calculation shows that over 2000 cu km of sediment must have been ripped from the uplifted section of the Earth's crust just to form the canyon itself.

Yet this is not all: beside the road to Grand Canyon Village on the south rim there rises a prominent conical hill, over 300 metres high, known as Red Butte. This is composed of a weak reddish rock capped by the remnant of a laval flow that has been dated---by analysis of its unstable radioactive components---as approximately 9 million years old. At the time the lava flowed out over the landscape the hilltop must presumably have formed part of a valley floor. The implication is that in the last 9 million years or so huge volumes of debris ---in places over 300 m thick---have been stripped from the rim of the canyon. The strikingly even skyline that greets the visitor to the canyon overlooks is due to this having progressively uncovered a particularly thick and resistant stratum of limestone." (R2) This is truly an awesome quantity of sediment. Is it all spread out downstream from the Canyon? In ETV6-X3, it is stated that the Gulf of California contains little sediment from the Colorado. More information is needed here. (WRC)

X4. The relatively uneroded canyon rim. "...the rim of the canyon is capped with a layer of hard limestone that has scarcely been touched with erosion. Edwin D. McKee of the U.S. Geological Survey writes that 'The level, flat and almost featureless skyline of Grand Canyon is an outstanding characteristic of the plateau of northern Arizona'. If the Grand Canyon were millions of years old, the rim of the canyon would be cut up with erosion. It would not be level. It would not be flat. And it would not be featureless." (R1) It should be added that the erosive forces were powerful enough to remove 300 meters of overlying rock and cut the canyon itself. One would think that there would be more evidence of erosive action. (WRC)

References

R1. Daly, Reginald; "The World's Rivers Are Thousands Not Millions of Years Old," Earth's Most Challenging Mysteries, Nutley, 1975, p. 262. (X4)

R2. Rice, R.J.; "The Canyon Conundrum," Geographical Magazine, 55:288, 1983. (X1-X3)

ETV8 Flume-Like Furrows on Continental Slopes

Description. Subparallel furrows running downslope on the lower continental slope. The furrows are 3-5 meters wide, 4-13 meters deep. Those observed were cut into calcareous clay-

stone.

Data Evaluation. A single series of observations, with photographs, from a research submersible. Details are lacking, especially on the geographical distribution of the phenomenon. Despite this, the reality of the furrows is apparent. Rating: 2.

Anomaly Evaluation. Basically, the anomaly exists because the physical processes that excavated the furrows are unknown, although density currents are suspected. However, it is difficult to account for the parallel pattern and deepness in solid rock with density currents. Rating: 3.

Possible Explanations. Density currents.

Similar and Related Phenomena. The extensive gullies existing on the continental slopes (R1). These gullies are almost certainly the product of slumping, and they are not considered sufficiently anomalous to catalog here.

Examples

X1. New Jersey continental slope. "Abstract. A sea bottom of middle Eocene calcareous claystone cut by downslope-trending furrows was observed during an Alvin dive to the mouth of Berkeley Canyon on the continental slope off New Jersey. The furrows are 10 to 50 m apart, 4 to 13 m deep, linear, and nearly parallel in water depths of 2,000 m. They have steep walls and flat floors 3 to 5 m wide, of fine-grained sediment. Mid-range sidescan-sonar images show that similarly furrowed surfaces are found on nearby areas of the lower continental slope, not associated with canyons. The furrows are overlain in places by Pleistocene sediments. Although they show evidence of erosional origin, they do not appear to be related to observed structures, and their straight, parallel pattern is not well understood. A general cover of flocky unconsolidated sediments implies that bottom-current erosion is not active now." (R1)

"These flume-like features are believed to have been formed by the eroding action of downslope currents---possibly density currents." (R2)

References

R1. Robb, James M., et al; "Furrowed Outcrops of Eocene Chalk on the Lower Continental Slope," Geology, 11:182, 1983. (X1)

R2. McGregor, Bonnie A.; "The Submerged Continental Margin," American Scientist, 72:275, 1984.

ETV9 Labyrinthine Topography

Description. Systems of erratic, interconnected channels cut into sediments or solid rock. There is some resemblance to interbraided channels and dendritic drainage patterns, but, generally speaking, labyrinthine topography is much more chaotic.

Data Evaluation. The "Labyrinth" of Wright Dry Valley, Antarctica, has been studied in depth, but very little exists in the literature on other examples. Rating: 2.

Anomaly Evaluation. No consensus exists as to the origin(s) of labyrinthine topography, although catastrophic erosion is favored by analogy with the Channelled Scablands (ETV5). In the case of Wright Dry Valley, volcanic heating has been invoked to produce local catastrophic flooding, thus avoiding more general inundations. Still, in today's geological milieu, any phenomenon requiring heavy flooding must be considered mildly anomalous. Chemical weathering has also been invoked to explain labyrinthine topography. All in all, we do not seem to have a serious anomaly here. Rating: 3.

Possible Explanations. Catastrophic flooding; chemical erosion.

Similar and Related Phenomena. The Channelled Scablands (ETV5); the so-called "rock cities" (ETP2); the Martian channels, also thought to be the consequence of flooding (AME1); megaripples (ETR3), and other evidence suggesting large-scale flooding.

Examples

X1. Rouge River Valley, Oregon. "Since the partial base-leveling of the 'Rouge River Valley,' which doubtless was accomplished nearly at sea-level, the territory has been elevated and the basin tilted, mainly toward the northwest. The valley plain descends from an altitude of about 1900 feet at Ashland to less than 1300 feet where the C. & O. R.R. approaches the Rouge River. In ascending along the river, the gradual rise in the plain is everywhere quite perceptible, and it has attained an altitude of approximately 2000 feet where the main stream issues from the foot-hills proper of the Cascade Mountains. This tilting has increased the gradient of the streams, causing them to cut below the old level, and all the principal ones now flow in comparatively narrow, sharp-cut, canyon-shaped troughs, excavated from 30 to 75 feet below the valley plain. These canyons are few and widely separated, telling of the youthfulness of this new cycle of erosion.

The inter-stream tracts are broad plains, undissected by deep gullies. Some portions of them are without timber or even chaparral, although generally supplied with a sparse growth of grass, and in the vernacular of the country are known as deserts. It is on these 'deserts', some of which are four or five miles in length and one to three miles in width, that is developed the peculiar type of erosion which has given rise to this paper.

When viewed from a distance, the surface of the 'deserts' appears to be remarkably even, suggesting an absolutely uneroded, water-laid deposit such as might result from the complete filling of a broad shallow lake basin. But, upon endeavoring to cross these barren plains in the rainy season, the traveler is unpleasantly made acquainted with the fact that the whole surface is cut up by a system of shallow gulleys or gutters, in which water commonly stands, but there is rarely observed a flowing stream. This system of gulleys is not of the familiar dendritic type of other regions. The gutters are all connected, but branch and inter-branch in a very confusing manner. There seem to be no trunk streams (properly so called) and tributaries. In fact, there is a perfect network or labyrinth of gutters carved into the surface of the plain, completely surrounding and isolating low, gently rounded mounds of gravelly material from 30 to 150 feet in diameter, and whose tips represent the original plain surface of the valley floor, and give these 'deserts' their apparent evenness as seen from a distance.

The gutters are from 3 to 30 feet in width, and are constantly narrowing and widening from no cause which has yet appeared. Sometimes they head in a small rounded basin, 30 to 50 feet in diameter. Indeed, it may be said that the whole system is made up of rounded, elongated basins, connected by narrower channels. Yet whatever may be the width, all portions of these gulleys are trenched to about the same depth beneath the original surface, namely, about 3 feet. The little basins at the heads are as deep as the gulleys on the borders of the 'deserts' where they are about to enter the canyon valleys of the main streams. They are floored with rounded, waterworn cobbles of black volcanic rock, of comparatively uniform size, and never seem to contain any ordinary stream deposits such as gravel or sand." (R1) In a way, the situation reminds one of patterned-ground terrain. (ETP1) (WRC)

X2. Wright Dry Valley, Antarctica. "Abstract. An area of some 18 square kilometers at the head of Wright Dry Valley displays an erosional terrain of unique characteristics---a labyrinthine complex of erratic, interconnecting channels cut to depths of more than 100 meters in bedrock. It is interpreted as a result of catastrophic fluvial erosion, probably analogous to that which produced the Channelled Scabland of eastern Washington, though on a greatly reduced areal scale." (R2)

C.R. Warren has proposed that volcanic action under the ice created a flood of meltwater that subsequently cut the labyrinthine channels. (R3)

M.J. Selby and A.T. Wilson avoid catastrophism with a salt-weathering hypothesis. (R4)

References

R1. Hershey, Oscar H.; "A Curious Phase of Inter-Stream Erosion in Southern Oregon," Science, 11:614, 1900. (X1)

R2. Smith, H.T.U.; "Anomalous Erosional Topography in Victoria Land, Antarctica," Science, 148:941, 1965. (X2)

R3. Warren, Charles H.; "Wright Valley: Conjectural Volcanoes," Science, 149:658, 1965. (X2)

R4. Selby, M.J., and Wilson, A.T.; "The Origin of the Labyrinth, Wright Valley, Antarctica," Geological Society of America, Bulletin, 82:471, 1971. (X2)

ETV10 Uneroded, Elevated Plains of Great Age

Description. Elevated, low-relief land surfaces, which are dated in hundreds of millions of years. The question is why such "paleoplains" have not been eroded significantly over such long periods of time.

Data Evaluation. One scientific survey of worldwide, elevated paleoplains has been found, plus a creationist article asserting that elevated paleoplains contradict uniformitarianism. Obviously, more data are required here. Rating: 3.

Anomaly Evaluation. As one geologist has put it, the survival of paleoplains is an embarrassment to the prevailing theory of landscape evolution. Of course, paleoplains would be even more of an embarrassment if they strongly imply that their geological dating is wildly incorrect. Our rating is based on the milder evaluation. Rating: 2.

Possible Explanations. Paleoplain dating is far off the mark. Elevated paleoplains have not evolved as expected due to local climatic conditions.

Similar and Related Phenomena. The Channelled Scablands (ETV5); youthful rivers (ETV6); incised meanders (ETV11). High-level, inland erosion surfaces (ETE4).

Examples

X1. General observations. "According to evolutionary theories for the origin of landscapes, elevated plains should be rapidly incised by erosion and bear a well-developed drainage system in only a few millions of years. Elevated, low relief land surfaces, therefore, should be evidence of the 'youthful' stage of landscape evolution, while low-lying, low relief surfaces ('peneplains') might indicate the 'old age' stage. C.R. Twidale, a physical geographer from Australia, argues that remnants of old paleosurfaces of low relief (what he calls 'paleoplains') constitute an important part of many contemporary landscapes in various parts of the world. Some of these elevated paleoplains are assigned 'Jurassic' or even 'Triassic' ages (approximately 200 million years in the evolutionary uniformitarian estimates of age). Examples of elevated paleoplains include the enormous Gondwana Surface of southern Africa (a large part of which has been assigned a 'Cretaceous' age) and various paleoplains of central and western Australia (some of which has been assigned probable 'Triassic'age). L. C. King believes that these paleoplains were formed by erosion due to sheet flooding of the surface (the 'pediplain' idea). Today they are being destroyed by downcutting erosion in stream channels.

What is amazing is that these plains have survived without major stream channel erosion. Twidale says, 'The survival of these paleoforms is in some degree an embarrassment to all the commonly accepted models of landscape development. He notes that the Davisian theory offers 'no theoretical possibility for the survival of paleoforms,' and marvels at the 'ample time for the very ancient features preserved in the present landscape to have been eradicated several times over.'" (R2; R1)

References

R1. Twidale, C.R.; "On the Survival of Paleoforms," American Journal of Science, 276:77, 1976. (X1)

R2. Austin, Steven A.; "Did Landscapes Evolve?" Institute for Creation Research Impact series no. 118, April 1983. (X1)

ETV11 Incised Meanders

Description. Meanders in deep gorges cut into high plateaus and mountainous regions.

Data Evaluation. With only a single general observation at hand and no listing of specific incised meanders, we must consider the data to be inadequate. Rating: 3.

Anomaly Evaluation. Classical meandering streams are found in broad, flat valleys with soft, easily eroded sediments. Contemporary geological theory easily disposes of such situations. But one finds it more difficult to apply the same theory to deep, meandering gorges, particularly those in hard rock. Until we find a reasonable theoretical treatment of incised meanders, we will classify the phenomenon as merely a curiosity. Rating: 3.

Possible Explanations. None offered.

Similar and Related Phenomena. Paleoplains (ETV10); Grand Canyon enigmas (ETV7).

Examples

X1. General observations. "Incised meanders. Another universal characteristic of alluvial streams is the phenomenon of meandering. Many analytical and experimental studies have been made to determine the cause and mechanics of meandering, but these have been only partially successful. It is well accepted, however, that stream meandering requires relatively mild stream gradients and easily eroded banks. If the slopes are steep and the sides resistant, then erosion will occur primarily at the beds, and the stream will cut down essentially vertically, forming a canyon section.

Most remarkable, therefore, are the intricate meandering patterns found frequently incised in deep gorges in high plateau and mountainous areas. These would seem to defy any explanation in terms of the ordinary hydraulics of rivers, and geologists' suggestions (superposed meanders, for examply!) seem to be oblivious of such hydraulics." The author, a creationist, ventures that a catastrophic origin is indicated for incised meanders. (R1)

References

R1. Morris, Henry M.; "Geological Evidence Clearly Indicates a Catastrophic Origin of Sedimentary Strata," in Why Not Creation? Walter E. Lammerts, ed., Grand Rapids, 1970, p. 131. (X1)

TIME INDEX

Age Index (Years)

Geological Period Index

Time-of-Event Index

PLACE INDEX

FIRST-AUTHOR INDEX

SOURCE INDEX

ETV1-R42
250:42 Mar ETV2-R13
250:66 Apr ETC4-R2
256:112 Feb ETB3-R19
Scientific American Supplement
12:4806 ETV4-R2
16:6374 ETE2-R1
Scientific Monthly
60:286 ETB1-R21
61:443 ETB1-R20
62:95 ETB1-R22
65:283 ETM1-R26
66:174 ETM1-R27
66:269 ETM1-R28
66:293 ETM1-R29
66:297 ETM1-R30
66:356 ETM1-R31
Sea Frontiers
28:66 ETV1-R45
32:269 ETS1-R3
Search
14:99 ETE2-R11
Seattle Times
--- Nov 23, 1984 ETB7-R3
Sky and Telescope
12:8 ETB1-R39
26:268 ETC3-R9
43:93 ETC1-R24
50:156 ETC2-R13
63:249 ETC2-R25
ETC3-R21
Smithsonian Institution, Annual Report
1897:359 ETE1-R4
1898:363 ETL1-R2
Soil Science Society of America, Journal
43:558 ETB1-R52
Soil Science Society of America, Proceedings
18:195 ETM1-R37
Submarine Canyons and Other Sea Valleys (Book)
--- ETV1-R36
--- ETV6-R5
65 ETE3-R5
275 ETV2-R8
Submarine Geology (Book)
--- ETV1-R34
--- ETV2-R6
Sunset
114:16 Apr ETM12-R13
Symons's Monthly Meteorological Magazine
22:8 ETB7-R1
Target Earth (Book)
--- ETC2-R3
--- ETV1-R30
24 ETB1-R41
146 ETM1-R47
Tectonophsyics
63:397 ETL3-R2
US Geological Survey Seventeenth Annual Report
1895-1896:521 ETM1-R8
Why Not Creation? (Book)
131 ETV11-R1

SUBJECT INDEX