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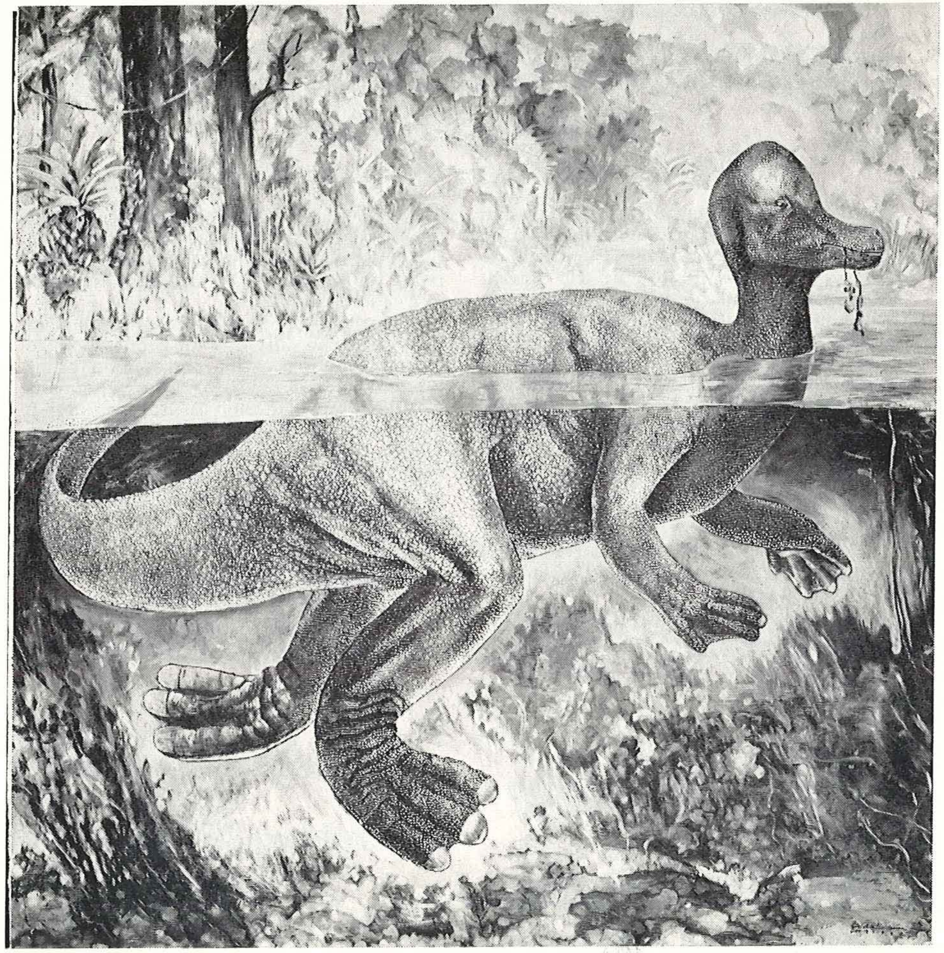

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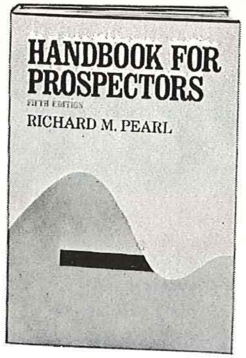


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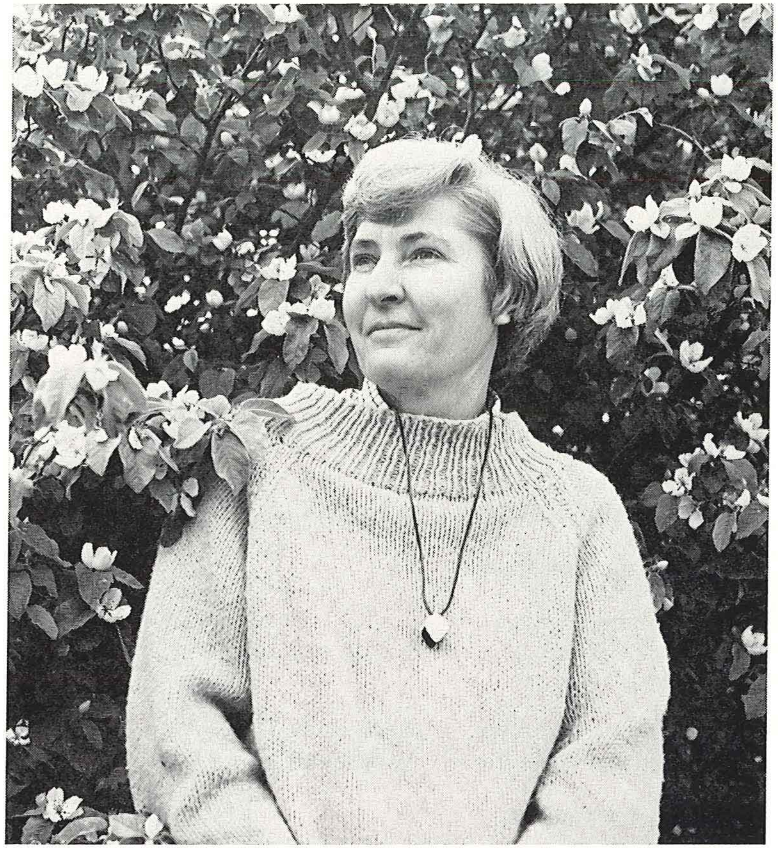
# Dedication



This issue of EARTH SCIENCE is dedicated to
Mary R. Hill

*Formerly Editor-in-Chief of* California Geology *and now Publications Coordinator of the California Division of Mines and Geology, Mary R. Hill has been photographer, film maker, recreation director, historian, author, teacher, and professional geologist with the Phillips Petroleum Company and the Illinois Geological Survey. Her 1970 film* Barrier Beach *is distributed internationally. She has written books on California uranium, jade, gold, and diamonds, Sierra Nevada geology, technical writing, and California and Nevada mining history. Your editor also knows her as President of the Association of Earth Science Editors. There is no question here of women's equality, but rather, can the men catch up?*

# POTHOLE FORMATION

## By Michael C. Mackiewicz

*The author is a geoglogy graduate of the University of Connecticut. An amateur astronomer, he is currently in the Army and will be stationed in Hawaii.*

Potholes, sometimes referred to as Indian Paint Pots, were believed by some to have been the work of Indians. These paint pots were supposed to serve a dual purpose: 1) to hold the war paint of the warriors and 2) to act, somewhat like a mortar, as a grinding bowl for the wheat and corn the Indians harvested.

Today, the general theory on pothole formation is one in which swirling currents of water carrying clastic (broken) material physically grinds a hole into the country rock. The higher current velocity required to transport this sediment is characteristic of rapids and waterfalls. Some areas receive clastic material through glacial transport. As the ice sheet melts, the area is then supplied with the necessary water for sediment transport.

A pothole is formed in a rock by the combined forces exerted on the walls and bottom of a depression by sediment scouring and an increase in water velocity. Initially, the opening of the pothole is narrow, causing the current velocity to increase as it flows through. As the hole's diameter increases, the current's rate of flow approaches the initial velocity that it had before entering the hole. The result is a decrease in the erosional power of the sediment and water, plus a reduction in the rate at which the diameter of the hole increases.

The deepening of the pothole depends on larger stones settling towards the bottom and becoming trapped. This sediment does not remain stationary but is continually forced into circular motion by swirling currents flowing near the bottom. This insures a continuous grinding process at the base of the hole. If an excessive amount of settling out occurs, the downward rate of erosion will then decrease. When the bottom is covered by sediment, the diameter at the base of the hole widens by side erosion

Cavitation is another method of pothole formation. This process is dependent on changes in current velocity and internal pressure. An increase in current velocity causes a decrease in fluid pressure. This is analogous to Bernoulli's principle of fluid flow in constricted pipes. If the pressure falls below a critical value, small bubbles of water vapor form. As the diameter and depth of the hole increases, the current's rate of flow decreases but the pressure rises. This increase in pressure if rapid enough causes the bubbles to collapse, producing shock waves. The force of the impact produced by the shock waves smashing into the walls and bottom of the hole causes the dislodgement of grains. The dislodged grains contribute to the erosion of the pothole by acting as grinding tools.

Potholes form most often in areas which erode easily, contain joints or fractures, and where depressions are present. The pothole in Figure 1 formed in an easily eroded layer of gneiss. The back wall of this pothole is a pegmatite and is more resistant to erosion then the gneiss.

Rocks which exhibit closely spaced joints tend to break off in blocks before a depression forms into a pothole. This occurs because as the depression increases in diameter and depth, adjoining holes intersect and the remaining rock is deprived of support. If the distance between joints is large enough to prevent

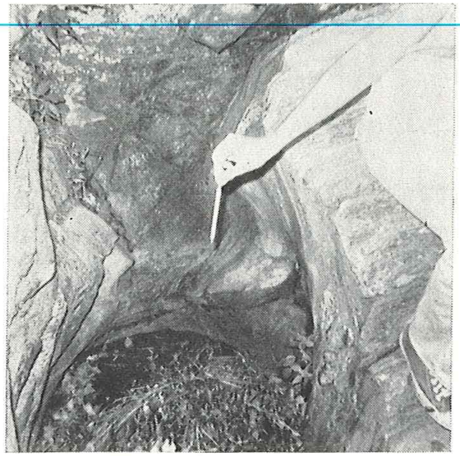


Fig. 1. Pothole eroded in the Southington Mountain Formation by the Poquonock River, in Bridgeport, Connecticut. The rock is gneiss, and pegmatite forms the back wall.

the above block erosion, the holes may deepen into potholes.

Potholes which form at the base of waterfalls erode most rapidly into large cylindrical holes. These extra large potholes are called plunge pools and eventually undercut the face of the waterfall. (Ref. 1)

Observing potholes in the field can give clues to where waterfalls once fell, or where rivers had flowed. But additional field work is required to determine the source of the water and the clastic material needed for pothole formation. Below is part of a report on a pothole eroded in bedrock along Chaffeeville Road, about 1500 ft. west of Burleyville, Connecticut.

The pothole is eroded in an outcrop of gneiss, located on the side of a hill. The outcrop is about 100 ft. above the Fenton River. Knowing that valleys are downcut by rivers, we can assume that the Fenton River had supplied the water and sediment for the pothole to form. Further field observation revealed the presence of kame terraces, drumlins, and kettle holes, all characteristic of glaciated regions. The lack of river bed deposits near the pothole would suggest 1) rapid pothole formation and 2) formation as a result of the melting glacier releasing its diversified sediment load. (Ref. 2)

Eventually, potholes may mar an entire river bed. Adjoining holes, through lateral erosion, will connect at their bases and form small bridges which connect the upper portion of the potholes. These bridges soon break down from erosion. The life-cycle of potholes may be considered a contributing factor in rivers eroding to base-level.

### References


1. von Engelin, O.D., *Geomorphology*, Macmillan Company, New York, 1942.
2. Mackiewicz, Michael, "Glaciation of the Fenton River Valley", unpublished, 1972.

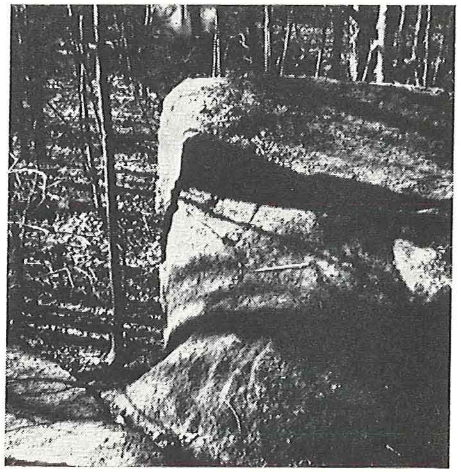



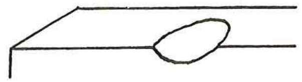
Fig. 2. Pothole is partially eroded in a joint. The rock is gneiss and is located near Swamp Brook, Storrs, Connecticut.

## *Our Cover Photo*

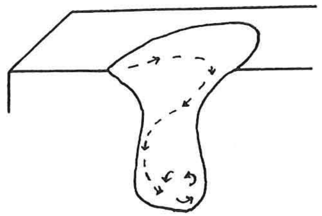
*Corythosaurus* is a duck-billed dinosaur from the Cretaceous rocks of midwestern Canada.

*National Museum of Canada*

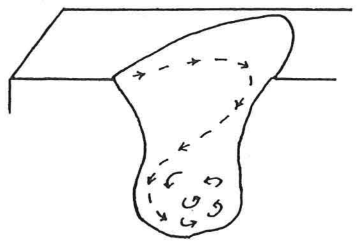
## Stages in Pothole Formation



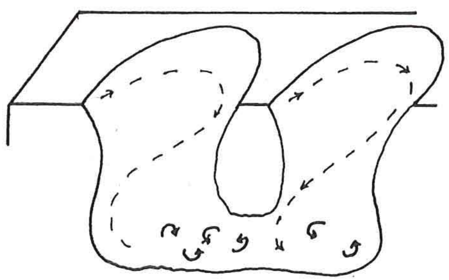
Depression in rock caused by grinding action of water carrying clastic material.



Depression eroded into the shape of a pothole. Water spiraling (shown as dashed line with arrow) into pothole erodes inner walls. Swirling currents (shown as small lines with arrows) plus clastic material at base of pothole deepens the hole.



Mature pothole: spiralling currents still flowing in. There is now an appreciable amount of sediment build-up at the bottom which increases the rate of side erosion.



Adjoining potholes connect at the bottom through side erosion. The bridge connecting both potholes will soon break away due to erosion.

# *Journeys In Geology*

## Rediscovering Siccar Point

*By Richard M. Pearl*

Siccar Point, on the east coast of southern Scotland, is quite possibly the spot where geology as a science began. It is "certainly the most famous single exposure of a British unconformity," says John Challinor. And the principle of unconformity—here, a time lapse between adjacent sedimentary beds that occupy different positions—probably is essential to the understanding of historical geology. Add to this the meaning of fossils, and you have the basis of geologic thought.

In the company of Sir James Hall and John Playfair, James Hutton in 1796 skirted the coast by boat—the "journey can be made only by sea," wrote Hutton.

In the mid-1960's, Mrs. Pearl and I drove in a "hired" car to find Siccar Point by land and to stand where the masters stood when they first saw the unconformity that, as Challinor said, "was 'needed' to confirm Hutton's theory of the geological cycle." The Old Red Sandstone rests at a sharp angle on Silurian strata: something must have happened between the times of their deposition.

It was raining, as it seemed to do most of the time, and we could not see far. Inquiring of a man nearby, we were advised to ask at the pub, for the barkeep "knew everything." This gentlemen knew indeed and told us, but we were, he said, the first Americans who had come to him; although every so often, somebody drove up from London to look at the place. He connected it with geology, though rather vaguely.

So out to the Point we went, and saw what Hutton, Playfair, and Hall saw and thrilled to long before. Even the rain did not take away the quiet excitement of being where history—including geologic history—had been made. This, after all, is to me the chief purpose of travel, which is usually neither easy nor cheap, no matter what the travel writers imply.

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## GEOLOGIC WONDERLANDS

## *America's State Parks*

### Falling Waters State Park

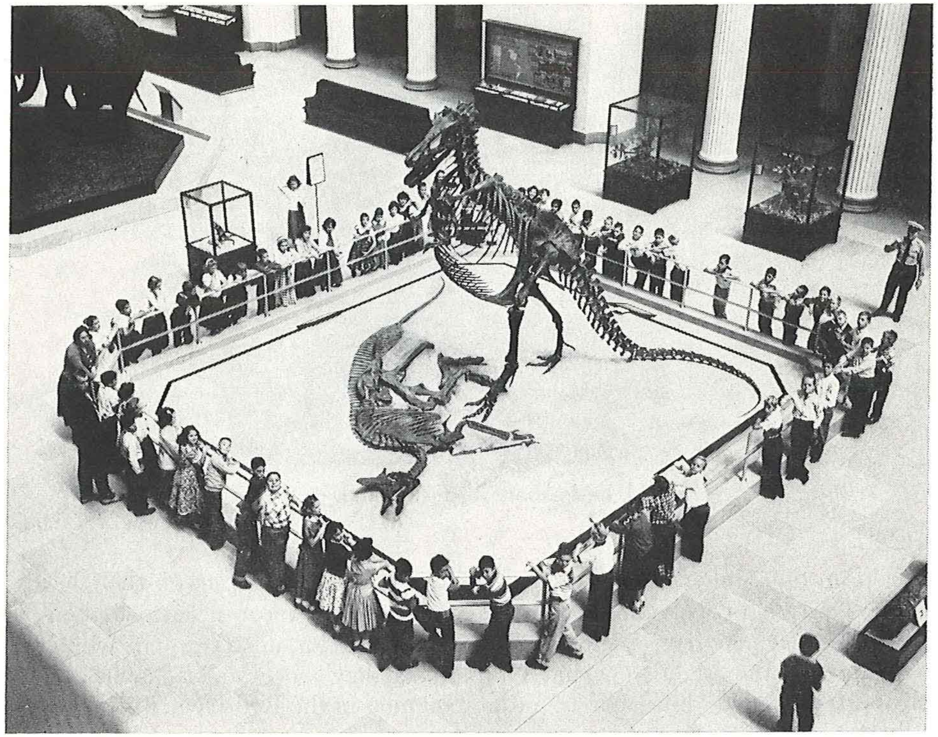
Four miles south of Chipley, in Washington County, Florida, is Falling Water; the state park of that name occupies 155 acres. Here, a small stream dashes down more than 100 feet into a round, smooth-sided opening in limestone. This well, known as a chimney, is about 20 feet across and is typical of a vast number of similar cavities in the limestone beds of Florida. These are caused by the dissolving action of carbonic-acid ground water. Some are exposed at the surface, as at Falling Water, and others are revealed when quarrying and mining removes the rock that covers them.

### Fox Ridge State Park

The ridges of this 845-acre park were known as hogbacks, although they are not the same as the hogbacks of foothills country, being long lobes of glacial moraines. The family of Abraham Lincoln was one of many, mostly from Kentucky, which traveled the high and dry ridges above the Embarrass (pronounced *Ambraw*) River in wet weather. The park is 6 miles south of Charleston, in east-central Illinois.

# Cretaceous Creatures

By Richard M. Pearl



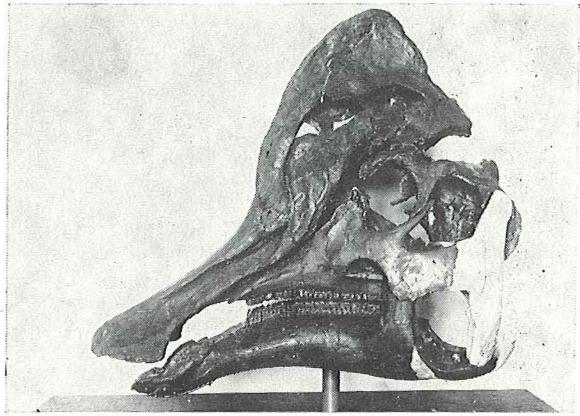
*Tyrannosaurus* (standing) and a duck-billed dinosaur
*Field Museum of Natural History*

In Latin, Cretaceous means chalk. Most of the world's deposits of chalk were formed during that geologic period, which was named from the chalk cliffs along the English Channel. On the other hand, not all Cretaceous rock is chalk—only a small part is. From rocks of this age have come some of the weirdest of all the dinosaurs. This was the climax of the Age of Reptiles.

Most Cretaceous dinosaurs were ornithischians, whereas the saurischians, which were more abundant in the Jurassic, fell behind in numbers. Though declining in North America, the great sauropods continued elsewhere. Armor-plated *Stegosaurus* barely crossed the time border and then became extinct.

A large (30-foot) Cretaceous dinosaur of more than usual interest was *Iguanodon*—the first dinosaur to be studied. It had a thick spike on its thumb, perhaps for grasping and pulling off vegetation and perhaps as a weapon. It lived on the twigs of the araucaria tree. We know this dinosaur best from the 33 or more remarkable skeletons that were found in 1878 in a pit in Belgium.

Related to *Iguanodon* was *Hadrosaurus*, the first dinosaur found in America. One member of this abundant group (formerly known as *Trachodon)* is noted for the large number of leaf-shaped teeth in its long, broad, and flat head. Some duckbills must have had 2,000 teeth—but no dentists. These animals had webbed feet and hands, the front legs being very short. The world's largest dinosaur, a duckbill, was dug up in Baja California, Mexico, in 1970—a full 100 feet in length.



Hooded hadrosaur, a duck-billed dinosaur
*National Museum of Canada*

Certain duck-billed dinosaurs had curious prongs and crests on their heads. These were shaped like helmets or hatchets or tubes, most of them being hollow. Their use may have been to help the sense of odor, or to store air while the owner was submerged in water. Or perhaps they were an ornament. These crested, or hooded, dinosaurs are rather common in the Red Deer River area of Alberta, Canada.

*Iguanodon* and his relatives were ornithischians and therefore plant eaters. The smallest and most primitive of them was *Hypsilophodon*, measuring 5 or 6 feet from end to end. Because it was thought to have a grasping foot, *Hypsilophodon* was credited with climbing trees (like the tree kangaroo)—something dinosaurs seldom did! It seems, however, that whoever assembled the best known skeleton put the thumb on backward. Even so, this agile dinosaur may have given rise to the late, horned forms such as the famous *Triceratops* described later.

Similar in ways to both *Stegosaurus* and "*Trachodon*" was the boneheaded dinosaur, *Pachycephalosaurus*. His skull grew high and was covered with thick, solid bone. Around it (and on his nose) were knobs and spikes of all sorts. It has been guessed that he may have used his skull as a battering ram. "Packy" was discovered in Montana by a group of high-school students and other amateur fossil hunters.

A suborder of ornithischians, living only in the Cretaceous Period, was Ankylosauria. *Ankylosaurus* is sometimes called the tank dinosaur because of its bulky build and heavy armor. It looked like an armadillo and reached about 17 feet in length. Flat, overlapping plates covered the head and back like a turtle, the sides were protected by heavy spikes, and the tail ended in a bony club.

Volume 1, GLACIAL GEOMORPHOLOGY. Volume 2, PERIGLACIAL GEOMORPHOLOGY. Clifford Embleton and Cuchlaine A. M. King. John Wiley & Sons, Inc., 605 Third Avenue, New York, New York 10016. 2d edition, 1975. 203 pages, photographs, drawings, maps, tables, bibliographies. Clothbound $49.50, $25.00, paperbound $24.95, $12.50.

*Periglacial* refers to the environment beyond the edge of the ice itself. These then are both parts of a second edition of the previously combined subject, and they are not only attractively written but are most beautifully presented in these Halsted Press books. Tors, pingos, and palsas may sound queer, but they really exist; in fact, the Russian for a palsa is the even more peculiar *torfyanoy bugor*. But, then, this might be expected of anybody who likes cold soup. The glacial specialist will appreciate having these books. Periglaciation is a research area largely dominated by Polish geologists.

## *Considering the Market*

Robert Frost: *New Hampshire*

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CULTURAL GEOGRAPHY ON TOPOGRAPHIC MAPS. Karl B. Raitz and John Fraser Hunt. John Wiley & Sons, Inc., 605 Third Avenue, New York, New York, New York 10016. 1975. 139 pages, maps. Price not stated.

A loose-leaf, paperbound set of maps of 30 diversified communities in the United States and Canada, this is a fine instructional manual in the use of maps in geography. The maps are in color and are the original government topographic sheets, of uniform size. Map lovers will find this is entirely adequate and very interesting for individual instruction without a teacher. The study guide will do the job for you. A most enjoyable product.

THE MOSCOW OPAL MINES—1890 to 1893 (The First Commercial Opal Mines in the United States). Ron Brockett. Available from the author, 3000 Lester Road, Denair, California 95316. 2d edition, 1975. 65 pages, photographs, drawings, maps, bibliography. Paperbound $3.00.

This offset publication tells the story of the opal mines at Moscow, Idaho. It endeavors to represent them as commercial deposits. Most of the history consists of newspaper items, excerpts from correspondence, and some official reports before the turn of the century.

THE ENCYCLOPEDIA OF WORLD REGIONAL GEOLOGY, PART I: Western Hemisphere (Including Antarctica and Australia). Edited by Rhodes W. Fairbridge. Dowden, Hutchinson & Ross, Inc. Distributed by Halsted Press, John Wiley & Sons, Inc., 605 Third Avenue, New York, New York 10016. 1975. 704 pages, photographs, drawings, maps, tables, bibliographies. $40.00.

Volume VIII of the Encyclopedia of Earth Sciences Series deals with the regions mentioned, whether geographically logical or not. They are alphabetically arranged, the letter R having one page, including photographs, some letters having many pages of places. It would be entirely unfair to criticize this editor for his indefatigable efforts to produce a series of modern encyclopedias on geology, and any imbalances in the parts are probably impossible to avoid. Some of the best material, as usual, was written by Dr. Fairbridge. We may, nevertheless, be dismayed at the complaints of poverty and unprofitability, requiring "unpaid and generous help," even contributions from college professors including the editor, when we realize that the present and past publishers have ranged up to half-billion-dollar companies. To add to an old saying, there are plenty of worthwhile things to be done in this world if you don't care who gets the credit—or who pays the bills.

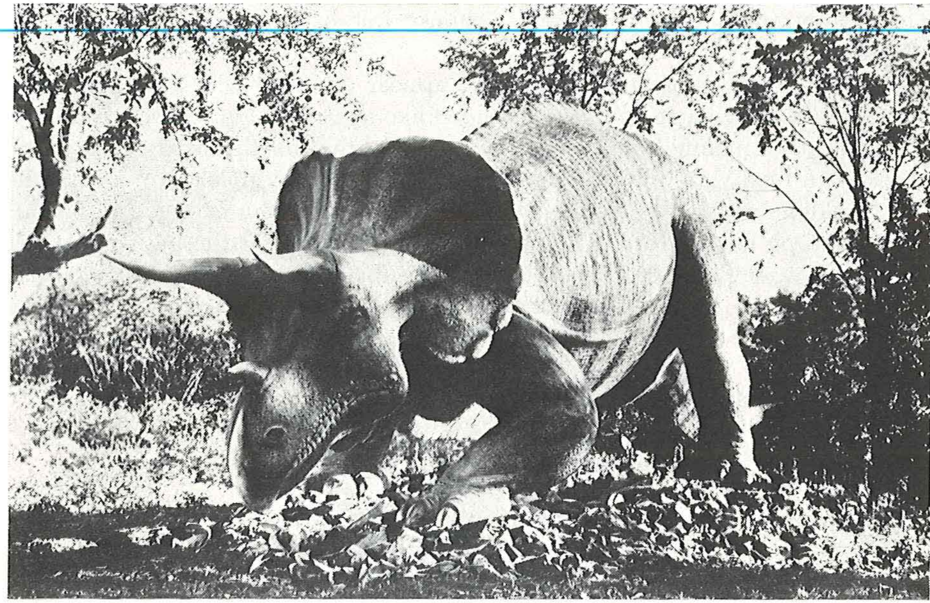
GROWTH RHYTHMS AND THE HISTORY OF THE EARTH'S ROTATION. Edited by G. D. Rosenberg and S. K. Runcorn. John Wiley & Sons, Inc., 605 Third Avenue, New York, New York 10016. 1975. 559 pages, photographs, drawings, maps, tables, bibliographies. $57.00.

Growth lines on fossil shells show that the earth is slowing up and by how much. So do growth rings on trees. These are just two of the biologic clocks described in this book.

A series of contributed papers deals with the speed of the earth's rotation. The approaches are from astronomy, geophysics, paleontology, biology, and even history. Some techniques have been suspected for a long while; others are very new, and even sound far out; but they are probably more true than not.

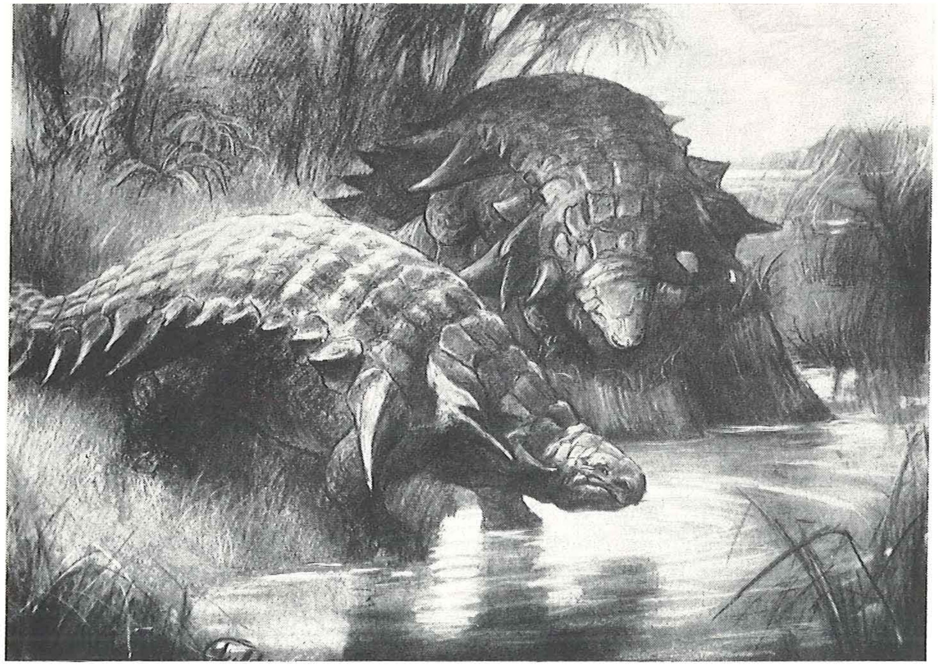
PETROLEUM AND THE CONTINENTAL SHELF OF NORTH-WEST EUROPE. Edited by Austin W. Woodland. John Wiley & Sons, Inc., 605 Third Avenue, New York, New York 10016. Volume 1. Geology. 1975. 501 pages, photographs, drawings, maps, tables, bibliographies, glossary. $47.50.

Thirty-eight papers given at a conference on the Continental Shelf are printed in this large Halstead Press volume. They represent mostly commercial rather than academic sources. The contents are technical and professional, of much interest to the international oil industry.



*Triceratops*

*Sinclair Refining Company*

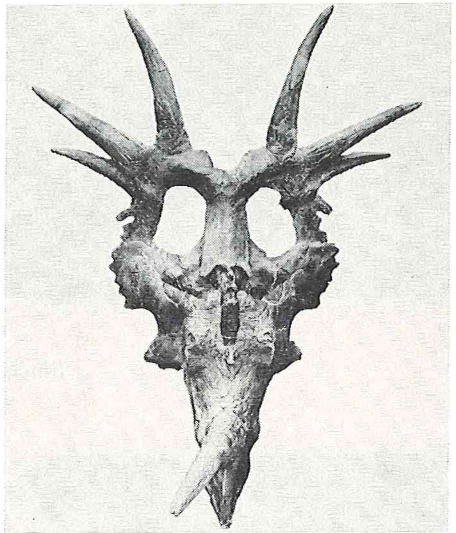


*Ankylosaurus*

*National Museum of Canada*

This fellow could protect himself!—"clumsy but hard to crack," says A. O. Woodford.

The last suborder of ornithischians to appear on earth was Ceratopsia, the horned dinosaurs. Their skulls were shaped like the beak of an enormous parrot. (*Triceratops*—a mental failure—had the smallest brain for the size of its skull of any known land vertebrate.) A large, bony frill extended back over the shoulders, holding strong neck and jaw muscles and also protecting the animal. *Protoceratops,* famous for her eggs, had little or no horn. As these dinosaurs developed, however, horns grew on the nose or above the eyes or in both places.



Spike-frilled skull of *Styracosaurus,* head on
*National Museum of Canada*

*Monoclonius* belonged to this group. It had one nose horn like a rhinoceros. *Diceratops* had two eye horns. *Triceratops* had three horns; when first found by George L. Cannon, Jr., in Colorado in 1887, it was thought to be a large bison, about 20 feet long. *Styracosaurus* had a horn on his nose and six vicious spikes above his neck.

Living on all these Cretaceous vegetarians were the huge theropod carnivores—terrible lizards indeed. Of these, the best known was the worst: *Tyrannosaurus.* Almost 50 feet long, standing 20 feet high on his hind legs, which had three toes on their clawed feet, and weighing almost 8 tons—he was the "king of the tyrant reptiles." Anyone who invited this charming chap to dinner could expect to be the meal. Fossil bones of the largest sauropods show his tooth marks. Perhaps, however, he lived as a scavenger.

*Gorgosaurus* is another North American dinosaur like *Tyrannosaurus,* and *Tarbosaurus* is from Russia. Their disposition was probably no better than his.

Another theropod was *Ornithomimus,* or *Struthiomimus.* But this dinosaur, which looked like an ostrich and was about the same size, had lost all his teeth and could scarcely eat flesh. Possibly, he had to live on insects or leaves or fruit. Maybe, instead, he robbed the nests of other dinosaurs for eggs—his horny beak was suitable for egg eating, and he could run fast.

# Book Reviews

## By Richard M. Pearl

SPRINGS OF COLORADO. Richard M. Pearl. Earth Science Publishing Company, Post Office Box 1815, Colorado Springs, Colorado 80901. 1975. 36 pages, photographs, drawings, bibliographies. Paperbound $2.75.

Explaining mineral springs, their origin and importance, this new book by the Editor of EARTH SCIENCE then describes 32 interesting spring localities in Colorado. Classifications of springs are given. The photographs are both historical and current, coming from the Western History Department of the Denver Public Library and the Penrose Public Library, Colorado Springs. The large, clear sketches of the geologic origin of springs were made to order by Sarah Andrews. Good enamel paper makes the illustrations clear.

Certain of the springs of Colorado have curious histories. There is Hartsel and its man-eating mosquitoes, Eldorado Springs and its wire-balancing acrobats, Clarke's Springs and their ability to magnetize steel, and others. At Glenwood Springs is the largest outdoor warm-water swimming pool in the world.

TREASURES FROM THE EARTH: The World of Rocks & Minerals. Benjamin M. Shaub. Crown Publishers, Inc., 419 Park Avenue South, New York, New York 10016. 223 pages, color plates, photographs, drawings, tables, bibliography. $19.95.

This handsome book is more of a beautifully illustrated textbook of mineralogy than the colorful art works of which there have been quite a few in recent years. The contents follow standard school material, addressed to the collector as well as the student, rather than a gallery of spectacular specimens like the others just referred to. In other words, the emphasis is on explanation, decorated with pictures both in color and black-and-white. Certainly an appealing volume, for which Joel E. Arem was consultant.

MINERALS AND GEMS: A Color Treasury for Collectors and Guide to Hunting Locations. Russell P. MacFall. Thomas Y. Crowell Company, 666 Fifth Avenue, New York, New York 10019. 1975. 242 pages, color plates, photographs, drawings, maps, tables, bibliography. $17.50.

The main part of this large-format book is mostly a translation by Edwin Greene of an Italian book published in 1973 and written by four authors: Ambrosio Del Caldo, Cesarina Moro, Carlo Maria Granaccioli, and Matteo Boscardia. To this has been added a section on North American collecting localities by Russell P. MacFall, whose name appears on the whole book. Don Pitcher made the line maps.

Apart from the rather peculiar assignment of credits, how does the book compare with the rather numerous other fancy color-books of recent date? It is a little less expensive than some, much less so than others. The color, even though of Italian origin, is proportionately inferior to them. The text is good, even with the mistakes inevitable in a job of trying to report on collecting localities all over the continent.

COLLECTING FOSSILS. Alan Majors. St. Martins Press, Inc., 175 Fifth Avenue, New York, New York 10010. 1974. 208 pages, color plates, drawings, bibliography, glossary. $8.95.

Published in Edinburgh by John Bartholomew & Son, Ltd., this attractive book has many nice drawings of plant and animal fossils. It also tells how to collect, but you should know that it has mainly a British approach. This is such a pretty little book!

# Jade in Stone-Age Siberia

*By Richard M. Pearl*

Jade has been written about in a vast literature. Most of this deals with Chinese jade, including the material from Burma and other places in southeastern Asia. Some covers the jade from New Zealand, and a number of articles describe the jade from the lake dwellings of Switzerland. No separate book, however, has treated the uses of jade in Siberia during the Stone Age.

Many archaelogists, anthropologists, and ethnologists have not distinguished between jadeite and nephrite, the two main types of true jade. Indeed, the Chinese, who used them most and best, did not seem to make the distinction either. Practically all of this article has to do with nephrite, the more common kind of jade.

People of the Paleolithic, or Old Stone Age, could not manipulate jade because of its toughness, which it owes to its fibrous structure. By the time of the Neolithic, or New Stone Age, however, they had learned how to saw and grind hard stones, and the use of jade spread from China to India and Siberia.

Siberian jade occurs as smooth boulders west of Lake Baikal. A. G. Betekhtin gives its occurrence in a slaty rock along the rivers Onot, Chika, Khorak, and Zhara-Zhelga. The rolled boulders lie at the foot of the outcrops.

Flaking jade is so difficult that it was employed only when necessary. Sawing was resorted to in order to make grooves. Even this was not easy, and pieces were sawed entirely through for further use only because the material was too valuable to waste.

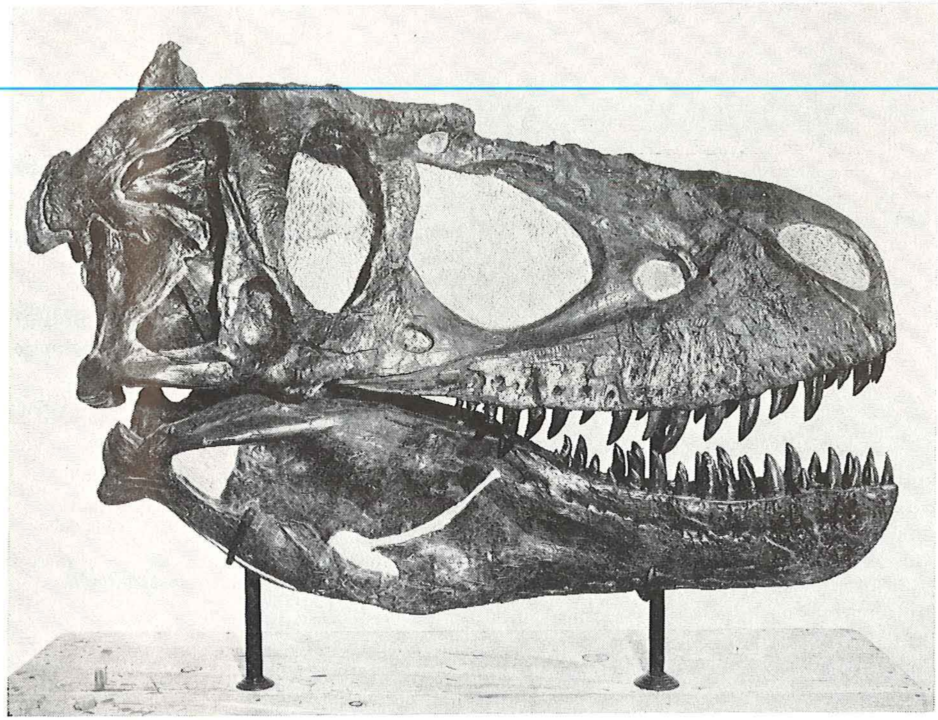
Rings and disks of jade for personal adornment, rather than for tools, were produced by cutting out blanks in the shape of thin plates. These blanks were grooved in two places and then broken apart, in the manner that chemistry students prepare glass tubing. The blank was then ground down. You can see that sawing was just part of the procedure, but it was done to take advantage of the fibrous structure of jade.

Some of the jade rings were as much as 4 inches across, as seen in white nephrite in the Irkutsk Regional Museum. Templates appear to have been used often, hollow drilling (bush drilling) for the rest. A series of concentric rings could be made from the same rough.

Nephrite was a favored material for whittling knives, which were used for various purposes besides preparing game. Jade axes and adzes were helpful in making dugout canoes, more so than other rocks also used.







*Tyrannosaurus* skull
*Field Museum of Natural History*

*Gorgosaurus*
*National Museum of Canada*

# Building Stones of the World

By Richard M. Pearl

*stone to beauty grew—*
Ralph Waldo Emerson: *The Problem*

Long before the introduction of metal, natural stone was used to build houses and wall cities. The Stone Age preceded the Bronze Age, although neither of these terms had any direct relevance to our subject. Even quarrying as an industrial art existed before metal tools were known, as is well evidenced by the workings at Aswan, Egypt. Suddenly abandoned, they provide evidence of stone tools of great efficiency and of wooden pegs, which were pounded into a row of holes and soaked with water, causing them to expand. The American Indian extracted blocks of stone, as well as broken fragments of obsidian, turquoise, and many other mineral materials, by heating the rock and then dashing water on it.

In many places, natural stone is the only constituent of manmade structures. The history of its use is a fascinating study. Certain fine books deal with this story, which has appealed alike to geologists, engineers, architects, artists, and others. Colossal stone sculptures of ancient cultures, huge pyramids, obelisks, and other forms are famed for both the skilled workmanship and the problems that were overcome in transporting and erecting them.

Several decades ago, it seemed as though the use of natural stone would soon be made obsolete by the increase of concrete and brick construction. Even where, as in Denver, laws prohibited frame dwellings, it was seldom that stone was substituted. And where, as in Jerusalem, all buildings had to be faced with stone, the basic material was a plaster-cast facade. But its maintenance cost and the general realization that durable stone, with its almost infinite variety, is strongly competitive with concrete, brick, glass, plastic, wood, and metal has resulted in a renaissance of natural stone.

Termed dimension stone when produced to definite sizes and/or shapes, this material has strength, durability, hardness, and ornamental qualities, whether polished, cut, sawed, ground, or left in its natural state. It may be employed in many types ranging from rough stone to finished panels, outside or inside, and for monumental, ornamental, and decorative uses, as well as for industrial and other special uses that require specific shapes and sizes. Some of these have been familiar for centuries past, such as for grindstones, blackboard slates, stone curbing, and lithographic limestone. Some such applications may seem to have disappeared from the modern scene, until you look for them, and there they are. Even the colors and patterns of natural stone offer as much diversity as manufactured substitutes.

It is the occurrence and use of the famous building stones of the world that this series has to do with. Scarcely a corner of the globe does not yield rock of great interest and beauty.

conclusion to which all positive testimony tends receives the like negative justification from the fact that no other hypothesis has a shadow of foundation.

It may be worthwhile briefly to consider a few of these collateral proofs that the chalk was deposited at the bottom of the sea. The great mass of the chalk is composed, as we have seen, of the skeletons of *Globigerinae* and other simple organisms embedded in granular matter. Here and there, however, this hardened mud of the ancient sea reveals the remains of higher animals which have lived and died and left their hard parts in the mud, just as the oysters die and leave their shells behind them in the mud of the present seas.

There are, at the present day, certain groups of animals which are never found in fresh waters, being unable to live anywhere but in the sea. Such are the corals, those corallines which are called *Polyzoa*, those creatures which fabricate the lamp shells, and are called *Brachiopoda*, the pearly nautilus, and all animals allied to it, and all the forms of sea urchins and starfishes. Not only are all these creatures confined to salt water at the present day, but so far as our records of the past go, the conditions of their existence have been the same; hence, their occurrence in any deposit is as strong evidence as can be obtained that that deposit was formed in the sea. Now the remains of animals of all the kinds which have been enumerated occur in the chalk, in greater or less abundance, while not one of those forms of shellfish which are characteristic of fresh water has yet been observed in it.

When we consider that the remains of more than 3,000 distinct species of aquatic animals have been discovered among the fossils of the chalk, that the great majority of them are of such forms as are now met with only in the sea, and that there is no reason to believe that any one of them inhabited fresh water—the collateral evidence that the chalk represents an ancient sea bottom acquires as great force as the proof derived from the nature of the chalk itself. I think you will now allow that I did not overstate my case when I asserted that we have as strong grounds for believing that all the vast area of dry land at present occupied by the chalk was once at the bottom of the sea as we have for any matter of history whatever, while there is no justification for any other belief.

There is more curious evidence, again, that the process of covering up, or, in other words, the deposit of *Globigerina* skeletons, did not go on very fast. It is demonstrable that an animal of the Cretaceous sea might die, that its skeleton might lie uncovered upon the sea bottom long enough to lose all its outward coverings and appendages by putrefaction, and that, after this had happened, another animal might attach itself to the dead and naked skeleton, might grow to maturity, and might itself die before the calcareous mud had buried the whole.

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## *Letters*

We all owe our paleontologists and geologists as well as our professors a debt of thanks we could never repay. It is due to such men and women that we know about our geological past and its various life forms and events such as mountain building, former seas, lakes, oceans and land masses. Fossil displays are to be seen in museums from many locales. Our fossils did not walk to the museums nor did they collect, identify, or clean themselves. Such work was done by those who collect fossils and must often work under very harsh climatic conditions and travel across many miles of rugged terrain.

The rockhound has also played his part in regard to many new and rare finds made and turned over to various schools and museums. Such thoughtful action has saved many a rare or new fossil and therefore allowed us to piece together our jigsaw puzzle and give us a better understanding of the life and events of our geological past.

I wish to thank all the persons involved in our search for knowledge of the geological past. Let us all protect and put to good use our many fossil and archaeologic sites.

*Douglas Valney*

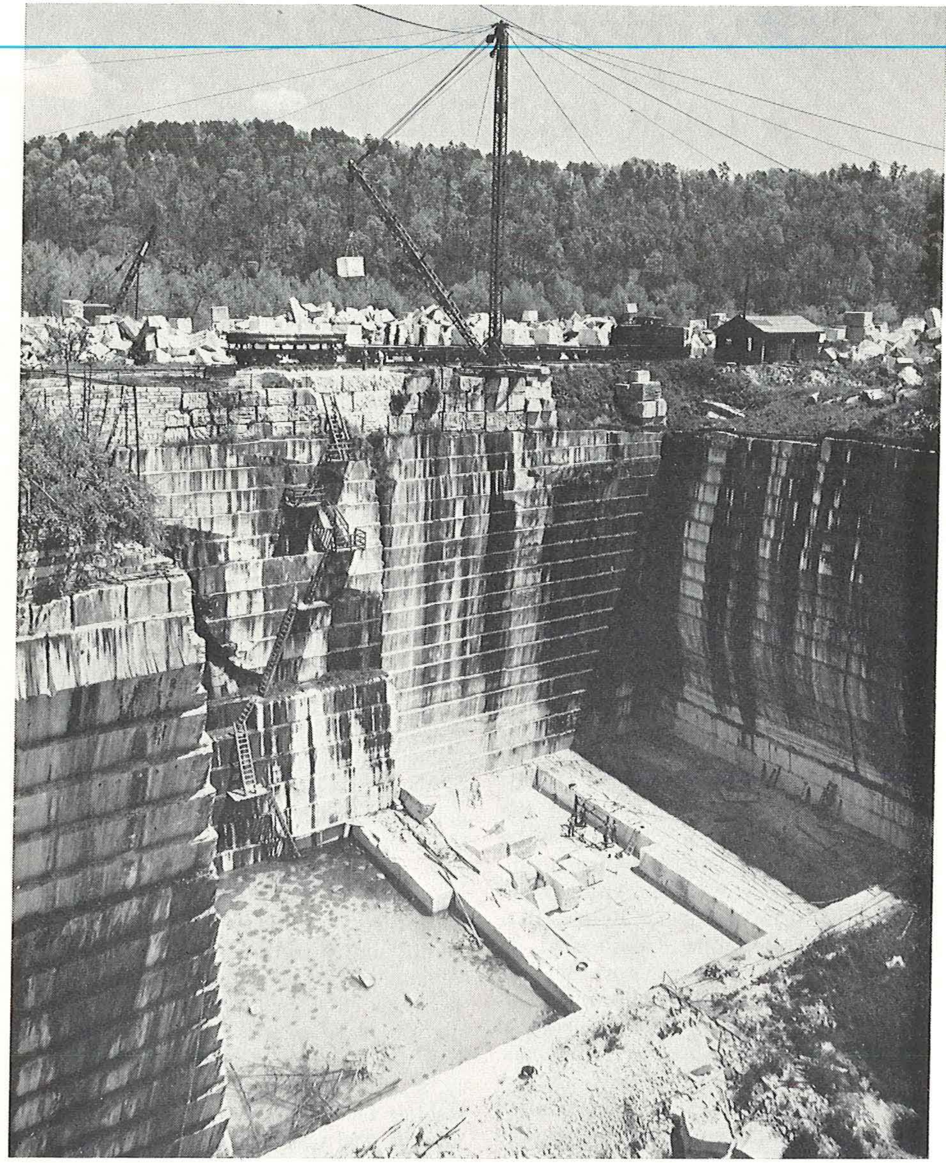
which the components of the chalk are arranged and of their relative proportions. But, by rubbing up some chalk with a brush in water and then pouring off the milky fluid so as to obtain sediments of different degrees of fineness, the granules and the minute rounded bodies may be pretty well separated from one another and submitted to microscopic examination, either as opaque or as transparent objects. By combining the views obtained in these various methods, each of the rounded bodies may be proved to be a beautifully constructed calcareous fabric, made up of a number of chambers communicating freely with one another. The chambered bodies are of various forms. One of the commonest is something like a badly grown raspberry, being formed of a number of nearly globular chambers of different sizes congregated together. It is called *Globigerina,* and some specimens of chalk consist of little else than *Globigerina* and granules. Let us fix our attention upon the *Globigerina.* It is the spoor of the game we are tracking. If we can learn what it is and what are the conditions of its existence, we shall see our way to the origin and past history of the chalk.

A suggestion which may naturally enough present itself is that these curious bodies are the result of some process of aggregation which has taken place in the carbonate of lime; that, just as in winter the rime on our windows simulates the most delicate and elegantly arborescent foliage—proving that the mere mineral water may, under certain conditions, assume the outward form of organic bodies, so this mineral substance, carbonate of lime, hidden away in the bowels of the earth, has taken the shape of these chambered bodies. I am not raising a merely fanciful and unreal objection. Very learned men in former days have even entertained the notion that all the formed things found in rocks are of this nature, and if no such conception is at present held to be admissible, it is because long and varied experience has now shown that mineral matter never does assume the form and structure we find in fossils. If anyone were to try to persuade you that an oyster shell (which is also chiefly composed of carbonate of lime) had crystallized out of sea water, I suppose you would laugh at the absurdity. Your laughter would be justified by the fact that all experience tends to show that oyster shells are formed by the agency of oysters and in no other way. And if there were no better reasons, we should be justified, on like grounds, in believing that *Globigerina* is not the product of anything but vital activity.

Happily, however, better evidence in proof of the organic nature of the *Globigerinae* than that of analogy is forthcoming. It so happens that calcareous skeletons, exactly similar to the *Globigerinae* of the chalk, are being formed at the present moment by minute living creatures which flourish in multitudes, literally more numerous than the sands of the seashore, over a large extent of that part of the earth's surface which is covered by the ocean.

However, the important points for us are that the living *Globigerinae* are exclusively marine animals, the skeletons of which abound at the bottom of deep seas, and that there is not a shadow of reason for believing that the habits of the *Globigerinae* of the chalk differed from those of the existing species. But if this be true, there is no escaping the conclusion that the chalk itself is the dried mud of an ancient deep sea.

The evidence furnished by the hewing, facing, and superposition of the stones of the pyramids that these structures were built by men has no greater weight than the evidence that the chalk was built by *Globigerinae,* and the belief that those ancient pyramid builders were terrestrial and air-breathing creatures like ourselves is not better based than the conviction that the chalk makers lived in the sea. But as our belief in the building of the pyramids by men is not only grounded on the internal evidence afforded by these structures, but gathers strength from multitudinous collateral proofs and is clinched by the total absence of any reason for a contrary belief, so the evidence drawn from the *Globigerinae* that the chalk is an ancient sea bottom is fortified by innumerable independent lines of evidence; and our belief in the truth of the



Georgia marble quarry operation
*Georgia Marble Company*

# GEOTHERMAL ENERGY

## A LOOK INTO THE FUTURE

**By W. Alan Benson**

The energy crisis in America is focusing increasing attention on possible new sources of energy: solar, tidal, wind, fission, fusion, and geothermal. Traditional sources of energy are being rapidly depleted by an ever-growing level of industrialization. Available domestic sources of oil and gas are diminishing at a rapid rate, 4 to 6 percent per year for oil and 7 to 8 percent for natural gas; furthermore, by 1980 industry will be prevented from using natural gas.

Geothermal energy provides an attractive alternative to present energy sources. Estimates place the amount of heat in the upper 10 miles of the earth's crust at 2,000 times the amount of heat that would be produced if the world's entire supply of coal were burned (Henahan, 1974). If only 10 percent of the heat trapped in the top 2 miles of the crust could be extracted and turned into electrical power, it would provide 58,000 MW annually for 50 years. Robert Rex, president of Republic Geothermal in Whittier, California, estimates that the energy trapped beneath California's Imperial Valley could meet the electrical needs of the Southwest for 200 years. Today, Italy, the USSR, Iceland, Mexico, New Zealand, Japan, and the United States are producing electrical energy from geothermal resources.

Geothermal steam and associated resources includes (1) all products of geothermal processes, embracing indigenous steam, hot water, and hot brines; (2) steam and other gases, hot water, and hot brines resulting from water, gas, or other fluids artificially introduced into geothermal formations; (3) heat or other associated energy found in geothermal formations; and (4) any byproduct derived from them. (Geothermal Steam Act of 1970)

This report is a summary of the history of geothermal energy, the factors that have spurred its development, the various types of geothermal resources and how they can be used to generate electricity, and the problems preventing immediate and widespread implementation of geothermal energy as a viable power source.

Geothermal energy should be considered as an alternate source of energy for the production of electricity.

### HISTORY

On a minor scale the use of geothermal heat began over a century ago, when the earth's heat was used in a few isolated locations for space heating. Geothermal generation of electricity began in 1904 when steam from fumaroles at Lardarello, Italy, was used to drive a small turbogenerator that lit five electric bulbs. Since then, development of geothermal energy has proceeded slowly, impeded by the abundance, portability, and low cost of fossil fuels. In 1958 electrical power from geothermal steam became commercial at Wairakei, New Zealand, and in June 1960 the first geothermal steam power plant in the United States began producing at The Geysers, California. Presently, seven countries are commercially producing electric power from geothermal energy, and several more are planning to go on-stream within a year or two. Worldwide installed generating capacity has reached 936 MW and will probably increase rapidly. In December, 1970 President Nixon signed into law the Geothermal Steam Act of 1970 providing legislation for leasing, development, and use of geothermal resources.

### GROWTH FACTORS

Various economical, political, sociological, and technical factors, evolving over

# GEOCLASSICS

## *ON A PIECE OF CHALK*

**By Thomas Henry Huxley**

A great chapter of the history of the world is written in the chalk. Few passages in the history of man can be supported by such an overwhelming mass of direct and indirect evidence as that which testifies to the truth of the fragment of the history of the globe which I hope to enable you to read with your own eyes tonight. Let me add that few chapters of human history have a more profound significance for ourselves. I weigh my words well when I assert that the man who should know the true history of the bit of chalk which every carpenter carries about in his breeches pocket, though ignorant of all other history, is likely, if he will think his knowledge out to its ultimate results, to have a truer, and therefore a better conception of this wonderful universe and of man's relation to it than the most learned student who is deep-read in the records of humanity and ignorant of those of nature.

The language of the chalk is not hard to learn, not nearly so hard as Latin, if you only want to get at the broad features of the story it has to tell, and I propose that we now set to work to spell that story out together.

We all know that if we "burn" chalk the result is quicklime. Chalk, in fact, is a compound of carbonic-acid gas and lime, and when you make it very hot the carbonic acid flies away and the lime is left By this method of procedure we see the lime, but we do not see the carbonic acid. If, on the other hand, you were to powder a little chalk and drop it into a good deal of strong vinegar, there would be a great bubbling and fizzling and, finally, a clear liquid, in which no sign of chalk would appear. Here you see the carbonic acid in the bubbles; the lime, dissolved in the vinegar, vanishes from sight. There are a great many ways of showing that chalk is essentially nothing but carbonic acid and quicklime. Chemists enunciate the result of all the experiments which prove this by stating that chalk is almost wholly composed of carbonate of lime.

It is desirable for us to start from the knowledge of this fact, though it may not seem to help us very far toward what we seek. For carbonate of lime is a widely spread substance and is met with under very various conditions. All sorts of limestones are composed of more or less pure carbonate of lime. The crust which is often deposited by waters which have drained through limestone rocks in the form of what are called stalagmites and stalactites is carbonate of lime. Or, to take a more familiar example, the fur on the inside of a tea kettle is carbonate of lime; and, for anything chemistry tells us to the contrary, the chalk might be a kind of gigantic fur upon the bottom of the earth kettle, which is kept pretty hot below.

Let us try another method of making the chalk tell us its own history. To the unassisted eye chalk looks simply like a very loose and open kind of stone. But it is possible to grind a slice of chalk down so thin that you can see through it—until it is thin enough, in fact, to be examined with any magnifying power that may be thought desirable. A thin slice of the fur of a kettle might be made in the same way. If it were examined microscopically, it would show itself to be a more or less distinctly laminated mineral substance and nothing more.

But the slice of chalk presents a totally different appearance when placed under the microscope. The general mass of it is made up of very minute granules, but embedded in this matrix are innumerable bodies, some smaller and some larger, but, on a rough average, not more than a hundredth of an inch in diameter, having a well-defined shape and structure. A cubic inch of some specimens of chalk may contain hundreds of thousands of these bodies compacted together with incalculable millions of the granules.

The examination of a transparent slice gives a good notion of the manner in

# The Toledo War

By Richard M. Pearl

until they came to the borders—*Exodus* 16:35

The boundary between Ohio and Michigan was in such dispute in the year 1835 that both sides assembled a force of militia on the border and prepared for civil war.

Ohio had been a state since 1803. Michigan was still a territory (since 1805), trying hard to get into the Union but delayed by unfavorable reports about its swampy land and poor soil. These reports limited immigration and prevented the growth of population. In addition, the boundary was a problem, and Michigan could not be admitted without fixed boundaries.

Ohio insisted on the Harris Line, which would keep for the state a valuable frontage on Lake Erie, including the mouth of the Maumee River and the proposed eastern end of the Wabash and Erie Canal. Michigan wanted the Fulton Line instead—not so much for the lake frontage as for the good farmland in that area. Said William W. Woodbridge, of Detroit: "An acre of Country to the south is of more importance to us than miles in the north. A considerable part of the Country claimed by Ohio is of the finest we have; to be deprived of it would materially delay the period of our admission into the Union."

Only 470 square miles was at stake. But the issue was violent. Feelings ran so high that the territorial government of Michigan was banished, a constitution was adopted, and state officials were elected—all without approval of Congress. Although many brawls took place at the border, no one was seriously injured. This government lasted a year and a half.

The boundary quarrel is known as the Toledo War, because the disputed area included the city of Toledo. Ohio finally won in 1837, when Congress decided on the more northern line. Michigan, however, was admitted as a state at this time and given 9,000 square miles in the Upper Peninsula. This was long thought to be worthless land.

Considering the effort that Ohio made to get this strip of land, it is curious to note that both Indiana and Illinois missed the chance to be much larger than they are. Simply by failing to ratify the boundaries given in the enabling acts of these states, each would have become a larger size, as provided in the Ordinance of 1787.

a period of years, culminated in 1974 and 1975 in a spurt of growth for the geothermal industry. The stimuli came from:

### Potential Unavailability of Important Fuels

The energy crisis of 1974 brought a realization of the reserve-production status of the fossil fuels. The traditional patterns of power sources, transportation, and consumption have been, or soon will be, disrupted.

### Need for Environmentally Acceptable Energy Sources

Geothermal energy production, when compared to other means of power generation, produces minimal impact upon the environment. The environmental problems geothermal energy does have, such as brine disposal and ground subsidence, are relatively easy to overcome.

### Escalating Cost of Fossil and Nuclear Power

The capital cost of geothermal power plants are low when compared to nuclear or oil-fired plants. Capital cost per installed kilowatt hour is between $200 and $400 for geothermal power, and, in contrast, a nuclear power plant costs between $700 and $1000.

### Availability of Federal Lands

Federal lands first became available for geothermal exploration and leasing in January, 1974 when the Geothermal Steam Act was implemented. Over 75 percent of potentially commercial geothermal regions are on public lands in the western half of the United States (Fuchs and Huttrer, January 1975).

## THE GEOTHERMAL RESOURCE

Heat is conducted first from the earth's hot interior into the crust, and then it is transferred to the upper crust by either thermal conduction through solid rock, or convective flow of water through permeable rock. This heat constitutes the basis for geothermal energy. Most of this heat is too diffuse to be of economic value, but sufficient concentrations of geothermal heat have been located to give confidence that adequate reserves of geothermal energy may be extracted. The challenge for both short- and long-term exploitation is to locate concentrated areas of geothemal heating that can be economically developed.

The characteristics of geothermal deposits that determine whether they can be economically exploited are temperature, pressure, volume, depth, and hydrology. Geothermal resources are graded by temperature, depth, availability, and salinity of water. These factors determine the cost of field development; the physical, chemical, and environmental problems of production; and the forms of utilization.

The Federal Energy Administration has classified geothermal resources as either vapor-dominated systems, liquid-dominated systems, geopressurized basins, hot and dry rock formations, and near-normal thermal gradient environments.

### Vapor-Dominated Systems

Vapor-dominated systems are a rarity among geothermal resources but are also the easiest and cheapest to develop. A dry-steam reservoir develops when ground water comes into contact with geothermally heated rocks. The water is heated, perhaps to 300-plus degrees Fahrenheit, but because of the extreme pressures at depth it remains liquid. As the water moves up to the surface, either through natural fissures in the rock or through a well bore, the pressure drops and the super-heated water flashes into dry, super-heated steam.

Two years before the Gold Rush turned San Francisco into a boom town, William Bell Elliot, surveyor and explorer, discovered a valley of geysers while charting the mountainous country north of the city. The steam resulted from water heated to 375°F 1,000 feet below the surface seeping up through fissures and flashing into steam. The area, called The Geysers, is the location of the only commercially developed and operated geothermal power plant in the United States. Development of the field began in 1922 when drillers tapped a reservoir, but impurities in the steam proved too corrosive and abrasive for the piping and turbines. In the mid-Fifties two small companies, Magma Power and Thermal Power, teamed up to prospect and drill on leases they had acquired in The Geysers area. New stainless steel alloys solved the corrosion problems, and in 1960 Pacific Gas and Electric (PG&E) went on-line with a 11 MW power plant powered by steam purchased from Magma-Thermal. The steam is fed directly to the turbines from the wells after filtering. Today PG&E generates 396 MW from The Geysers field, the capacity of an average nuclear power plant, from 100 wells, some over 8,000 feet deep. By 1977 15 turbines are planned to be in operation, generating 908 MW of electricity.

### Liquid-dominated Systems

Even though dry-steam fields present minimal problems in development and production, expansion is limited by their scarcity. The majority of the fields to be developed in the future will be of the liquid-dominated type, either hot-water types or steam-water mixture types. The most spectacular example of a liquid-dominated field that will probably never see commercial development is Yellowstone National Park. Power production is complicated in liquid-dominated fields by the high concentrations of minerals and salts dissolved in the water. The geothermal water of the Imperial Valley, California, a typical liquid-dominated field, is greater than 2 percent dissolved minerals. The solids are precipitated and deposited on piping and turbine blades whenever the pressure on the water drops and more of it flashes into steam (Kiefer, 1974 and Gould, 1974).

### Geopressurized Sedimentary Basins

Drillers exploring for oil and gas in the northern Gulf Coast area have discovered vast geopressurized reservoirs of hot water and natural gas. Heat is trapped in the water in highly porous sands beneath an impermeable clay layer that acts as an insulator. Pressures and temperatures are extremely high. Additional energy is available from the basins in the form of mechanical energy derived from the pressure and, also, from burning the natural gas. Developmental experience at the present consists of only two wells. Very little is known about the size of the reservoirs and how long they could be expected to last under commercial development (Kiefer, 1974).

### Hot Dry Rock Formations

Larger areas of the western United States are underlain with geothermal regions that are dry. Because of the geology of the areas, no water has been able to filter from the surface down to the hot formations. Several organizations, principally the Energy Research and Development Administration (ERDA), have been working to develop a process whereby this heat could be extracted to generate electricity.

### Near-normal Thermal Gradients

To date no viable means for utilizing near-normal thermal gradients has been proposed. If near-normal environments could be utilized to generate electricity, the FEA estimates that they could provide up to 10 percent of the Eastern Seaboard's power.

## PROBLEMS OF IMPLEMENTATION

As with any radically new process the problems of implementation are as numerous as they are varied. The problems fall into roughly the following areas: technical, environmental, political, economical, sociological, and educational.

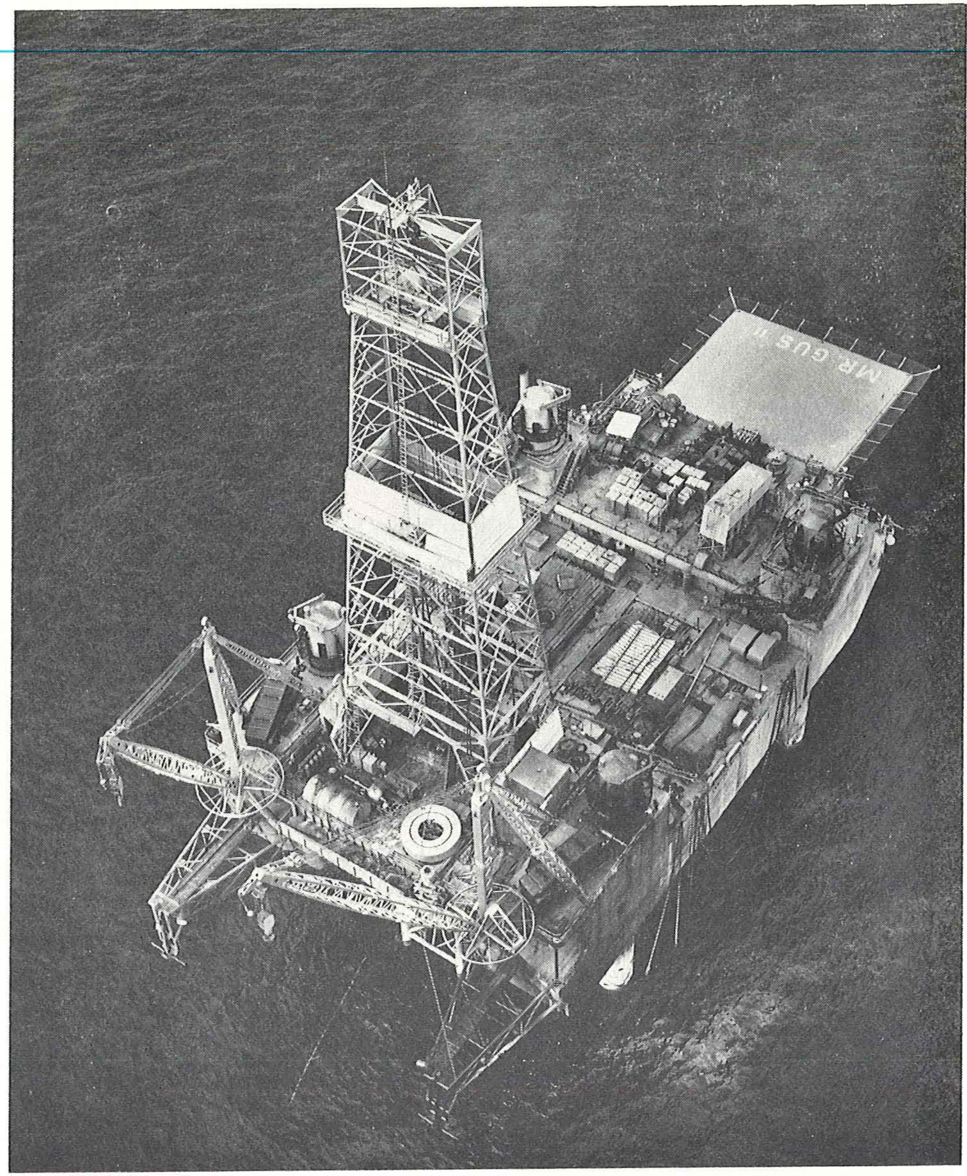
### Technical

Present geothermal fields are geologically unique occurrences that require a customized approach to development. Hardware and software to meet every application have yet to be developed.

Some areas of technology are unresolved due to gaps in the state of the art. In many instances solutions to problems already exist in petroleum, mining, or chemical technologies but have not yet been recognized as applicable to particular problems in the geothermal field.

### Environmental

The pollution of surface and ground waters by the disposal of toxic and saline




Mr. Gus II is one of the giant portable drilling rigs operating in the Gulf of Mexico in the search for new sources of petroleum.

*Cities Service Company*

*Fossilisation,* an outline on the processes of fossilization then available. During the same year, Wepfer published a monograph on the preservation of large labyrinthodont mastodonsaurs in the processes of fossilization then available. During the same year, Wepfer published a monograh on the preservation of large Red Sandstone of Germany. In this work, which contained many aspects of a true taphonomic study, Wepher ventured to attribute the accumulations of dense masses of mastodonsaurian remains in deltaic-lagoonal areas not to periodic mass mortality in place, but to transportation after death. Wepfer applied work on paleogeography and paleoclimatology.

Comparative analysis of preservation is not possible without first observing the present day processes of sedimentation and burial. A number of short papers describing the circumstances of recent deaths and burials have been published by biologists and paleontologists. In 1927 Weigelt, for example, dedicated an entire volume to the study of the transport and distribution of dense accumulations of recent vertebrate carcasses, attributable to causes other than mass mortality. He discussed the potential paleobiological significance of these observations, but failed to formulate a systematic rule for these processes. Richter in 1928 proposed the term *aktuopaläontologie,* removing paleobiology from the study of recent burials. Richter's new concept, however, lacked the comparative analysis of recent and ancient processes of burial so vital in paleoecology. During the years 1933 through 1939 Efremov published papers on burial of fossil land vertebrates and finally in 1940, he criticized the limited concept of actuopaleontology and introduced instead the broad new branch of paleontology which he named *taphonomy.*

Efremov discussed taphonomy in conjunction with sedimentation and the geological column as a whole, and suggested a parallel term, litholeimonomy, for the study of the preservation of lithofacies through space and time. The

sides Charles Darwin, was M. M. Tetyaev who in 1939 emphasized the destructive aspect of the geological processes in his book *General Geotectonics,* a book now extremely rare and undeservingly forgotten. Following Tetyaev's thought, Efremov discussed the destructive events in the history of the earth and the principles of conservation of different sediments during the course of geological time. He grouped facies (phases) on the basis of their ability to withstand destruction through time into two groups: the *ultrafacies,* which are preserved in the geological record, and the *infrafacies,* which have perished from the geological record. Inasmuch as the organisms inhabiting the infrafacies (such as uplands, dry regions of nonsedimentation, in fact, most familiar terrestrial environments) may differ utterly from these preserved in the ultrafacies, the concept of infrafacies-ultrafacies would seem to have considerable significance.

## Future Developments

Taphonomy is still a very young discipline, and much work remains to be done until it "comes of age." We remain surprisingly ignorant of some very basic questions. For instance, vertebrate paleontologists need to know: how do animals die? what are the effects of predation and/or scavenging in terms of skeletal destruction? how long do decomposition and disintegration of carcasses take under various climatic regimes? how far can whole skeletons or isolated bones be transported? do isolated bones or teeth or skulls travel in the suspended load or the bed load of a stream? can the environmental preferences of animals be inferred from the lithofacies in which they are preferentially preserved? are there lower size limits below which articulated materials are not normally preserved? Lists of similar fundamental problems could be drawn up by invertebrate paleontologists and paleobotanists. Until some of these basic questions are understood, we will be a long way from being able to explain the occurrence of fossil deposits. We hope that this review may help to devel-

geothermal waters must be prevented. One suggestion has been to reinject the water back into the formation, but the consequences of reinjection are almost unknown. New Zealand has had success with cooling ponds when ground reinjection is not possible.

The utilization of hot and dry rock formations requires the injection of large amounts of water into geologically active areas. There is a possibility that the water may trigger earthquakes along already active faults.

The extraction of large volumes of subsurface waters may, over long periods of time, cause differential subsidence of land surfaces. Differential subsidence is irreversible and can be damaging to gravity flow systems like irrigation and flood-control systems, sewer systems, and natural water sources. Structures such as railroad beds, airport runways, and foundation systems can also be seriously degraded. The petroleum industry has controlled subsidence by repressurization with water, but experience is lacking in dealing with geothermal areas.

### Political

Progress has been hindered by a government attempting to create and regulate a trouble-free industry without any existing experience in that industry. The government has moved exceedingly slowly in matters of regulation, taxation, and overall policy for the geothermal industry. For example, the Geothermal Steam Act was signed into law in December of 1970, but was not implemented until January 1, 1974, a delay of over 3 years.

Also slowing progress are questions concerning the legal status of geothermal resources as they relate to land use and property rights. For instance, is geothermal energy covered by water law or mineral law? The U.S. District Court for the Northern District of California in the case of the United States vs. Union Oil of California *et al* held that the geothermal resource is water and belongs to the owner of surface and/or water rights. The decision has been appealed by the loser, the United States, and if upheld would

eral states to realistically include geothermal resources.

### Economical

The economic questions in relation to the geothermal resource stem from unanswered technical problems and from an absence of an established industry cost history. The economic picture is further clouded by industry pressure from competing fuels and uncertainty about future prices.

### Sociological

Few laymen are aware of the nature of geothermal energy or the special aspects of its discovery and utilization. The ability of the geothermal industry to share land with established users such as agriculture and forestry must be emphasized. Geothermal plants in Italy and New Zealand demonstrate the possibilities for coexistence.

### Educational

Perhaps the most formidable obstacle hindering the large-scale development of the geothermal industry is the lack of trained scientists, engineers, landmen, administrators, and operating personnel. These specialists have obtained their expertise through experience and experimentation—no formal courses of study or textbooks exist in the field. Professional societies and universities are beginning to offer short courses and seminars to fill the void. The result is that trained personnel will be in tight supply for at least a decade.

## CONCLUSION

The Department of Interior has estimated that it should be possible to develop as much as 132,000 MW of geothermal generating capacity by 1985. The National Petroleum Council estimates that only 3500 MW is possible over the same time span. Within these two extremes geothermal energy could provide between 0.5 and 20 percent of our electrical power within a decade.

Long-term restructuring of the energy sector of the United States natural resource system is needed. The value of blocks should preclude usage in boilers and internal combustion engines. The need is to rely on an energy source that does not have high industrial application such as solar, nuclear, wind, wave, or geothermal.

Geothermal energy has many problems facing it, yet it also has been proved a cost-effective energy source. Over the long term geothermal energy should be established as an important source of power in many parts of the world.

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# *Geotravels*

## *By The Geologic Observer*

*all upper-crust here.*—
Thomas Chandler Haliburton:
*Sam Slick in England*

### *Glacier Bay National Monument*

Both the St. Elias and the Fairweather Ranges send glaciers down to the fjords of Glacier Bay, the largest unit in the National Park system. Its 2,803,840 acres—stretching southward from the Canadian border—are, however, not accessible except by boat or plane; a local boat provides sightseeing service. The 20 very large and other smaller glaciers

and huge icebergs float in the bay. Large pieces of ice break from Margerie Glacier, and ice cliffs 100-200 feet tall can be seen on most of the tidewater glaciers. The changing climates of the past, as well as predictions as to the future climate, are seriously studied here. Curiously, most of the glaciers are receding, but some (especially Grand Pacific Gla-

Now that the term paleoecology has become firmly embedded in American geological literature, its roots in Efremov's taphonomy are seldom recognized. Taphonomy has for many years been implied but seldom applied. In this respect, taphonomy is considered to be a synonym of paleoecology by many modern paleontologists, while others disregard it altogether or are unaware of it.

Taphonomy, however, is not equivalent to paleoecology, because by definition paleoecology is the "science of the relationship between ancient organisms and their environment." Paleoecology, in other words, records the physical and biological conditions existing during the life or at the time of death of an organism. Taphonomy, in contrast, fills in the gap between the conditions during life of an organism and the study of its remains in the laboratory, and so is concerned with such intervening processes as destruction before burial, burial itself, diagenetic processes affecting preservation, and tectonic, geomorphic, and climatic events affecting survival of remains to the present and the liklihood of their discovery. Taphonomy is concerned with the survival of the remains of living organisms through time and space. This is clearly not paleoecology, but it should be equally clear that ecological factors such as preferred habitat, mode of life, and manner of death of an animal have a great deal to do with its chances for preservation.

Perhaps part of the apparent conflict of taphonomy with paleoecology stems from the fact that while invertebrate paleontologists generally consider the geological factors as well as the biological factors in their studies, vertebrate paleontologists have at times ignored the geological data obtainable at a fossil locality. Thus, the former have been reluctant to embrace the concept of taphonomy, because it has been implicit in much of their work, while for the latter, it is by and large a novel approach; hence its formulation and current advocacy by vertebrate paleontologists such as Efremov and others. A further reason for its importance to ver-

trast to invertebrates, vertebrates are only rarely preserved in place, and unless this can be proved (e.g. lungfish in a burrow; animals in tar or quicksand), transport must be assumed, which renders paleoecological interpretation more difficult.

## From Darwin to Efremov

Darwin realized the incompleteness of the geological record and outlined some of the reasons for it. He noted that modes of burial in marine and continental deposits differed and that fossilization on uplifted land areas would be more difficult than in basins. Geologists and burial of the remains of organisms, introduced a special branch of paleontology and stratigraphy, *biostratonomy* (not biostratinomy as cited by Imbrie and Newell, 1964, p. 5; but see note in Lawrence, 1968, p. 1316), to deal with the analysis of the distribution of organic remains in rocks. As Muller (1951) indicated, biostratonomy is the science of embedding of an organism or any of its parts in the sediments, and is concerned with the fate of an individual from the onset of the death struggle to definitive burial. As such it includes all of the early events with which taphonomy deals, but exludes all of the later vicissitudes which, as well as the early events, act to determine to what extent a given ecosystem will be represented as fossils on the laboratory study bench (see Lawrence, 1968, fig. 1).

Hecker (1941, 1948a, b, c) applied his paleoecological research to the deciphering of past burial processes in marine sediments, by studying the marine Devonian of the Russian Platform, and the Paleogene of the Fergana Basin. His paleoecologic studies of Jurassic Lake Karatau, on the other hand, dealt with burial processes in continental sediments, thus acquainting him with another distinct environment.

## From Actuopaleontology to Taphonomy

In the early 1920's large scale investigations of fossil preservation began to appear more frequently. One of these

# What Is Taphonomy?

By George A. Rabchevsky

Although the concept of taphonomy is slowly gaining recognition, most western paleontologists remain unaware of its salient features. Taphonomy (from the Greek words *tapho,* burial, and *nomos,* law) is a term first used by I. A. Efremov, a member of the Academy of Sciences, U.S.S.R. In 1940 he published a paper entitled "Taphonomy—A New Branch of Paleontology" in *Izvestia of the Academy of Sciences, U.S.S.R.,* based on a brief account published in the *Pan American Geologist* under the same title. After a decade of applying taphonomy to his own field work, he elaborated his original ideas in a major work, "Taphonomy and the Geological Record", which appeared in 1950 in *Trudy of the Paleontological Institute, U.S.S.R.* The following brief account summarizes some of Efremov's views on the nature of this branch of paleontology.

## Taphonomy

Efremov emphasized from the very first that any analysis of fossil assemblages must utilize both the geological and the biological data available to the investigator. He believed that this is the only approach that will permit correct interpretation of the causes of preservation of fossils and explain their distribution in the geological column. By investigating the processes of preservation of fossils and the distribution of known fossil localities in time and space, he attempted to explain the occurrence of known fossil localities, and to predict the occurrence of others (or infer their previous existence if they have now been obliterated). Taphonomy thus relies on both modern biology and historical geology to provide a unique interpretation of the fossil record. Many earlier paleontologists have disregarded the physical setting of the preserved floras and faunas, and so have failed to docu- vertical changes in the biota cannot by itself provide a complete picture of the ancient life of a particular "ecological event" recorded in the rock. Therefore, Efremov advocated the study of fossil assemblages in conjunction with the associated lithologies, which at one time were soft sediments and part of the physical environment of the living animals. He also strongly emphasized that attention should be directed to the importance of the geological processes of degradation and destruction of fossil localities, processes to which little attention had been given.

In summary, Efremov's taphonomic studies are predicted on the following assumptions:

1) Organisms are biological indicators of environmental conditions

2) Sediments are physical indicators of environmental conditions

3) Remains of Recent and fossil organisms provide biological clues to the causes of their deaths and concentrations

4) The sedimentary matrix enclosing the fossils indicates the physical conditions at the time of their burial, but may not necessarily relate to the cause of their deaths

5) Horizontal and vertical distributions of fossils in the rock unit may provide evidence for both the biological and physical causes of their deaths and concentrations

The ultimate goals of Efremov's taphonomy, based on these premises, may be stated as follows:

1) Taphonomy attempts to explain the occurrence, in time and space, of known fossil localities

2) Taphonomy attempts to predict the discovery of other preserved fossil localities

3) Taphonomy attempts to establish the former existence of fossil localities in areas where the evidence for them has

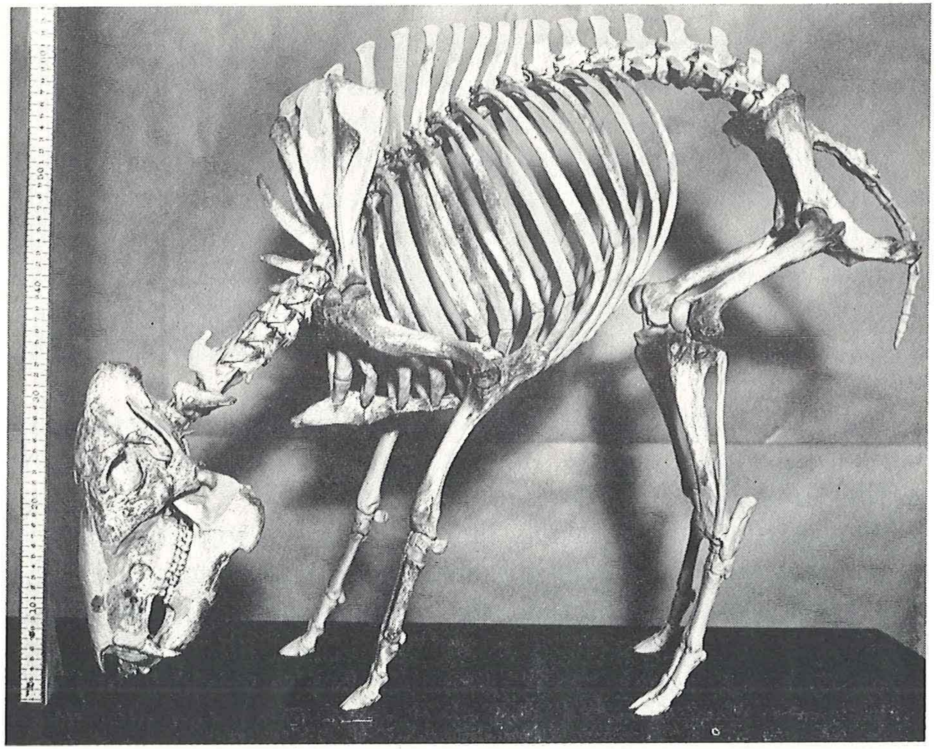
# Fossils in Rocks

By Richard M. Pearl

You will find fossils almost entirely in sedimentary rock. Igneous rock usually burns up fossil evidence. As a plant falls into loose sediment, it will be caught for the future to uncover. When an animal moves across sediment, it leaves tracks that will someday become fossils. Perhaps the dead animal is buried intact. Either tracks or actual remains are considered fossils.

Among the largest of all fossils are the bones of dinosaurs and the huge mammals that lived during the Tertiary Period of geologic time. Entire bodies of wooly mammoths have been recovered from frozen tundra in Siberia and Alaska.

Among the smallest fossils are the countless millions of



Skeleton of Ice-Age peccary

microscopic plants and animals found in certain rocks, such as limestone and shale. These are mostly one-celled forms, including foraminifers, conodonts, and ostrocodes, as well as others that are not often collected by beginners. They must be looked at under magnification. So must such things as tiny fish scales and some parts of higher animals.

In between in size are a host of animal and plant fossils—fish, shells, petrified wood, dinosaur footprints, shark teeth, and many more.

Teeth, shells, and bones are common fossils because they are durable. In fact, only the hard parts of organisms are usually preserved to become "the living record of the dead." Wood is usually the only part of plant life to be saved from decay on a large scale. Pollen and spores of ancient trees are also well-preserved, but these are extremely tiny.

Quick burial is necessary if fossils are to be preserved. Otherwise, decay will set in, and scavengers will destroy the original material. Most fossils are found in sand and mud that was deposited in shallow water, for this is where life is most abundant. The gently shifting sediment covers the evidence and protects it. When the sediment turns to rock, the fossils remain until erosion or man sets them free.

The burial of Pompeii by Mount Vesuvius in the year A.D. 79 is a good example of how fossils can be preserved by volcanic ash. The John Day Basin in Oregon has given up superb fossils of Tertiary mammals. Plants, fish, and even butterflies—more than half of the world's fossil butterflies—have been taken from ancient Lake Florissant, near Pikes Peak, Colorado, where a rain of volcanic ash filled the lake.

You are not apt to find fossils in sand dunes unless the wind has covered them quietly. Yet, dinosaur eggs were discovered in the Gobi Desert of Mongolia.

Most of the fossils of early man have come from the caves in which he lived and buried his dead. The dry air has protected the fossils. Actual mummies of cliff dwellers have been found in caves in the southwestern corner of the United States.

Probably the greatest fossil locality in the world is in Hancock Park, Los Angeles. Called the La Brea tar pits, they have yielded more than 1,000 skulls of the dreaded saber-toothed tiger and over 100,000 bones of various birds. These animals lived during the Ice Age. Some of them were trapped in the tar that they thought was water. Others were caught when they came to eat the helpless prey. Few escaped.

Thomas Jefferson found a claw of what he believed was a very large lion in a cave in Virginia. It has, however, been proved to belong to a ground sloth. This was a curious animal that was as bulky as an elephant and walked on top of its feet as they bent under him.

Fossils are usually thought of as petrified, but they need not be. Petrification occurs when mineral matter filters into the pores of plants or animals. It may then replace the organic matter. Because mineral matter is heavier than organic substances, and because it fills hollow spaces, the fossil becomes heavier. It also becomes harder, as a rule.

Petrified wood is the best known example of petrification. The wood is usually replaced by silica, but other chemicals can have the same effect. The mineral pyrite (fool's gold) often replaces shells, making bright specimens.

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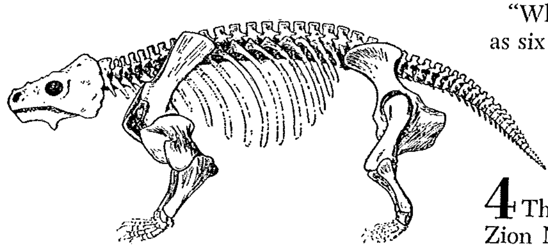
## *Six Impossible Things Before Breakfast*



"Why, sometimes I've believed as many as six impossible things before breakfast."

—Lewis Carroll: *Alice Through the Looking Glass.*

**1** The first reptile seems to have been the cotylosaur. The Texan *Seymouria* may be an example.

**2** The Black Rapids Glacier, in Alaska, moved 115 feet daily during the winter of 1936-1937.

**3** Sweet gas is natural gas free of hydrogen sulfide; sour gas contains a no-

**4** The Narrows of the Virgin River in Zion National Park, Utah, have a depth-to-width ration unmatched by any other major American canyon. The 2,000-foot-deep gorge is only 70 to 100 feet wide at river level.

**5** Trilobites and segmented worms seem to have had the same ancestor (Riccardo Levi-Setti: *Trilobites*).

**6** The highest point on Antarctica changes from time to time. It now seems to be the summit of Vinson Massif, 16,-