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FACTS ABOUT FOSSILS

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FOREWORD

Oregon is a rich storehouse of plant and animal fossils. A constantly growing interest in these forms of prehistoric life dates from the 1860's when Dr. Thomas C. Condon, Oregon's great pioneer geologist, then a missionary at The Dalles, first studied a fossil sea shell found in central Oregon.

In response to the demand for information from students and collectors, the Department has published articles on fossils from time to time in The Ore.-Bin. Because the supply of these articles is nearly exhausted, a collection of most of them has been assembled to make up Miscellaneous Paper No. 3.

Authors of the various articles are: Dr. J. E. Allen, formerly a geologist with the Department; Dr. E. L. Packard, formerly head, Department of Geology, Oregon State College; Mr. R. E. Stewart, geologist with the Department; Dr. Ralph W. Macy, professor of biology, Reed College; and Mr. W. F. Barbat, chief geologist, Standard Oil Company of California.

F. W. Libbey
Director
June 5, 1953

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What Are Fossils?*

Definition

Broadly speaking, a fossil is any evidence or record of past life, whether that evidence is direct or indirect. Any evidence, so long as one can tell something about the type and form of the life that once existed, can be considered a fossil. The word is derived from the Latin "fossa," a ditch, and literally means "something dug."

What are the different types of fossilization?

This record of past life may be in the form of original material of the plant or animal which has been preserved. Usually only the hard parts of animals are preserved; the flesh, skin, and even hair decompose rapidly, while the bones and teeth may last until they are buried and the decaying action of air and bacteria can no longer act upon them.

In rare cases the entire animal may be preserved. The more or less intact bodies of the wooly mammoth, an extinct elephant, are frequently found frozen in the perpetual ice of Siberia and Alaska. So well preserved are these carcasses that sled dogs have been known to feed upon them, and the hides and skeletons have been taken to museums and mounted for display. The mammoth became extinct many thousands of years ago, but he has been preserved in nature's cold storage.

The giant ground sloth, a great browsing animal who lived in the deserts of southwestern America many hundreds and perhaps thousands of years ago, has also been preserved in part, in this case by drying. Its dried-up skin and hair and portions of its mummified body have been discovered in caverns.

The more resistant teeth and bony structures of animals may be preserved in a fair state for millions of years, and the hard parts of now extinct shellfish are frequently found imbedded in the rocks. At Rancho la Brea (now Hancock Park in Los Angeles) a great pool of asphalt existed thousands of years ago. Water birds became entrapped upon its deceptive lakelike surface. Coyotes and wolves trying to feast upon the birds also became entangled. Mammoths bogged down upon its banks, and the saber-toothed tigers feeding upon their slowly sinking carcasses were also caught. All were engulfed in the tar and their bones were preserved. This pit is now one of the most prolific sources of vertebrate fossils known.

Wood that is buried under sediments gradually gives up its gases and liquids due to the pressure of the overlying rock, and is turned to more or less pure carbon. This is called preservation by carbonization. The best example of this is coal, consisting as it does of plant remains that have been carbonized to a greater or less degree. Anthracite coal and even graphite result when this squeezing process is aided by heat. The changes may go to such limits that little but carbon remains of the original material. The bituminous and lignite coals (the coal of the Oregon Coos Bay region is a subbituminous grade) result from a less complete elimination of the volatile materials. The woody structures and leaves are better recognized in these types.

The original material of fossils is frequently replaced or petrified in such a way as to preserve beautifully the most delicate structures. Water percolating through the sediment dissolves out the original material, molecule by molecule, at the same time replacing it with the chemicals in the water, so that even microscopic structures may be preserved in the new material. Lime, silica, iron oxides, or iron sulfide, or even silver, may be the replacing material. In the case of replacement by silica, the raw material may be in the form of opal; opalized wood is frequently found in Eastern Oregon and whole petrified trees

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*Extract from Chapter 1, Bulletin 18, pages 2-4, by John Eliot Allen, 1939.

are common in the basalts of Washington. Bones and shells, as well as wood, are occasionally replased, and the resulting material is not only as hard as rock, but actually is rock. Calcification (replacement by lime) usually occurs when there is limestone near, and the red iron oxide (rust) also acts as a replacing agent where much iron is present in the surrounding rocks or in solution.

Frequently the only record we have of a fossil consists of its imprint in the rock, the fossil itself having been dissolved by the ground waters or having rotted completely away. In the case of bones and shells, the hollow remaining is called a mold; in the case of flat fossils such as leaves, an impression. If the sediment in which the fossil was buried is fine-textured, the details of the mold can be sufficiently clear for accurate identification. The hollow mold may be filled in by the chemicals carried by the ground waters and form what is called a cast. A cast has the same outward appearance as the original fossil, but does not preserve the internal structures as does petrification.

Where are fossils found?

Fossils are most frequently found in marine sediments. This is due in part to the greater abundance of sea-living animals; the necessity for burial in order to be preserved as a fossil; and the predominance of sea-deposited sediments. The rivers are constantly bringing sand and silt and organic material into the sea, and the teeming life there is constantly dying and falling to the bottom to be covered up and preserved as the sediment hardens to shale, sandstone, or limestone. Members of the clam and snail groups are found buried in the rocks over a large portion of the earth. Corals, sand dollars, shark's teeth, and even hard parts of sponges are not uncommonly found, but remains of the soft jelly fish, sea cucumber, and sea anemone are very rarely preserved, and then only as imprints. Fossils appear less frequently in sediments laid down by rivers or in lakes than in ocean sediments, and are still more rarely found in sediments such as volcanic ash or sand dunes laid down on dry land. Tree leaves are sometimes found in ash, but probably only when the ash and leaves fell into small lakes and pools of water. Trees covered over with molten lava flows are frequently replaced by silica. If the wood is partially or wholly burned by the heat of the lava, a mold may be left in the solidified rock to show where the tree once lay. In numerous cases trees have been surrounded by lava and have remained upright in their original position.

Why are fossils valuable?

It would be impossible to trace the development of plant and animal types through the ages if it were not for the remains of past life on the earth. The fossils in different layers of rock in the crust of the earth can be compared and a story can be constructed, incomplete to be sure, of the growth and changes which took place in the life forms during the passage of millions of years in the history of the earth.

Although fossils do not tell their age in actual terms of years, they do tell their age in relation to other fossils; so that by their use, the paleontologist has built up the geologic calendar of the events of the past.

The groups of animals that used to live together in any one place and time can be reconstructed, and will even tell (by comparison with present-day types) the sort of climate in which they lived. It would be impossible to explain how the horse came to run on its middle toe (hoof) or how the elephant developed its trunk if it were not for the study of primitive fossil types. Fossils, therefore, give us a key to the origin of the forms we see today.

Fossils also have their uses in economic fields. Oil geologist now almost universally use microscopic fossils (especially Foraminifera) to determine the relationships between the rock formations cut in drill holes and to correlate oil-bearing rocks from place to place.

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Why Study Fossils?*

By

Dr. E. L. Packard

Pleistocene man was a student of both minerals and fossils. He early recognized the superior qualities of flint for the manufacture of his sharp-edged tools and he brought fossil specimens into his caverns.

Twenty thousand years later the Greek philosophers were puzzling over strangely marked stones which had some resemblance to the shelled life of the sea. Even Aristotle did not understand them. He seemed to have believed that fossil fish lived motionless in the rocks. Some of his contemporaries and followers expressed their wierd conceptions of the origin of fossils. For some fifteen centuries no one made a careful study of fossils, and all adhered to the ancient idea that fossils were formed by some plastic force of nature; represented some strange manifestation of the influence of the stars; were the unsuccessful attempts of the Creator to populate the earth; or that they were due to some other equally fantastic action. Finally men began to examine fossils more critically and realized that they represented animals and plants that once had lived on earth. Their study, however, was restricted to the mere description, for no scheme had been devised that would tell when they were living or the order of their appearance on earth.

As early as 1719 writers were showing the evidence for their belief in an orderly arrangement of the rocks of the earth's crust, and the idea of a succession of beds or "formations" was formulated. Among such writers was Linnaeus (1768) and Justi (1771). They introduced the time element, for they recognized that the bottom-most bed in a geologic section was the oldest in the series. Werner emphasized this time conception and taught the necessity of precise description of the mineralogical characters of each "formation." William Smith advanced a step further by proving that the fossil content of a stratum would servo as a valuable aid for the identification of a given bed or formation. This made it possible to correlate fossiliferous beds outcropping at distant places. Thus fossils became a tool for correlation in the hands of that founder of stratigraphy, and geologic mapping of contemporaneous strata became possible. All stratigraphic geology is founded on these principles of superposition of strata and the contemporancity of identical or closely similar faunas and floras.

Still another step was necessary before the study of fossils could be made to reveal the history of life. Cuvier described the fossils of a given formation, and recognized that those from one bed differed from those in a bed above. He attributed the difference to world catastrophes, as the Deluge, and a subsequent recreation of the life as represented by the fossils in overlying beds. Lyell in 1832 objected to such an interpretation but it remained for Charles Darwin to explain clearly such faunal differences on the basis of organic evolution.

Fossils then acquired an added interest. The biologists sought among fossil specimens the evidences of primitive ancestors of living types; and their colleagues, the paleontolegists, discovered remarkable evolutionary sequences, such as the horse series, and described unimagined animals of past ages. The whole vista of life, thus was extended back for hundreds of millions of years, and the outline of the history of life became clearer.

Since the study of fossils was of interest to both the stratigrapher and the biologist, an extensive literature has been developed. Fossils found in innumerable localities have been named, described, and their geologic ranges accurately determined. This body of information so necessary to the identification and correlation of strata has become, in the hands of the trained geologists, an invaluable tool for all geologic work involving sedimentary rocks.

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* Reprinted from The Ore.-Bin, vol. 7, no. 8, pp. 47-48, August 1945.

The economic importance of the study of fossils was first recognized some thirty or forty years ago when active exploration for oil began in this country. It was evident that the petroleum geologist must know sequences of strata through which the bit was passing. To do this he relied in part on the fossils which were brought up by the driller and which matched those in the sequences he had established from nearby surface exposures. Thus the correct identification of the index or key fossils from each horizon was of great importance. Trained paleontologists were therefore employed to build up faunal successions and to identify each fossiliferous horizon passed through by the drill.

This demand for closer correlations led to more extensive collecting, accurate determination, and the publication of faunas by federal, state, or institutional agencies. Universities and colleges were called upon to train paleontologists, who readily found employment with producing oil companies. Such studies led ultimately to an investigation of the long neglected group of minute fossils known as Foraminifera, whose calcareous shells, though abundant, had never been adequately studied. By the twenties, the importance of microfossils was recognized. Hundreds or thousands of specimens might occur in a cubic inch of rock taken from a well core. Micropaleontology laboratories were soon established in educational institutions and by the leading oil companies. Other groups of minute fossils were discovered. Consequently the microscope has become a necessity in the laboratories of the oil companies.

The study of fossils, as we have seen, has through thousands of years, given man glimpses of the life of the past; furnished proof of the fact of organic evolution; given an outline of the history of life on earth through some 1800 millions of years, and unexpectedly developed into a tool in the hands of stratigraphic and economic geologists which permits precise identification of strata often containing a wealth of oil or other geologic resources.

The future of paleontology lies in the further development of that "pure" science, its future contributions to a number of biological sciences, and the further expansion of these practical aids to the economic and industrial life of the country.

How can we contribute to the advancement of "pure" and applied paleontology of this State?

1. By intensive systematic collecting, at all known fossiliferous horizons of the State.

2. By the establishment of adequately equipped and staffed laboratories at Oregon State College, the University of Oregon, and the State Department of Geology and Mineral Industries.

3. By the study, identification, and publication of paleontologic data in such a form that it may be easily available to the general public as well as specialists.

4. By the building up within the State a complete collection of carefully labeled fossils, and by so organizing the collection that it may be available to qualified persons for the identification or further studies of the ancient animal and plant life in Oregon.

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Fossils Will Tell*

By

R. E. Stewart

The earth story

Two thousand million years is a long time in anybody's language; even in that of a geologist.

Yet our earth is believed to be at least 2,000,000,000 years old, perhaps 2,050,000,000, perhaps much older.

During that time the earth's crust has been repeatedly bent, broken, and contorted --- raised high into the air --- plunged deep under the sea --- shaken by great earthquakes and volcanic eruptions --- buried under continental ice sheets --- parched and baked by the desert sun --- lashed by angry seas and stormwinds --- caressed by cool temperate breezes and by gentle zephyrs of the tropics.

And all the while, over most of the land surface, and especially upon the bottoms of lakes, seas, and oceans, beds of conglomerate, gravel, sand, clay, lime, mud, and deep-sea ooze have been piled one upon another; and in them, as upon the pages of a great book, has been recorded for those who will take the trouble to learn to read it, the story of the ages.

Plants and animals in great abundance and variety populated the globe throughout most of recorded geologic time even as they do today; lived, died, and were buried in the sediments that went to form the rocks in which we now find their fossil remains. Occasionally fossils are also found in igneous rocks. All animals and plants of the present are descendants of this long "Parade of the Living"[1] and consequently the rocks of the earth, together with the land, water, and air of the present day, constitute a veritable museum and laboratory of natural science and hold the most complete known record of the development of life upon our planet.

Nature has divided her story into eras, periods, epochs, and lesser units, even as our authors divide theirs into chapters, paragraphs, sentences, and phrases. Her divisions constitute the divisions of geologic time. Each raising or lowering of the land or sea, each change or shift of climate, each period of volcanic activity, when occurring on so grand a scale as the earth has witnessed many times during its history, interrupts or alters the development and distribution of life forms and the deposition of the rock material in which their remains are buried and preserved. When the land is covered by comparatively quiet waters it is built up by the addition or deposition of rock material which is continually being carried into the water by streams and the wind. When it is raised above the water and exposed to winds and storms, waves, running water, and various other forces of nature, much of the deposition ceases, erosion or wearing down of the land begins, and the continuity of sedimentation and of the record of life is broken, although partial records may be preserved in deposits formed over restricted areas by lakes, streams,

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[1] Bradley, John Hodgdon, Jr., Parade of the Living, Coward-McCann, Inc., New York, 1930. A nontechnical "story of the geologic history of life on earth."

* Reprinted from The Ore.-Bin, vol. 7, no. 12, pp. 73-79, December 1945.

vulcanism, wind, and other agencies. The widespread deposits which have accumulated during times of general land submergence carry the story of the main chapters of geologic history, while breaks in the sequence of deposition caused by intervening periods of widespread emergence and erosion serve to separate these chapters one from another.

The following table shows the major divisions of geologic time during which the known sedimentary rocks of the earth were deposited, together with the approximate number of years that are believed to have elapsed since the beginning of each division.

Eras	Periods	Epochs	Approximate elapsed time in years
Cenozoic (Recent life)	Quaternary	Holocene or Recent	25,000
		Pleistocene (Glacial)	1,000,000
	Tertiary	Pliocene	15,000,000
		Miocene	35,000,000
		Oligocene	50,000,000
		Eocene	70,000,000
Mesozoic (Mediaeval life)	Cretaceous		120,000,000
	Jurassic		150,000,000
	Triassic		190,000,000
Paleozoic (Ancient life)	Permian		220,000,000
	Pennsylvanian		254,000,000
	Mississippian		280,000,000
	Devonian		320,000,000
	Silurian		350,000,000
	Ordovician		400,000,000
	Cambrian		500,000,000
Proterozoic (Earlier life)			
Archeozoic (Primeval life)			
Eozoic (Dawn life)		At least	1,750,000,000
Unrecorded interval of earth history Origin of the earth		At least	2,000,000,000

The specialist and fossils

Our good fossil record begins with the Cambrian, but the animals of that period were so highly developed that the existence of animal life upon the earth before that time appears to be a certainty, and objects believed to be fossils have been reported from as far back as the Archeozoic. Fossil shells and shell-like animal remains may be collected from all of the post-Proterozoic sedimentary rock series, which have a reported[2] maximum known thickness of 306,700 feet, or approximately 58 miles.

To the geologist and biologist falls a major portion of the task of reading and interpreting this record of the earth's history.

The scope of geology has become so broad and its applications so varied that every geologist must, almost of necessity, become a specialist along some line before he has been long out of college. Some will go into teaching; some into industrial work; others will join various governmental surveys;and still others will make expeditions to distant, little-known regions of the earth - all in the interest of geology and its application to the knowledge, wealth, and welfare of mankind.

Among all of these will be specialists galore. There will be economic geologists, mining geologists, mineralogists, petrologists, petroleum geologists, field geologists, subsurface geologists, engineering geologists, military geologists, geophysicists, geochemists, oceanographers, volcanologists, historical geologists, structural geologists, stratigraphers, paleontologists, and many others.

The work of some of these has a more obvious and immediate practical application than that of others, but the work of each is actually very closely tied in with and very important to that of all the rest. The contribution of the "pure" scientist, that frequently scorned and often unheralded Daniel Boone of science who probes the distant frontiers and horizons of theoretical possibility, is, in the long run, probably most important of all.

It would be difficult to pick from the various fields of geology any one that is more fundamental, more indispensable than any of the others. In all probability, however, stratigraphy and structural geology would be placed at or near the top of the list by any experienced geologist.

Stratigraphy is the study of rock strata, the conditions of their deposition, their composition, character, distribution, geologic sequence and relative age. It deals largely, although not entirely, with those features and characteristics which date back to the time of deposition.

Structural geology deals with the attitudes of rock strata, with those features and relationships which have developed for the most part since deposition as a result of folding, breaking, and faulting. Folding and faulting may result in the accumulation of oil, gas, and water, and in exposing or bringing to within workable distances of the surface all manner of ores and other mineral resources. Breaking and faulting form zones favorable for subsequent mineralization. From both economic and a purely scientific standpoint, therefore, it is very important to map the stratigraphic and structural geology of areas which may have mineral possibilities and to map it carefully and well.

One of the most important tools in stratigraphic and structural geology, and therefore, in geologic mapping, is paleontology, the science of the life of past geologic time.

The Ore.-Bin[3] recently carried an excellent review of man's interest in fossils from the time of his earliest fantastic misconceptions of their true origin, nature and significance to that of his final realization that they represent animals and plants that

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[2] Wilmarth, M. Grace, The geologic time classification of the U.S. Geological Survey compared with other classifications: U.S. Geol. Survey Bull. 769, pp. 6-7, 1925.

[3] Packard, E. L., "Why Study Fossils?": The Ore.-Bin, vol. 7, no. 8, pp. 47-48, August 1945.

once lived upon the earth, his knowledge of their significance in the chronology of life development and earth history, and his application of this knowledge to practical problems in biology and geology. In summary the author states that:

> "The study of fossils. . . .has through thousands of years, given man glimpses of the life of the past; furnished proof of the fact of organic evolution; given an outline of the history of life on earth through some 1800 millions of years, and unexpectedly developed into a tool in the hands of stratigraphic and economic geologists which permits precise identification of strata often containing a wealth of oil or other geologic resources."

Fossils constitute the chief evidence in problems of correlation and are among the best indicators of geologic age.

Geologic age and time

Strictly speaking, the geologic age of rocks should probably be considered in terms of the number of years that have elapsed since their deposition. Actually, however, geologists usually think of geologic age in terms of stratigraphic position and date the age of strata more with regard to their place in the record of a series of geologic events than to any consideration of actual elapsed time in years. For example, the Coaledo formation is said to be "upper Eocene" in age, not "55,000,000 years old," and the Astoria formation is similarly dated as "middle Miocene."

Rocks exposed in separated localities are said to correlate if they are of equivalent geologic age. The geologist's work in correlating them consists in determining this age equivalence. Correlation may, therefore, be defined as the determination of equivalence in geologic age and stratigraphic position of stratigraphic units in separated areas.

As we have already seen, the time during which the fossiliferous rocks of the earth were deposited is measured, not in just thousands, tens of thousands or even hundreds of thousands of years, but in hundreds of millions and perhaps in billions of years. During that time earth's first and simplest living things made their appearance, and from them through the processes of organic evolution have developed the whole past and present plant and animal kingdoms of our planet.

Effects of environment

The changes involved in these evolutionary processes were made largely in response to changes in the environments in which the organisms were privileged or forced to live, as, for instance, changes in temperature, humidity, light, food supply, enemies, relative elevations of land and sea, and, in the case of water-living forms, such additional factors as depth, salinity, and turbulence of the water.

In general these environmental changes took place gradually and at rates which permitted most of the plants and animals either to adapt themselves to the new conditions or migrate to areas where their normal environment still prevailed. Sometimes, however, new conditions developed so rapidly that many species and groups in the areas so affected were unable either to survive or escape the changes, and consequently dropped out of the picture altogether. Unless their lines were perpetuated in other areas of favorable environment, the exit of these forms was final and they became extinct.

So long, however, as they persisted elsewhere without appreciable evolutionary change, they might reappear with recurrences of favorable environment. Such migratory reappearances usually threw them into different floral and faunal associations than before, thus giving rise to distinctive fossil assemblages which we now find even more valuable than index fossils in many problems of correlation.

It follows, therefore, that most sedimentary rocks contain fossils and fossil assemblages which differ from those in older and younger rocks but resemble those in rocks of equivalent age, and that consequently the geologic age and correlation of rock strata may be determined from the fossils they contain.

Not all rocks contain fossils, but in many cases the age of unfossiliferous rocks may be determined from their stratigraphic and structural relationships to fossil-bearing beds. In general they may be assumed to be older than overlying beds and younger than underlying beds, although older beds may overlie younger as a result of overturn, faulting, or intrusion. Igneous rocks are younger than rocks through which they have passed in working their way toward the earth's surface.

Fossils also indicate the conditions of deposition of the rocks in which they occur. Since organic development was primarily a response to environment, the fossil remains of the plants and animals of the past reflect the conditions which brought them into being and thereby give authentic evidence of the conditions under which the sediments of their time were deposited.

The role of paleontology in oil exploration

Paleontology plays an important role in many branches of economic geology. A good example is its application to the discovery and production of petroleum.

The four primary requirements for an oil field are (1) a source, (2) a reservoir, (3) a trap, and (4) a discoverer.

The discoverer is usually an experienced operator with initiative, "know-how," ample finances, good equipment, experienced personnel, persistance, and courage. Occasionally a discovery is made by the fellow who comes in (frequently "on a shoestring") equipped with little except the courage to rush in and a desire to gamble (usually with other people's money) on something involving greater risk than the puppies and the ponies.

Experienced, legitimate operators nearly always, and other operators sometimes[4] base their exploratory drilling upon careful, detailed geological and, often, geophysical studies.

The problems that face a geologist upon going into a new area are legion, but, regardless of all others, if he is in search of petrolsum he will be constantly on the lookout for (1) organic shales which may have served as source beds for oil and gas; (2) permeable, porous beds which may serve as reservoir rocks; and (3) traps in which the oil and gas may be accumulated and held under high pressures.[5]

Organic shales commonly contain the remains of many minute plants and animals from which petroleum is believed to have been derived. Most of our west coast oil appears to have come from diatoms - plants so small that thousands of them may be found in less than a cubic inch of shale.

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[4] Meinzer, O. E., (in charge of Div. of Ground Water, U.S. Geol. Survey), "Introductory Note" to Ellis, A. J.,"The Divining Rod, A History of Water Witching,": U.S. Geol. Survey Water-Supply Paper 416, pp. 5-6, 1917. Considers and discredits the forked twig, or so-called divining rod, and other more complicated spurious instruments (frequently referred to as "witch sticks," "doodlebugs," etc.) used for locating water, oil, or other minerals.

[5] Illing, Vincent C., Role of Stratigraphy in Oil Discovery: Am. Assoc. Petrol. Geologists Bull., vol. 29, no. 7, pp. 872-884, July 1945. Treats the subject under three subtitles: (1) Stratigraphy and Source Rocks; (2) Stratigraphy and Reservoir Rocks; (3) Stratigraphy and Oil Preservation.

Reservoir rocks must be sufficiently porous to provide storage space for oil and gas, and sufficiently permeable to permit relatively free migration. They must also be accessible to oil and gas from the source beds, as by direct contact between the source and reservoir beds, or by movement of the oil and gas through intervening beds or along faults or other fractured zones.

Within areas of accumulation, however, there must be no avenue of escape from the reservoir beds if wells drilled into them are to be commercially productive. These areas constitute the traps and oil pools which are the final objective of the field geologist.

These traps may be either structural, stratigraphic, or both.[6] Their multiplicity of types is too great to fall within the scope of this paper, but they may be found both described and illustrated in almost any good textbook on petroleum geology.

Structural traps are due chiefly to folding and faulting; stratigraphic traps to pinching out of the reservoir beds or to variations of permeability within them. Structural traps are the ones most commonly reflected at the surface. In the search for stratigraphic traps and for structural traps that lack surface expression we are largely dependent upon subsurface geology and geophysics.

Faulting may literally make or break a trap; make it by sealing off the upper truncated ends of broken and tilted reservoir beds against rocks which are impervious to oil and gas, or break it by providing a fractured zone along which oil and gas may escape or water may enter the reservoir sands.

In nearly all cases the field geologist will need fossil evidence in connection with his stratigraphic and structural studies from the very beginning. He will want to be able to recognize and correlate all rock formations within his area. As the work progresses he will need to correlate more closely in order to detect faults and other structural irregularities which may have a bearing upon oil accumulation.

His first knowledge of possible source and reservoir rocks will be based upon surface evidence, but any hole drilled to test them for oil and gas will be so located as to penetrate them at depths of several hundred or several thousand feet. Consequently he will need to know the stratigraphic interval between the surface rocks at the drill site and the sand he wishes to test in order to be able to estimate the depth at which the sand should be encountered. This calls for detailed analysis of fossil ranges.

As soon as possible after going into the field, therefore, the experienced geologist familiarizes himself with the fossils of his area. Many require detailed study for which he has neither time nor facilities in the field, and consequently they are sent to laboratories especially staffed and equipped for such work. This is particularly true of the microfossils whose ranges are worked out in great detail from samples taken at close intervals throughout all exposed sections of the sedimentary rocks of the area.

During the drilling that follows these field and laboratory studies, paleontology work is continued in even greater detail than before. The problem shifts from surface to subsurface geology, and buried details of stratigraphy and structure that control the accumulation of oil and gas are worked out largely through the study of well cuttings and cores. Micropaleontology, the study of microscopic fossils, is one of the most important branches of subsurface geology.

Statistics[7] show that in California:

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[6] Wilhelm, O., Classification of Petroleum Reservoirs: Am. Assoc. Petrol. Geologists Bull., vol. 29, no. 11, pp. 1537-1580, November 1945. An excellent detailed study and classification of petroleum reservoirs.

[7] Moody, Graham B., Developments in California in 1944: Am. Assoc. Petrol. Geologists Bull., vol. 29, no. 6, p. 652, June 1945.

"Fourteen of the 32 (oil and gas) fields discovered during 1944 were located through subsurface studies. Another 4 discoveries resulted from a combination of subsurface and surface geology and 7 more discoveries from a combination of subsurface geology and geophysical work. Subsurface geology, therefore, played a major role in the discovery of new fields."

Fossil study, a universal aid

Petroleum geology is by no means the only field to which paleontology is extremely important. Any project involving field work and mapping in marine sedimentary rocks will of necessity draw heavily upon paleontology for some of its most critical data.

Fossils are closely tied in with every important relationship of sedimentary rocks, for they are scattered through all of the earth's sedimentary series and some of its igneous rocks as a part of the rocks themselves. They are coal. They are diatomite. They are building stone. They are the remains of organisms from which petroleum and natural gas have been formed. They constitute the chief evidence in problems of correlation and are among the best indicators of geologic age. They indicate the conditions under which the sediments of their time were deposited. They have lived during periods of earth history when horses had five toes, fishes wore coats of armor, and enormous beasts and reptiles roamed the lands and swam the seas.

What stories these fossils could tell if they could only talk!

Better let us say, what stories they could tell if we but understood their language, because to the person who has learned to understand them, fossils - no daisies they - will tell their secrets any day.

***

GEOLOGIC TIME CHART

ERA	PERIOD	EPOCH	OROGENIC EVENTS	DOMINANT LIFE: ANIMAL	DOMINANT LIFE: PLANT	DURATION (Figures are Millions)	BEGINNING YEARS AGO (Figures are Millions)
CENOZOIC	QUAT'Y	RECENT		Man		25000 Years	25000 Years
		PLEISTOCENE	Cascadian Revolution			1	1
	TERTIARY	PLIOCENE				11	12
		MIOCENE			Deciduous Trees	18	30
		OLIGOCENE		Mammals Birds		10	40
		EOCENE				15	55
		PALEOCENE				5	60
MESOZOIC	CRETACEOUS		Laramide Revolution			55	115
	JURASSIC		Nevadian Disturbance	Reptiles	Conifers Cycads Gingkos	40	155
	TRIASSIC		Palisade Disturbance			35	190
PALEOZOIC	PERMIAN		Appalachian Revolution		Scale Trees	30	220
	PENNSYLVAN'N (CARBONIFEROUS)			Amphibians	Cordaites Seed Ferns	30	250
	MISSISSIPIAN (CARBONIFEROUS)					30	280
	DEVONIAN		Acadian Disturbance	Beginning of Spiders and Insects Fishes	Ferns and Seed Ferns	40	320
	SILURIAN			Corals		30	350
	ORDOVICIAN		Taconian Disturbance	Higher Invertebrates		60	410
	CAMBRIAN			including Trilobites		80	490
PROTEROZOIC	KEWEENAWAN		Killarney Revolution				
	HURONIAN			Worms and other Soft-tissued Forms	Algae	1300	
CRYPTOZOIC EON (PRE-CAMBRIAN)	TIMISKAMIAN		Algonkian Revolution				
ARCHEOZOIC	KEEWATIN		Laurentian Revolution				Oldest known rocks 1800

TIME CURVE

Compiled by L.F. Hauperman

0 100 200 300 400 500 Million Years

SCALE of TIME

Fossils and the Course of Human Thought*

By
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Publication in 1859 of the Origin of Species by Charles Darwin was a milestone which has hardly been equaled for its profound effect on subsequent human thought. The idea that animals were not suddenly created in the advanced state in which we find them but were slowly evolved from lower forms was a radical departure from traditional thinking. As a result, many of the beliefs about the universe which had been taken for granted were subjected to thoughtful scrutiny. Nearly all writings of modern times definitely show in their outlook the influence of the changed attitude resulting from the discovery and practical establishment of the doctrine of organic evolution. Further, it may be claimed legitimately that evolution is the central problem of the field of biology, since all organisms and therefore all parts of organisms point to a common origin.

Included among the lines of evidence which show that evolution has undoubtedly occurred are comparative anatomy, comparative embryology, comparative parasitology, domestication of plants and animals, physiology, classification, geographical distribution, and paleontology. Of these, none has been more important than the study of fossils.

In times gone by people have pondered the meaning of fossilized remains. Some thought that they represented merely the victims of some flood of historical times. It is true that well-preserved fossils often belie their actual place in antiquity. Others felt that fossils were placed by the Creator to mislead the weak in spirit, or that they were the work of the devil. When in 1726 there was unearthed the fossil of a giant salamander, Professor Scheuchzer of Zurich pronounced it "the damaged skeleton of a poor sinner drowned in the Deluge." A century later the great French zoologist, Cuvier, showed its true nature. Cuvier himself, however, did not fully appreciate the significance of fossils as related to evolution. He explained the succession in fossil beds as follows:

> "If there be one thing certain in Geology it is that the surface of our globe has been subject of a great and sudden catastrophe of which the date cannot go back beyond five or six thousand years; that this catastrophe has overwhelmed the countries previously inhabited by men and by those species of animals with which we are today familiar; that it caused the bed of the previous marine area to dry up and thus to form the land areas now inhabited; that it is since this catastrophe that such few beings as escaped have spread and propagated their kind on the newly uncovered lands; that these countries laid bare by the last catastrophe had been inhabited previously by terrestrial animals if not by man and that therefore an earlier catastrophe had engulfed them beneath its waves. Moreover, to judge by the different orders of animals of which remains have been revealed, there were several of these marine irruptions."

Cuvier's theory of Catastrophism, as it is now called, suggested that repopulation after each catastrophe came from remnants which wandered in from unexplored lands. In this way he avoided a decision on the matter of special creation after each disaster and also disposed of the matter of the appearance of new kinds of animals in each strata. Later writers maintained the necessity of special creation after each catastrophe; one author decided there must have been twenty-seven such events!

Even though the great antiquity of fossils is now recognized and their meaning has been well investigated, there is yet much perplexity concerning individual cases. Breaks in deposition, and rising and sinking with changing habitats for living organisms will cause breaks in the fossil record. Tilting, shrinking, bending, folding, breaking and faulting may occur in fossil-bearing rocks; thus it is even possible to have older fossils above those of lesser age.

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*Reprinted from The Ore.-Bin, vol. 8, no. 3, pp. 19-23, March 1946.

Then the process of fossilization is the happy fate of relatively few individuals, and that mostly in favorabls localities. One reason why human fossils are so scant appears to be that primates thrive in more or less forested areas where sedimentary rooks are less likely to be formed, so that preservation is unlikely.

Of course, there have been those favored sites of coal beds, ancient resins known as amber, tar pools, and the frozen mud cliffs of Siberia. For obvious reasons preservation has been particularly good under conditions which prevailed in these places. An oooasional fossil shows with great fidelity the parts of the original owner. An ancient duck-billed dinosaur, Trachodon, in the upper Cretaceous of some 100,000,000 years ago died in soft mud so that its body form, even to the oharacter of the skin, is seen in satisfying detail.

If evolution is true, as we believe, then existing animals and plants are the present ends of long lines of slowly ohanging stooks, in most instances slowly diverging from central or common ancestry. If we consider only the species occurring in historical times we oan see the evidence of their relative stability and therefore oan readily imagine the vast extent of time required to produce the astonishing array of variety in plants and animals. Some million and a half speoies of animals and about a third of a million species of plants have been described and named, and this represents only a part of the number whioh exists. An examination of the Zoological Reoord will substantiate that in one group, the insects, thousands of undescribed species are found eaoh year.

But we have more than the mere twigs of the evolutionary tree. Already before us are the relatively complete fossil histories of some animals - for example that of the horse - and it would seem safe to predict that in the centuries of discovery to follow, the reoord will be far more complete, showing graphioally the course of evolution. Now we have enough clues to show us the probable origin of birds, of mammals, and of other forms.

When we examine skeletal material for details which will aid in understanding relationships between different kinds of organisms we reoognize at once that in major stooks, even in distantly related kinds of animals, one oan matoh parts bone for bone. Thus the bones in the wing of a bat oan be matched with the same kind of bones in the hand of man. Again, these are found to have their counterparts in the front appendagee of a whale. Parts whioh can be oompared in such a manner are said to be homologeus. It is evident that analagous structures suoh as wings of inseots and birds, sinoe they do not have the same fundamental origin and structure, obviously belong to animals which are unrelated. The value of the study of fossils is that we oan pieoe together the intermediate steps in the relationships of parts and therefore understand the relationships of their possessors. This is well illustrated in the oase of the horse and its anoestors.

The modern horse is a highly specialized animal; that is to say, various parts are highly modified to serve certain speoific purposes. Thus the skull is specialized through elongation, the molars are arranged for efficient grinding, and the incisors are fitted for cropping grass. The whole construction of the head region, then, is partioularly fitted for eating one type of food - grass. Grassy plains have little cover for hiding from enemies, and it appears that in the wild horse the ohief adaptation for escaping hungry carnivores was the ability to run rapidly, and this capability was achieved by limbs and joints molded to that end. An examination of the fossil horse stook shows the gradual change from an earlier more generalized (and therefore more primitive) condition to the present highly modified form.

The horse has only one digit in each foot; it is said literally to stand on its middle finger, the hoof being a modified nail. Leg bones are elongated and rotational movement is not possible. The latter has been sacrifioed to attain effioient back-and-forth motion for running. Splint bones on either side of the functional toes suggest former possession of additional functional digits at some time in the past. But speculation is not necessary here because the fossil record verifies the presence of additional digits in early horse ancestors.

The fossilized remains of Eohippus, forerunner of the horse, which lived some 60,000,000 years ago in western North America and elsewhere show that it was the size of a oat, that it had generalized teeth, and that there were four funstional toes on eaoh front foot and three such digits on the hind foot. The molars were short-crowned and without many ridges, which would indicate that these animals fed upon succulent vegetation rather than upon grass. The greater number of toes and the broader foot compared to size could well allow for existence near the margins of forests or swamps.

Examination of the fossil record reveals at least ten stages in horse evolution beginning with Eohippus. Since breaks in the sediments occur it appears likely that we will never have the complete record, but enough has been discovered to give us the unmistakable trend. By steps both feet lost toes, the hind foot always showing a greater reduction in this regard. Side toes successively became "dew claws" and then splints, the latter completely enclosed by skin. Without the fossilized remains we would be completely ignorant of all but the last step.

We have seen the trends in the horse line in which the changes were directional - the increasing complexity of the grinding surfaces of the molars and premolars, the increase in body size and length of legs, and the reduction in the number of digits. What could have brought about this directional change?

The most reasonable hypothesis states that these changes were parallel to those of the changing environment. Former lush forests and swamps gave way to firm grassland plains in which coarse grasses became the dominant basic food source. Given these changes, it was a matter of remodel or be eliminated. It is thought possible that from time to time variants appeared and these served as the basic material for natural selection. Variations not based upon mere changes in the somatic tissues would have to be ruled out since only mutations arising from modification of germinal tissue could be passed on through successive generations, a point demonstrated by modern genetics. Those mutants better able to eat coarse grass and those whose legs fitted them for greater speed were candidates for survival in a highly competitive world.

Now we may turn to the world of animals without backbones for another examination of the fossil record to see if here, too, there are similar trends from the more generalized plan of construction to the specialized condition. Indeed we are not disappointed, for in cases where the material is sufficient the same principle holds. The trilobites can serve as examples.

These aquatic animals which would have appeared much like large pill "bugs" were dominant forms of life at the beginning of the Cambrian, more than one-half billion years ago. At first they were generalized, then radiated into various types with differing habits. The more specialized groups developed long projections which very well may have been their undoing as the environment changed. One can well imagine that these parts increasingly hindered locomotion. In any event the more specialized forms disappeared first, followed by the entire trilobite line by the Permian period. Before we judge the trilobites too harshly for their failure to survive, we may note that as a group they were successful organisms for a period of more than 200,000,000 years, an interval two hundred times that of the existence of man as far as may now be determined. We know a great deal about trilobites: their diversity of species, some of their habits, success and failure as judged by survival, and yet no one has ever seen a living individual. Here the entire story comes to us from fossilized remains.

Turning to the record left by insects we again find a group which has persisted for a very long period - in fact some three or four hundred million years. They were already common in Carboniferous times. Shales of Kansas have yielded dragonflies with a wingspread equaling that of large birds, not to forget cockroaches nearly six inches long. One wonders about the mosquitoes of that time, if there were any! Baltic amber, ancient fossilized resin, has yielded ants perfectly preserved to the last little hair. Since various castes were preserved it may be inferred that some species of those ubiquitous insects had already gone social. Some species were primitive; others have remained unchanged to this day, a compliment to the stability of the gene. Not only ants but the fossils of many other groups of insects were preserved and many remain to be found.

Returning to our central theme of evolution, one of the most convincing types of evidence is that of the comparative study of wing veins of insects. Here we have a vast array of recent material in addition to the paleontological findings. On the basis of such comparative work Comstock and Needham of Cornell University, at the turn of the century brought forth a discovery which another great entomologist has termed the greatest single advance in the field of entomology. They arrived at a hypothetical primitive type of venation to which all wing veins can be related. However modified a given species may be, one can deduce how each vein in its wings is derived from a comparable vein of the primitive plan. This work has made possible a common and simple nomenclature of veins. Of special interest is the fact that fossils were used to substantiate the findings. In general the ancient insects had more primitive venation than those living today.

Thus far our discussion has dealt with animals other than man. Some people who are willing to accept at face value the fossil record of animals are much less willing to look squarely into the countenances of our own remote relatives of the past. Of course we are set apart, and we differ from other animals chiefly by virtue of brain development which has made it possible for us to literally change the face of the earth. Whether or not we want to call ourselves animals is just a matter of definition. A biologist, who learns comparative anatomy, comparative physiology, and other aspects of the field, has the animal relationship of man forced upon him by the sheer weight of evidence. Without question, the body is animallike. How we got that way has been partly revealed by fossil remains.

Earliest discoveries of Neanderthal remains came nearly a century ago and at that time there was general disagreement as to the meaning of the finds. Some thought they represented the victims of disease. One German scientist believed that a Neanderthal skull was that of a Russian soldier killed in the Napoleonic wars! It would be of interest to review the history of the discoveries of early human remains, but only a few of the findings can be mentioned. For recent details discussed in an authoritative but entertaining manner the reader would do well to consult William Howells' Mankind So Far.

Neanderthal Man lived somewhere between 50,000 and 100,000 years ago, was widely distributed over Europe and had a definite culture which fortunately included special burial. He differed sufficiently from ourselves to be considered a separate species. The brow ridges were beetling, the skull was carried far forward, and the posture was stooped in the extreme. There are numerous remains from many parts of Europe so that now we have a rather good picture of this formidable appearing type of person.

Pekin Man, the first traces of whom were unearthed near Pekin, China, in 1927, lived during mid-Pleistocene times, and was so different from modern man that he is considered to belong to a special genus, *Sinanthropus*, but the remains are very definitely human and not at all apelike. The brain capacity was much less than ours, the brow ridges were massive, the long bones were heavy since the marrow cavities were much smaller in proportion, and the teeth were distinctive. Parts of about forty individuals had been discovered by the beginning of World War II.

Java Ape Man, discovered by Dubois many years ago, probably dates back to the early Pleistocene of some half million years ago, and is more human than ape but is still more primitive than Pekin Man. Parts of several individuals have been recovered in recent years so that Dubois' early interpretations have been substantiated except for minor details.

These together with a good many other finds have given us the basis for believing that man like other animals has been subject to the evolutionary process. Actually this need cause no one any particular worry since it should appear just as suitable to have been created in this manner as by a sudden synthesis.

Having now made a brief survey of bits of the field of paleontology, or biological geology, we can see the great contributions which have been made to our knowledge of the past, and more important, how animals are related and what their trends of development have been. This information has formed some of the more convincing kinds of evidences for evolution. In turn it may be stated that no idea ever presented in modern times has had more influence on our way of thinking than has the doctrine of organic evolution. Therefore, a knowledge of fossils has actually been a strong factor in charting the course of human thought.

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The Fossils Called "Bugs"*

By

R. E. Stewart

In the parlance of the trade, microfossils are frequently referred to as "bugs," micropaleontology as "bug work," micropaleontologists as "bug men," and micropaleontological reports and publications as "bug reports" and "bug papers."

Perhaps microfossils came by the nickname, "bugs," as a result of their abundance, small size, and myriad variety of form, but one is led to suspect that the name was originally applied by someone seeking to avoid the use of long words which, in addition to involving a lot of verbiago, are inclined to fall into the category of "tongue twisters."

Paleontology, the study of fossils, is commonly divided into three specialized fields: (1) vertebrate paleontology, which deals with the fossil record of animals that had backbones, or spinal columns; (2) invertebrate paleontology, which deals with the record of animals that had no backbones, or spinal columns; and (3) paleobotany, the study of the fossil record of plants.

Micropaleontology is the study of fossils of microscopic size or structure from all three of these groups, vertebrates, invertebrates, and plants.

Among the vertebrate microfossils are:

- Fish scales
- Teeth from fishes and other small animals
- Otoliths and other microscopic bones or bonelike parts

Among the invertebrate microfossils are:

- Silicoflagellata
- Coccoliths and Rhabdoliths
- Foraminifera
- Radiolaria
- Sponge spicules
- Echinoid spines and skeletal parts
- Holothurian elements
- Annelid worm jaws (scolecodonts), plates, and tubes
- Conodonts
- Bryozoa
- Microbrachiopoda
- Micromollusca: pelecypoda, gastropoda, scaphopoda
- Microarthropoda: trilobita, archaeostraoa, branchiopoda, ostracoda

Among the plant microfossils are:

- Diatoms
- Algae
- Seeds
- Spores
- Pollen

After reading all of these names, it is not difficult to imagine someone with an aversion to profound vocabulary lumping them all together under the term "bugs" for short.

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*Reprinted from The Ore.-Bin, vol. 8, no. 10, pp. 69-74, October 1946, and vol. 8, no. 11, pp. 77-83, November 1946.

Vertebrate Microfossils

The vertebrate forms occur frequently in association with other microfossils, but to date most of them have received very little attention or study. Recent work on fish scales[1] has proved their value in correlation, and it seems probable that like attention to microscopic teeth and bones will likewise make them dependable indicators of geologic time and environment.

Scales, teeth, and various types of fish bones are no novelty to the average person, although few realize that they occur as microscopic fossils. For many people, however, "ear-stones" of fishes (otoliths) are something new under the sun. The following interesting historical sketch is quoted from a paper by R. B. Campbell.[2]

> "The micro-examination of Upper Cretaceous and Tertiary deposits frequently reveals small concretions of carbonate of lime not unlike seeds and which show definite sculpturing. These are easily recognized as 'fish otoliths' or 'ear-stones'. . . .
>
> "As is the case with many fossilized forms we find that Aristotle, Pliny, and other Greek and Roman scholars were familiar with the otoliths of fishes. They contented themselves with noting their occurrence. Characteristically during the Middle Ages these fossils were regarded with superstition and they were frequently borne as amulets. Some, called St. Peter's Stones because they bore the imprint of St. Peter's keys, were comparatively recently to be found in apothecary shops. In this connection they were used as a preventative and cure for colic and headache.
>
> "Even after these otoliths began to be studied by men of science strange ideas concerning them were entertained. It was even the opinion of some that these stones in the heads of fishes frequently brought about their death by attracting the cold in winter thereby causing their brains to freeze. Gradually more tenable explanations were offered and it was recognized that there was some connection with the hearing of fishes, the existence of which sense had hitherto been denied.
>
> "Klein (1740) showed the existence of otoliths in thirty fish and was of the opinion that these otoliths correspond to the little bones found in the ears of higher vertebrates (Hammer, Anvil, and Stirrup). This view . . . was adhered to down to Cuvier's time. Though Cuvier occupied himself but little with fish otoliths he ascertained that they have nothing to do with bones but consist of carbonate of lime. . . . He also regarded them as having excellent characteristics for the differentiation of species. . . ."

Otoliths were not "made use of in the science of paleontology or stratigraphy until in 1884 Professor Ernst Koken of Berlin published"[2] on otoliths from the Oligocene of north Germany and the Oligocene and Eocene of Mississippi and Alabama.

Since Koken the otoliths have not been given much attention by workers in the field of stratigraphy and "the literature has grown mainly with the work of Bassoli in Italy, Priem in France, and Schubert in Austria."[2]

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[1] David, Lore Rose, Use of Fossil Fish Scales in Micropaleontology, Carnegie Institution of Washington Pub. 551, pp. 25-43, pls. 1-6, figs. 1-9, July 18, 1944. Reprinted as Contribution No. 353, Balch Graduate School of the Geological Sciences, California Institute of Technology (Pasadena).

[2] Campbell, R. B., Fish Otoliths, Their Occurrence and Value as Stratigraphic Markers, Jour. Paleontology, vol. 3, no. 3, pp. 254-257, September 1929.

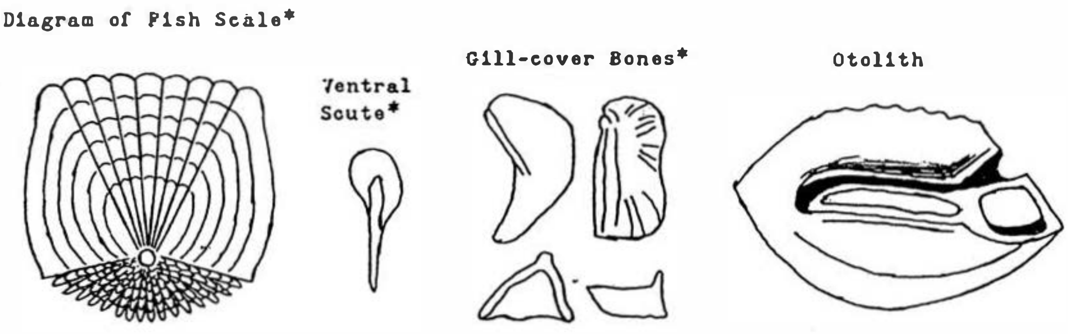

Fig. 1. Diagrams of Fish Microfossils

Single-celled Invertebrate Microfossils

The first five invertebrates listed belong to a major group or phylum of the animal kingdom called Protozoa. The Protozoa are unique among animals, in that all of them have one-celled bodies. All other animals are composed of many cells which are variously grouped to form specialized organs, such as those of sight, hearing, respiration, and digestion, and these cells differ one from another in accordance with the places they are to occupy and the purposes they are to serve in the functioning of the animal body. The living human body has been likened[3] to "an organization of 27 million million cells which live and work, die and disappear individually." 27,000,000,000,000 cells, that is! The protozoan is but 1.

The simple structure of the protozoan animal body stands in marked contrast to the myriad varieties of the tests or shell-like parts that are formed by most of those tiny creatures. In nearly all cases it is these hard parts that are found as fossils, and thousands of different forms (species) have been recorded - each having developed with the growth of a tiny single-celled protozoan.

Silicoflagellata

The following is quoted from a paper by Dr. G. D. Hanna.[4]

> "The Silicoflagellata form a small but exceedingly interesting order or class of protozoan animals. They have siliceous skeletons of unique structure and are known with certainty only from the upper Cretaceous to the present time. A few species are found living, widely distributed, near the surface of the sea, where they form a minor portion of the plankton.
>
> " ... the silicoflagellata as a group furnish most trustworthy horizon-markers ...
>
> "The features which make the silicoflagellates valuable as markers are: (1) they are usually common when they occur at all; (2) species are exceedingly limited as to number in any formation; (3) the species have a very short geological life; (4) being pelagic (free floating) in habitat they have a very wide geographic distribution; ....; (6) species are so distinct that they can be readily identified, and integration does not appear to have been noticed. In short these organisms are almost the paleontologist's ideal of marker-fossils."

Hanna points out, however, that those forms have not received the attention and study that they deserve.

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[3] Harvey, B.C.H., Simple Lessons in Human Anatomy, American Medical Association (1931), p.2.
[4] Hanna, G. Dallas, Silicoflagellata from the Cretaceous of California, Jour. Pal., Vol. 1, No. 4, pp. 259-260, Jan. 1928.
*David, L.R., op. cit., p. 28.

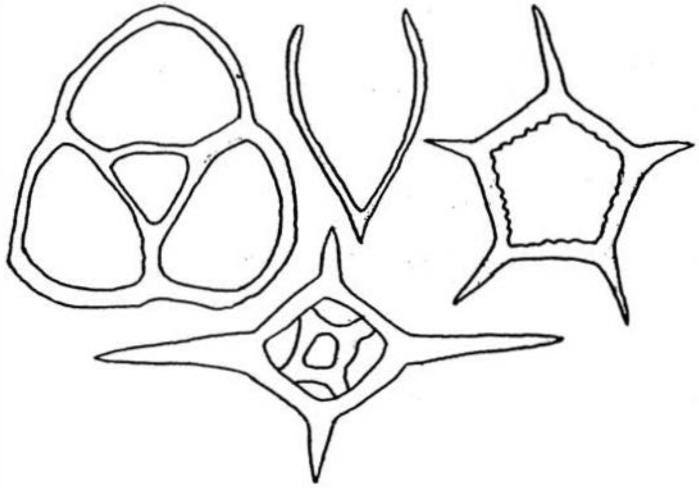

Fig. 2
Outline drawings of Silicoflagellata
Magnifications range from x375 to x650

Fig. 3
Coccoliths and Rhabdoliths
Magnifications about x1200

<u>Coccoliths and rhabdoliths</u>

There is a difference of opinion among investigators as to the true nature of small calcareous discs (coccoliths) and spicular bodies (rhabdoliths) which occur abundantly in modern marine-bottom deposits. Similar bodies have been recorded as fossils from rocks as old as the Cretaceous. Coccoliths and rhabdoliths are not visible under magnifications of much less than 700 diameters.

<u>Foraminifera</u>

Foraminifera are typically aquatic (water living) protozoans of microscopic size, although a few species are known to have attained sizes up to several inches in diameter. All except a few of the simplest forms secrete perforated protective and supporting skeletons called tests, and it is from this perforate or foraminate characteristic that the foraminifera get their name. Most tests are calcareous; a few completely siliceous. In many species the tests are composed of such foreign materials as sand grains, mica flakes, sponge spicules, or even other foraminiferal tests, more or less firmly cemented together by a secretion which may be calcareous, siliceous, ferruginous, or chitinous. One of the most primitive tests of all is composed solely of chitin.

Architecturally the tests may vary through a multitude of forms from a single simple chamber to a complicated, variously coiled multi-chambered structure. The following five plans or some modification of them are the characteristic arrangements for chambers in nearly all foraminiferal tests: single chambered, linear series, biserial series, plano-spiral coil, trochoid coil.

On the basis of ornamentation, also, there are thousands of easily recognized forms. Raised costae (ridges), knobs, spines, striations, and coarsely perforate areas form the most common types of ornamentation.

Numerous other variable details of the test structure such as details of the apertures, sutures, and general shape are used in distinguishing between genera and species of the foraminifera.

A few species live in fresh or brackish water, but the great majority are marine. About twenty-five species are pelagic and float at or near the surface of the ocean. Most species, however, are bottom dwellers, some being attached to plants, rocks, and other objects while others are free to crawl slowly about on the muds and oozes of the ocean bottom. In shallow waters today foraminifera are so abundant that the tests sometimes form obstructing shoals. The Globigerina oozes of the ocean depths are composed largely of foraminiferal tests. Thick limestones in Paleozoic and younger formations are composed largely of fossil foraminifera. The great pyramids of Egypt are constructed of such nummulitic limestones.

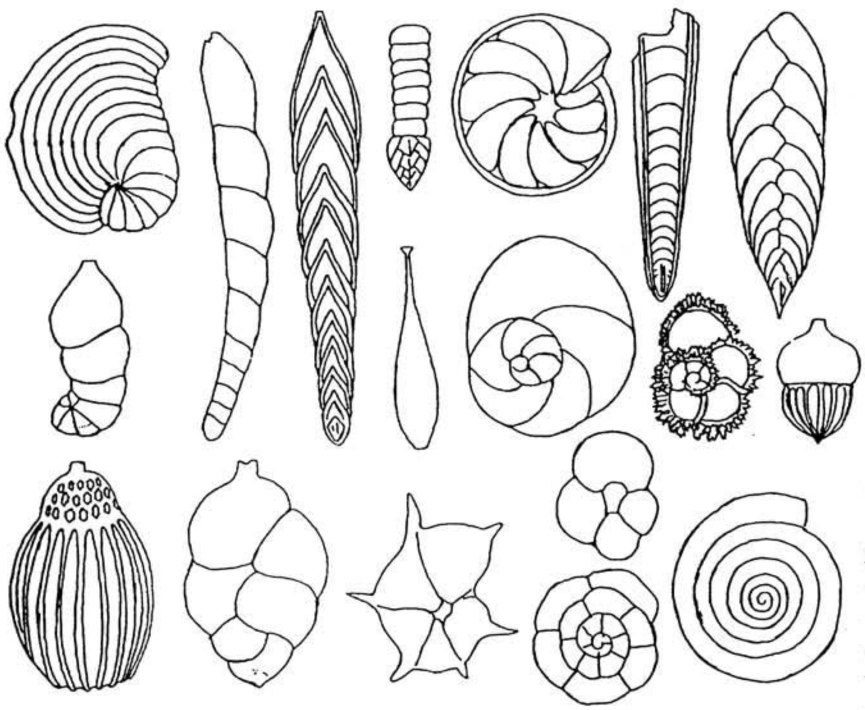

Fig. 4. Foraminifera. Magnifications range from x13 to x90.

Fossil foraminifera occur from the Cambrian to the Recent and are abundant in rocks younger than the Devonian. Species have definite geologic and geographic ranges, and when these are known in detail it becomes possible to determine the age of sediments and the conditions under which they were deposited.

The first discovery of foraminiferal tests was made by Janus Planous[5&6] in 1730 on the beach of Rimini, Italy, and in the following year Becarri[6] made the first discovery of fossil foraminifera in the Pliocene of Bologna. Since then many workers have studied this group, and a voluminous literature has been built up. Previous to about thirty year ago, however, these studies were pursued primarily on an academic or pure science basis, with little thought for any practical economic application which they might have.

During the past thirty years the petroleum industry has spent millions of dollars on research in micropaleontology and its application to the discovery and production of oil and gas, and as a result of this work the foraminifera have come to take first place among fossils used in stratigraphic and structural geology. In 1940[7] it was estimated that more than one million dollars was being spent each year on the operation of oil-company paleontological laboratories. The value of micropaleontology as a tool in geologic mapping and other requirements of academic and economic work has been so conclusively demonstrated by the results of this application to petroleum geology that many progressive colleges and universities, government geological surveys, and purely research organizations have incorporated it as one of their major projects, and others are reported planning to do so.

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[5] Planous, Janus (Giovanni Bianchi), Ariminensis de conchis minus notis Liber, cui accessit specimen Aestus reciproci Maris Superi ad littus portunque Arimini, pp. 1-88, pls. I-V, Venetiis, 1739.

[6] Zittel, Karl A. von, Textbook of Paleontology, Second Edition Revised, edited by Eastman, Charles R., vol. 1, p. 24, McMillan and Co., Ltd., London, 1927.

[7] Schenck, H. G., Applied Paleontology, Amer. Assoc. Petrol. Geol. Bull., vol. 24, no. 10, (October 1940), p. 1759.

Radiolaria

Last on our list of Protozoa are the radiolaria. These are minute single-celled animals which usually form exceedingly delicate siliceous skeletons that are typically spherical, discoidal, helmet-, cap-, or flask-shaped and variously ornamented with spines, bars, and lattice-work patterns.

Radiolaria are exclusively marine organisms and are found in vast numbers at all oceanic depths. As fossils they date back to the pre-Cambrian, and, according to Barrios,[8] they are the oldest of all known animal organisms, since they occur plentifully in the bituminous quartzites of Brittany, interbedded with pre-Cambrian gneiss. Although less frequently encountered in the fossil state than foraminifera, radiolaria have rather common occurrence and in some cases appear to have considerable value as guide fossils.

[8] Zittel, Karl A. von, op. cit., p. 43.

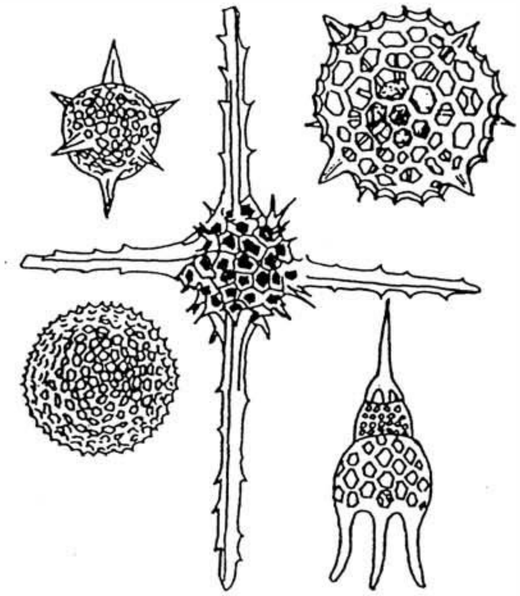


Fig. 5. Radiolaria. Magnifications about x6 (center fig.) to x250.

Many-celled Invertebrates

The remainder of the invertebrates listed on page 17 belong to various major groups or phyla of the animal kingdom, but all have one feature in common which distinguishes them from the Protozoa: the animal body in each case is multicellular (made up of many cells), whereas the protozoan is always a single-celled animal.

Sponges

The sponges comprise a group of multicellular, chiefly marine animals, the body form of which tends to be vaselike. Most modern sponges secrete skeletons of fibrous, horny material frequently reinforced by hollow siliceous or solid calcareous spicules of various shapes. In many of the older extinct species the spicules were thicker and united to form a solid trellis or framework. Sponges are sessile (attached) bottom dwellers. Calcareous sponges predominate in shallow coastal waters; many of the siliceous forms inhabit moderately deep to deep water. Due to their usual poor state of preservation and the difficulty of identifying them accurately, sponges are somewhat limited in value as index fossils.

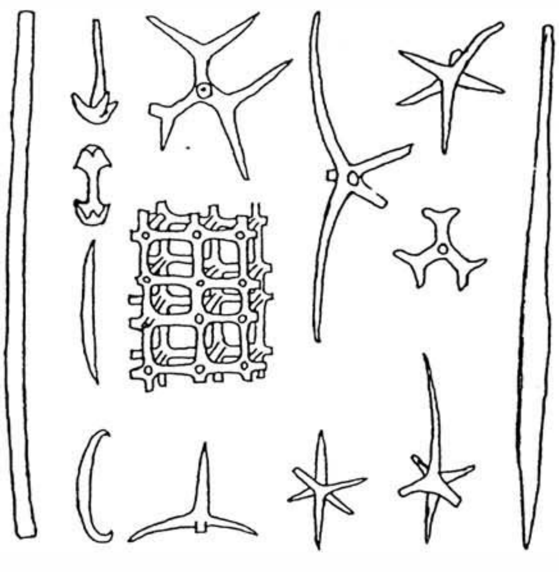


Fig. 6. Sponge spicules. Magnifications range from x12 to x36.

Corals

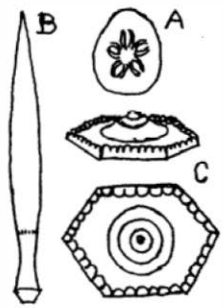
In the sense that magnification is frequently required in the study of their internal structure, corals should perhaps be included in any list of microfossils. However, since determinable minute individuals or parts are not commonly encountered or dealt with in microfossil studies, they are given only passing mention here.

Echinoderma

Similar mention should be given to the fact that crinoids (sea lilies) and several other groups belonging to the phylum Echinoderma (spiny-skinned animals) may eventually come to have important application in micropaleontology. Crinoid, echinoid and holothurian fragments have already received some attention. Whether any of the Echinoderma will become important microfossils in other than fragmental form remains to be seen. At present we know them primarily as megafossils.

Echinoids

Echinoids (sea urchins) are marine animals with hollow, subglobular to discoidal shells or tests composed of numerous thin, closely joined calcareous plates to which are attached superficial spines. A species with which most people are familiar is the "sand dollar" so commonly found on our present-day beaches. Unlike sponges, corals, and crinoids, which remain attached throughout their lives, echinoids are unattached and free to move about in and upon the sand, silt and mud of the ocean bottom. The depth range of living echinoids is from low water to nearly 18,000 feet.



Fossil echinoids range from Ordovician to Recent, but they are of importance as index fossils only since the Cretaceous. Only the plates, spines and a few separate skeletal parts are small enough to be classed as microfossils.

Fig. 7. A, Very small echinoid. Natural size. Most echinoids are much larger than this. B, Echinoid spine. Some are as large as this; many much smaller. C, Ambulacral plate from a large echinoid. Some plates are larger than this; many much smaller.

Holothurians

Croneis and McCormack[9] have given a good general description of holothurians, a portion of which is here quoted.

> "The holothurians (sea cucumbers) are stubby, worm- or cucumber-like creatures, varying in length from less than an inch to more than three feet. ... They constitute a fairly sharply defined group of marine invertebrates that is represented in modern seas by about 750 known species. They are especially abundant in tropical waters, but occur in temperate and polar seas as well; many of them form a part of the benthos, some indeed, being found as high as high water mark, but others have been dredged from depths as great as 2900 fathoms.
>
> " ... Their future potential importance to the paleontologist results chiefly from the fact that their body wall is generally beset with calcareous particles, which have been found (though heretofore quite generally unrecognized or disregarded) in strata of several geologic periods.
>
> "The calcareous bodies of the Holothuroidea are usually microscopic, but plates several millimeters across occur. Their shapes and sizes differ to such an extraordinary degree in the various genera and species that they constitute one of the fundamental bases for classification in the group. Indeed, the plates assume such unusual forms that we are convinced that many of them, although observed by the micropaleontologist, have been looked upon as indeterminate objects."

---

[9] Croneis, C. and McCormack, J., Fossil Holothurioidea, Jour. Pal., Vol. 6, No. 2, pp. 112-114, June 1932.

A number of the different calcareous parts are then noted, their names depending partly upon their locations and functions and partly upon their general shapes; military granules, supporting rods, rosettes, plates, tables, anchors, baskets, cups, wheels, hooks, and others.

Fossil holothurians are rather sparsely scattered through the geologic column from Cambrian to Recent.

Fig. 8. Holothurian elements. Magnifications approximately x250.

Annelid worm jaws (scolecodonts), plates and tubes

Annelid worms are elongated, segmented, bilaterally symmetrical animals, some of which are marine and some non-marine. The non-marine forms are unknown as fossils, and therefore do not concern the paleontologist.

Marine annelids are equipped with small silico-chitinous jaws and denticulated plates called scolecodonts which are frequently preserved as lustrous black fossils, and are unaffected by ordinary weak acids. Chitinous, scalelike surface plates and agglutinated chitinous or arenaceous tubes are also occasionally preserved, but their occurrence as fossils is rather rare. However, the small shiny black jaws may appear in rocks of all ages from Cambrian to Recent, and are especially common at many horizons in the Middle Paleozoic. The marine annelids have a questionable fossil record in the pre-Cambrian.

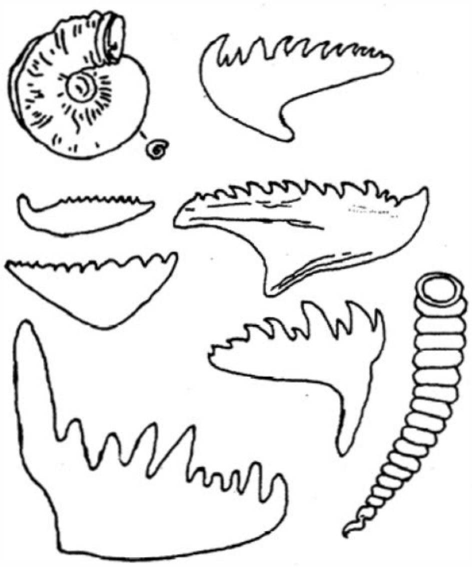


Fig. 9. Scolecodonts and annelid tubes. Magnifications x16 to x45, except tube at lower right which is about x3.

Conodonts

Conodonts, which comprise another group of toothlike microfossils, appear in marked abundance in the rocks of certain parts of the geologic column, and, within their restricted range, are very valuable tools in micropaleontology. Important differences between conodonts and scolecodonts are: (1) conodonts are composed of calcium phosphate, whereas the material of scolecodonts is chitin and silica; (2) although unaffected by acetic acid, conodonts are quickly destroyed by weak hydrochloric acid, whereas scolecodonts are unaffected by ordinary acids; (3) conodonts, although usually shiny, are translucent or nearly transparent and range in color from pale amber to light brown, as distinguished from the opaque, highly lustrous blackness of scolecodonts; (4) the known geologic range of the conodonts is confined to the Paleozoic, while that of the scolecodonts extends from the Cambrian, possibly pre-Cambrian, to the present time; (5) the derivation of conodonts is uncertain, but scolecodonts are known to be the jaws of annelid worms.

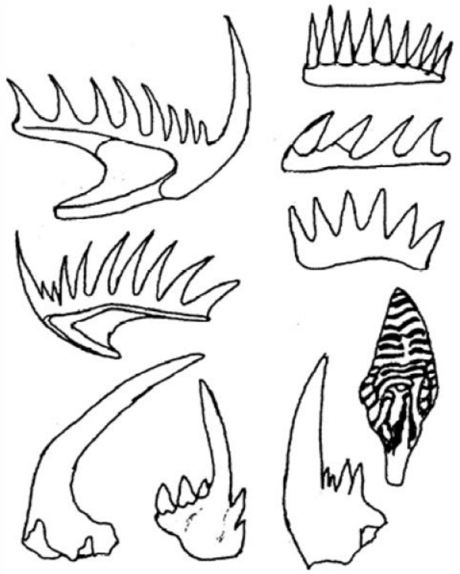


Fig. 10. Conodonts. Magnifications in the order of about x25 to x35.

Conodonts have been variously attributed to vertebrates, annelids, gastropods, cephalopods, and crustaceans, but they are now rather generally assumed to represent the jaw armor of an extinct group of primitive fishes. The fact of the matter is, however, that nobody knows for sure just what they really are.

Their native environment appears to have been in moderately shallow water near shore, possibly near the mouths of inflowing streams.

Bryozoa

The Bryozoa, whose name is derived from the Greek meaning moss animals, fall into somewhat the same category as the corals in the sense that magnification is more frequently applied to the study of the internal structure of their megascopic remains than to the study of separate microscopic individuals. The difference here, however, is that with the Bryozoa what appear to be megafossils are in reality colonies composed of many microscopic individuals variously grouped or linked together, whereas with the corals the megascopic forms frequently represent single individuals of very considerable size. With few exceptions, Bryozoa live associated in colonies, and the few that do not are minute in size. Bryozoan megafossils are colonies of Bryozoan microfossils.

The colonies display infinite variety of form. Of common occurrence are plantlike tufts and branching stems and fronds of various types, the branches at times forming regular and beautiful open-mesh lacework. Other forms spread over shells and various foreign bodies in the form of delicate interwoven threads, crusts of exquisite pattern, and nodular, globular and hemispherical masses of considerable size.

Most Bryozoa are marine and are attached throughout the greater part of their lives to the bottom and to various extraneous objects at all oceanic depths. A few genera live in fresh water. Their food consists chiefly of diatoms, infusorians and larvae. Their geologic range is from earliest Ordovician to the present time.

Brachiopoda

The Brachiopoda comprise a group of exclusively marine animals whose shells consist of two parts or valves so fastened together as to open and close like those of a clam. Clams, however, are not brachiopods. Brachiopods are found at all oceanic depths and are usually attached to various objects by extending muscles or by cementation. Their known geologic range is from lowermost Cambrian to the present, with maximum development in the Silurian and Devonian, and they have furnished many important index fossils. Microbrachiopods have not as yet received much study, but it is not improbable that the future will see many of them added to the already long list of important larger forms.

Mollusca (Pelecypoda, Gastropoda, Scaphopoda)

The major group or phylum, Mollusca, contains five subgroups or classes, all of which are best known from their megascopic forms. Three of these, however, the Pelecypoda, Gastropoda, and Scaphopoda, frequently appear in microfossil material and are therefore included here.

Pelecypoda

Pelecypoda are clams and similar animals with bivalve shells, many of which have common occurrence on our present-day beaches. They live in both fresh and salt waters in all parts of the earth, at all depths, and under all ordinary temperatures. Their known stratigraphic range is from the Ordovician to the present, with questionable occurrence in the Cambrian. Although micropelecypods have as yet received but minor attention in paleontologic literature, future study will doubtless show that they have some value in stratigraphic paleontology.

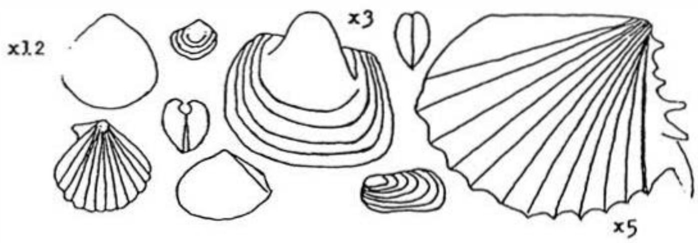


Fig. 11. Pelecypoda.

Gastropoda

The Gastropoda or snails have a worldwide distribution as both fossil and living land, marine and fresh-water animals. Of all the molluscs they exhibit the most manifold variety. Their record begins in the Cambrian and they are today at the height of their development and vigor. Literature on the megascopic fossil and living forms is voluminous. The microscopic forms have received considerable attention, but they merit and will doubtless receive much more study in the future.

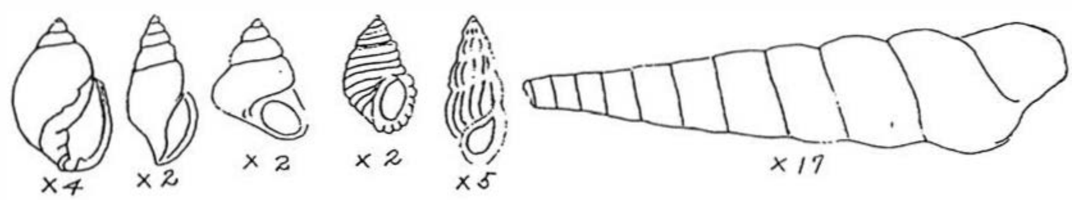


Fig. 12. Gastropoda.

Scaphopoda

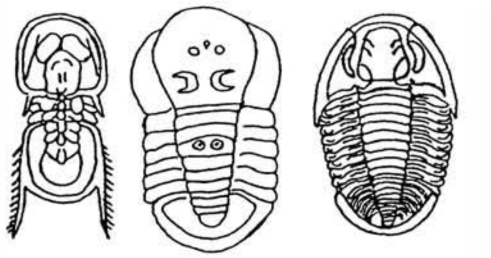
The scaphopod shell is tubular, generally somewhat curved (toothlike), and open at both ends. Scaphopods are exclusively marine dwellers, and for the most part inhabit deep water. They range from the Ordovician to the present time, but are of minor importance as stratigraphic horizon markers.

Fig. 13. Scaphopoda. Magnifications about x3.

Arthropoda (Trilobita, Archaeostraca, Branchiopoda, Ostracoda)

The phylum Arthropoda contains five classes, one of which, the Crustacea, contains four subclasses from which microfossils are known. Another of these classes is the Insecta. Among the Arthropoda, therefore, we find a possible source of suggestion for the term "bugs" as applied to microfossils, since a dictionary definition for "bug" is, "In popular language ... any animal resembling an insect, such as a spider or small crustacean ... A micro organism ..."

Trilobita



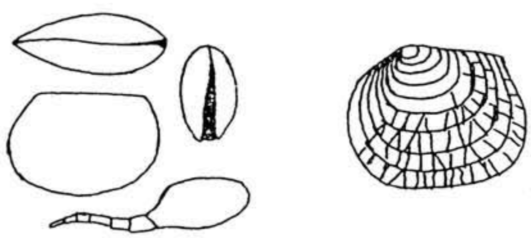
x5 x3 x1

Fig. 14. Trilobita.

No Trilobites are known to have lived since Permian time. From their fossil remains, however, it appears that they wore marine dwellers inhabiting relatively shallow to deep waters, whore they swam, crawled, and sometimes lived practically buried in the soft bottom mud. Their distribution was world-wide.

Trilobites had their origin in the pre-Cambrian, attained maximum development in the Cambrian and Ordovician, then waned in both numbers and variety to become extinct in the Permian. They constitute one of our most important fossil groups, but to date owe their importance primarily to megafossil forms. Microtrilobites should, and doubtless will receive further study.

Archaeostraca and Branchiopoda



Archaeostraca x4 Branchiopod x8

Fig. 15.

The Archaeostraca and Branchiopoda are of minor importance in paleontology, but many of them have small bivalve shells or carapaces much like those of ostracods and micropelecypods. Distinguishing features have to do largely with the animal body; sometimes with the material, shape, or ornamentation of the test. The Archaeostraca are extinct. The Branchiopoda range from Cambrian to Recent, their present day forms living mostly in fresh water and salt lakes.

Ostracoda

The ostracods constitute one of our most important microfossil groups, and in some areas and some parts of the geologic section rank with the foraminifera as index fossils. They occur abundantly in fresh, brackish, and salt waters from strand line down to depths of about 500 feet. Some occur at greater depths, but for the most part ostracods are not deep-water animals. Some are very active free swimmers while others crawl about on the bottom or on weeds and various other objects in the water. From the accompanying figures it is evident that it is a far cry from the simple, single-celled protozoan to the complex little animal that occupies the bivalve shell of the ostracod.

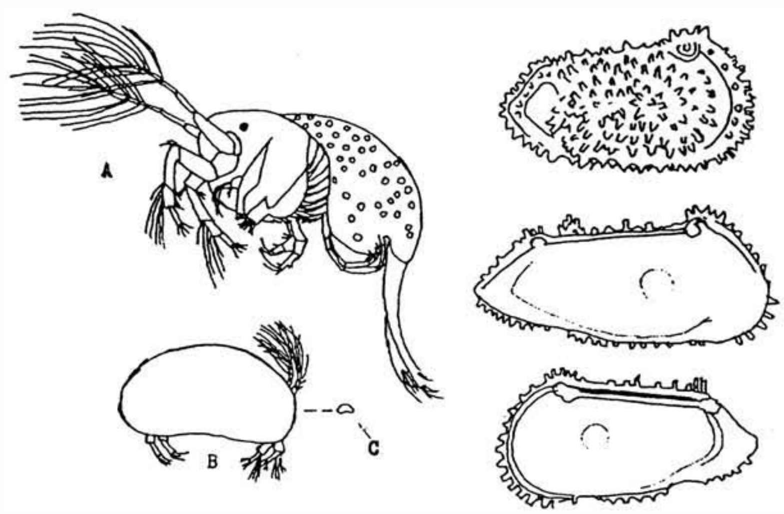


Fig. 16. Ostracoda. Magnifications of 3 figures at right about x40.

Figure 16-A is an enlargement of the animal that occupies the shell of figure 16-B, and figure 16-C shows the approximato actual size of the shell represented by figure 16-B. The geologic range of the Ostracoda is from Ordovician to Rocent.

Plant Microfossils

The fossil record of plants extends back into geologic history as far as that of animals. For the most part plants are less commonly encountered than animals, however, and they are but sparsely represented in strata older than the Pennsylvanian.

Diatoms

Most important among the microfossil plant forms are the diatoms. They are single-celled, largely pelagic, fresh-water and marine plants whose fossil record dates back to the Cretaceous where they are found so highly developed as to indicate an earlier period of evolution. They are important rock builders and are believed to have been the source of most of the petroleum in California. Their siliceous skeletons display an infinite variety of forms, and within their known geologic range are excellent horizon markers. In places they have accumulated in very extensive deposits which are mined for a variety of industrial uses.

Algae and miscellaneous forms

Calcareous algae are very important rock builders on present-day"coral" reefs and probably were of equal importance in the construction of ancient reefs. Their fossil record extends from the pre-Cambrian to the present. They give promise of being useful in correlation and as indicators of environmental conditions, but need much more study than they have received to date to develop their full possibilities along these lines.

Various other plant forms such as seeds, spores, and pollen are found as microfossils, and have some correlative importance in geological work.

The reader who desires further information on microfossils is referred to the following two publications, both of which contain extensive bibliographies as well as much authentic information and many excellent illustrations.

Cushman, Joseph A., Foraminifera, Their Classification and Economic Use, 3d ed., VIII + 480 pages, 78 plates, 8 text figs. Harvard University Press, 1940.

Shimer, Harvey W., and Shrook, Robert R., Index Fossils of North America, IX + 837 pages, 303 plates, 5 text figs. The Technology Press, Massachusetts Inst. of Technology, 1944.

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NO SALE FOR OLD BONES*

The market for fossil material, at least as far as most publicly supported museums are concerned, is practically nonexistent. The information comes from Dr. George Gaylord Simpson, Director of the Department of Geology and Paleontology of the American Museum of Natural History. Most museums, it seems, have limited funds for purchasing fossil material and many will not even accept fossils as a gift unless they are collected carefully and complete data are available concerning their occurrence and age.

Scientific-supply houses will buy fossils occasionally, but careful inquiry should be made before going to any great expense of collection. Dr. Simpson suggests that inexperienced collectors who find vertebrate fossils should get in touch with the nearest museum or paleontologist before attempting removal.

*Reprinted from The Ore.-Bin, vol. 15, no. 2, p. 14, February 1953.

...in other words, "BUG MEN"*

By

W. P. Barbat

The visitor to our Exploration Department was deeply interested, but some of the things he heard were hard to believe. He could appreciate, and could adjust himself to accept, a great number of applications of physics and chemistry to petroleum geology. Such things as detecting accumulations of oil, gas, and salt water in the unseen formations of a drilling well by testing the drilling fluid with fluorescent light, a "hot wire," and a galvanometer, seemed reasonable when our Chief Geologist explained them.

Others, such as recording on a film the varying natural electrical properties of the formations penetrated in a well, and translating this record into a log of the types of rock and their fluid content, were amazing, but certainly in tune with this age of wonders.

He listened with fascination as the Chief explained how sound waves, echoing from layers of rock miles below the surface, were commonplace tools of modern "rock hounds," or geologists, and how delicate recordings of the slight variations of the earth's gravitational pull, which occur from place to place, lead to the discovery of oil.

Finally, as he was about to leave, he heard something that strained his credulity. The phone rang. The Chief talked briefly, then excused himself, saying, "Would you mind if I dictated a short wire?" A girl stepped in. "Send this wire to the Taft Bug Laboratory, please: Dixon Community Well No. 1 reports formation change at 3785 feet. Samples to 3710 feet sent by express today. Please wire results."

He turned to the visitor. "It's one of our important wildcat wells, and operations depend on what the bug men find."

"Bug men!" exclaimed the visitor. "Who - and what - are they?"

The Chief chuckled. "That's what we call our micropaleontologists. Our laboratory for the Northern Producing District is at Taft; our Southern District laboratory is in Los Angeles."

"Well, bug men is a lot easier to pronounce, anyway," said the visitor. "If I remember rightly, paleontologists are the fellows who dig up old bones and reconstruct dinosaurs and saber-tooth tigers. I suppose your micropaleontologists, or bug men, dig up old bugs and infest their asylums with them. You have given me a lot of interesting and extraordinary information about your profession, but please don't tell me that you consult bug experts before deciding what to do next in an important wildcat well."

"That's what we do," answered the Chief, "and they <u>are</u> experts. But I'll have to explain a bit. The 'bugs' our micropaleontologists work with are tiny, single-cell animals, mostly smaller than the head of a pin. They are related to amoeba, but differ in that they have shell-like hard parts which show remarkable diversification. These little organisms are called Foraminifera and are quite widespread in the oceans. You would have to look at some with a microscope to appreciate the intricate form and delicate ornamentation of these little animals."

"But what have they to do with oil wells?" the visitor interrupted.

"Quite a lot. You see, their remains become a part of the sediment that accumulates on the sea bottom. After this material gets pressed into rock and folded into various types of geologic structures suitable for the entrapment of oil and gas, it becomes the job of the Petroleum Geologist to seek these structures and test them for possible production. The most reliable way of testing, as you can guess, is to drill into them with a prospect hole, and study the core-samples thus secured. The little fossils found in the samples tell us many things we need to know.

"The microfossils differ from area to area, and they differ with the temperature, salinity, and depth of the sea-water in which they formerly lived - just as the existing animals vary in our present seas. But more important to us, they differ with the passage

*Reprinted from <u>The Ore.-Bin</u>, vol. 15, no. 4, p. 23, April 1953. (Original article in <u>Standard Oiler</u>, November 1946. Used by courtesy of Standard Oil Company of California.)

of time. Successive layers of sedimentary rock tell a story of extinction of certain types of animals, of development and change of others. Migrations into and away from a given area of former sea bottom, or any change in the animal population which may be caused by changing conditions within the sea, tend to cause the fossils in succeeding layers of sedimentary rock to be different from those preserved in preceding layers.

"Now about the examination in the Bug Laboratory: A formation sample sent to our micropaleontologists is broken down by mechanical and chemical means into something like the mud it once was. This is washed through fine-meshed screens, which pass the mud but catch the microfossils along with a lot of other objects about the same size - teeth or parts of bone of fish, sea-shell fragments, sand grains, or maybe some incompletely disintegrated rock.

"After drying, the catch is spread on a black dish, placed under a microscope, and the microfossils are picked out with the tip of a moistened brush. They are placed in covered slides for study and identification.

"From knowledge and experience, the bug men decide what changes in the fossil content of each sample are caused by the passage of time. They have learned to recognize certain varieties as characteristic of certain rock layers; these they call 'markers.' Markers are like the numbers on a calendar - they give us reference points to measure the passage of geologic time.

"This applies to the samples I sent that wire about," continued the Chief. "The report we get should give the geologic age of the new formation the drill has entered."

"But why should you be concerned with how old it is?" demanded the visitor.

"Oh, we're not interested in the age as such, certainly not measured in years or millions of years as the case may be. But determining the age of this formation tells us in effect every other place that it has been encountered. It tells us where this rock layer crops out on the surface, and at what depth it occurs in all the other wells that have penetrated it. From this knowledge we can map the formation and show its surface and underground convolutions."

"I see what you mean," agreed the visitor. "It locates the geologic structure and shows where it is folded up and where folded down - and you say the structure controls the accumulation of oil. However, I don't understand why you need a report from your bug men to determine the course of action in this well."

"If this new formation the drill has entered is close to the oil sand we are looking for," the Chief explained, "we will reduce the diameter of the drill hole and keep a close watch for showings of oil or gas. This will put us in a position to make an economical test of the sand if the showings warrant. If the formation is not close, the age reported will probably give us a fairly accurate estimate of the additional feet we must drill to reach our objective.

"Then, too, if by some odd chance the formation proves to be older than the sand we hope to get oil production from, there is no need to drill deeper. Some sort of geologic complexity not previously known will be indicated, because the sand which should be there is missing, and we will abandon this well without delay and perhaps try another location. If a detailed study of the core samples from this well, combined with geologic data from other sources, discloses the reason for the missing sand,it may point to a location where we can drill with more assurance."

The visitor asked, a little banteringly, "Do your bug men, then, give you all the right answers and take all the guesswork out of oil prospecting?"

The Chief shook his head. "It would be easy for me to say yes, but unfortunately that is not always true. They do a remarkably good job of interpreting the life histories of organisms that lived aeons ago, but the complexities involved sometimes lead to incorrect conclusions. But even the mechanical tools geologists use do that too. However, experience has shown that we can rely a great deal on what the micropaleontologists tell us. We are fortunate indeed that these specialists have developed their skill to such a high level. We still have to 'ask the drill' in prospecting for oil in an unproved area, but the findings of the bug men remove some of the gamble."

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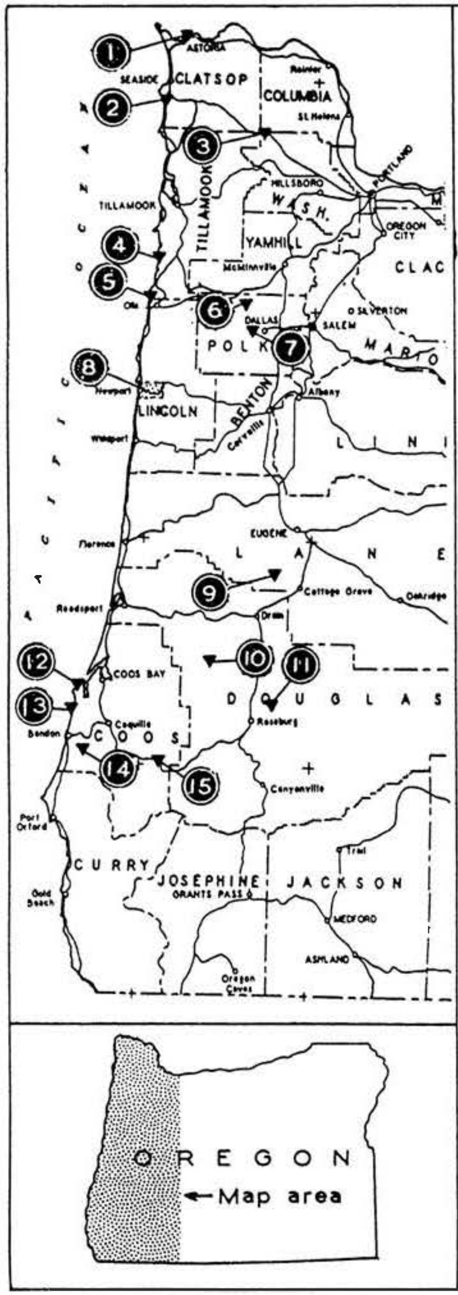
GENERALIZED GEOLOGIC TIME CHART FOR OREGON

Era	Period		Principal Geologic Events	Age*
CENOZOIC	QUATERNARY	RECENT	Mountain glaciers receding. Minor lava flows at McKenzie Pass, Cow Lakes, and near Mt. Hood.	.025
		PLEISTOCENE	Greatly enlarged glaciers in mountains. Eruption of numerous volcanoes in Cascades and central Oregon. Large lakes in south-central part of State. Elephants most abundant. Camels, peccaries and rhinos extinct.	1
	TERTIARY	PLIOCENE	Eruption of Cascade volcanic cones. Extensive outpouring of lava in south-central Oregon. Horse, rhinoceros, camel, antelope, bear, mastodon living in John Day country. Large areaa of grasslands due to drier climate east of Cascades.	12
		MIOCENE	Thick layers of Columbia River basalt extruded over much of State (middle Miocene). Creodont, rodents, horse, pig, rhinoceros, camel, and rabbit living in John Day country (lower Miocene). General wet climate with large and extensive forest areas (Sequoia).	30
		OLIGOCENE	Northwest part of State largely covered by shallow sea. Temperate flora growing in Mitchell area with elm, maple, sycamore, katsura trees plentiful. Three-toed horse, camels, saber-toothed tigers, oreodonts, enteleodonts, tapirs.	40
		EOCENE	Coos Bay coal forming in coastal swamps. Coast Range begins to rise in south. Forests of palms and figs buried by volcanic ash in central Oregon. Age of the running rhinos (brontotherium, hyracodonts).	60
MESOZOIC		CRETACEOUS	Intrusion of batholiths in Wallowas and Klamaths. Most of State covered by inland seas. Tree ferns growing near Austin in Grant County.	115
		JURASSIC	Ferns, cycads, ginkgoes, and conifers growing in forests near Riddle. Central Oregon invaded by sea. Brachiopods, ammonites abundant. Some reptiles.	155
		TRIASSIC	Islands in central Oregon surrounded by shallow sea. Sponges, corals, ammonites, gastropods, and nautiloids in Wallowa Mts.	190
PALEOZOIC		PERMIAN	Shallow seas cover much of State. Vulcanism in northeastern part.	220
		CARBONIFEROUS	Oldest known rocks in Oregon. Brachiopods, corals, ferns, and calamites have been found in the Suplee area. Much of State covered by shallow seas.	280
		PRE-CARBONIFEROUS	"Pre-Carboniferous" includes the vast stretch of geologic time extending back to the oldest rocks found on the earth. They are estimated to be 2 billion years old. A complete time chart appears opposite page 13.	2000

*In millions of years.



MICROPALEONTOLOGICAL PROJECTS IN PROGRESS*

by State of Oregon Department of Geology and Mineral Industries

1 Astoria city and environs, Astoria quadrangle. Astoria formation, Miocene.

2 Highway cut about 1-1/3 miles northeasterly from Cannon Beach on Oregon Coast Highway, Cape Falcon quadrangle. Miocene.

3 Cuts along Sunset Highway northwesterly and southeasterly from Sunset Tunnel near northeast corner of Timber quadrangle and northwest corner of Gales Creek quadrangle. Sunset Tunnel. Keasey section.

4 Sea cliff exposure 1-1/2 miles northerly from Cape Kiwanda, 500 feet south of Triangulation Station NIP, Nestucca Bay quadrangle. Oligocene.

5 Exposure near mouth of Salmon River, southwestern Nestucca Bay quadrangle. Nestucca formation, upper Eocene.

6 Section exposed along Mill Creek and South Yamhill River, northwestern Dallas quadrangle and southern Sheridan quadrangle. Upper Eocene and upper middle Eocene.

7 Ellendale quarry, about 2-3/4 miles east of Dallas, Dallas quadrangle. Middle Eocene.

8 Newport-Toledo section of Nye shale and Toledo formation along highway and Yaquina Bay shore from Newport eastward to a little beyond Toledo, Yaquina and Toledo quadrangles. Miocene-Oligocene-upper Eocene.

9 Highway cut near Lorane southwest of Eugene, Cottage Grove quadrangle. Stratigraphic position uncertain.

10 Turner's Basket Point locality northwest of Roseburg. Type Tyee formation, upper middle Eocene. Believed to belong between the Mill Creek-Sacchi Beach beds and the Umpqua formation.

11 Turner's Glide section along North Umpqua River northeast of Roseburg. Umpqua formation (middle Eocene below Tyee) with perhaps some Tyee at top of section.

12 Coastal section between Tunnel Point and Cape Arago south of Coos Bay, Empire quadrangle. Bastendorf and Coaledo formations. Oligocene and upper Eocene.

13 Sacchi Beach section along coast north and south of mouth of Five Mile Creek south of Cape Arago, Empire quadrangle. Appears to be same age as Mill Creek beds, upper middle Eocene.

14 Bear Creek southwest of Coquille, Bandon quadrangle. Umpqua formation, middle Eocene.

15 Turner's "Middle Fork of Coquille River section" southeast of Coquille along highway east and west of Remote just east of Coquille quadrangle. Umpqua and Tyee formations, middle Eocene.

*Geologic ages are tentative pending completion of work.

The map and list of microfossil localities on the opposite page was published in the October 1950 Ore.-Bin in order to outline projects then in progress under the program of studies in micropaleontology which was initiated by the Oregon Department of Geology and Mineral Industries in 1944.

The first seven papers under this program, parts I to VII of Department Bulletin No. 36, were published in collaboration with the late Dr. Joseph A. Cushman of the U. S. Geological Survey. After Dr. Cushman's death in 1949 it was hoped that Miss Ruth Todd, also of the Survey, might take over his part of the work, but the pressure of other duties made it necessary for her to withdraw. Therefore, the program is being continued by the Department of Geology and Mineral Industries.

The samples for these studies have been collected from Tertiary formations so located that the identification of the microfossils contained will greatly assist in unraveling the stratigraphy of western Oregon. Therefore, the work will be very important in assigning accurate ages to formations encountered in geologic mapping.

This program of studies in micropaleontology was outlined in the first volume of Bulletin No. 36 (1948) as follows:

> The object of this work, insofar as the microfossils are concerned, is to determine the character of their distribution in the sedimentary formations of Oregon, to establish microfossil zones for the correlation of strata within the geologic province of which Oregon is a part, and then to apply this information to the solution of stratigraphic problems.
>
> As shown in outline form, the procedure for this work will be as follows:
>
> I. Descriptive work
>
> a. Identify and record species found in Oregon that have already been named and described from various parts of the world in published literature.
>
> b. Name, describe, and illustrate new species.
>
> II. Stratigraphic work
>
> a. Determine the lateral and vertical ranges and relationships of genera and species found in strata of known geologic age.
>
> b. Determine the ages and ecologic significance of strata of unknown age encountered in the field by comparing their faunas with faunas from strata of known age.
>
> c. Apply these correlations (age determinations) and ecologic data to the solution of stratigraphic and structural problems, both economic and academic.
>
> These correlations apply to the solution of many stratigraphic and structural problems which are continually being presented, such as proper age relationships in constructing geologic maps, especially the state geologic map now in preparation, and studies of oil and gas possibilities in which age and succession of strata are all-important.
>
> * * * * * * *
>
> Interest will be concentrated on formations in the State of Oregon, but, in some cases in which they are vital to the solution of Oregon problems, formations from adjoining areas may be studied. The processes of geology were never appreciably influenced by political boundaries.

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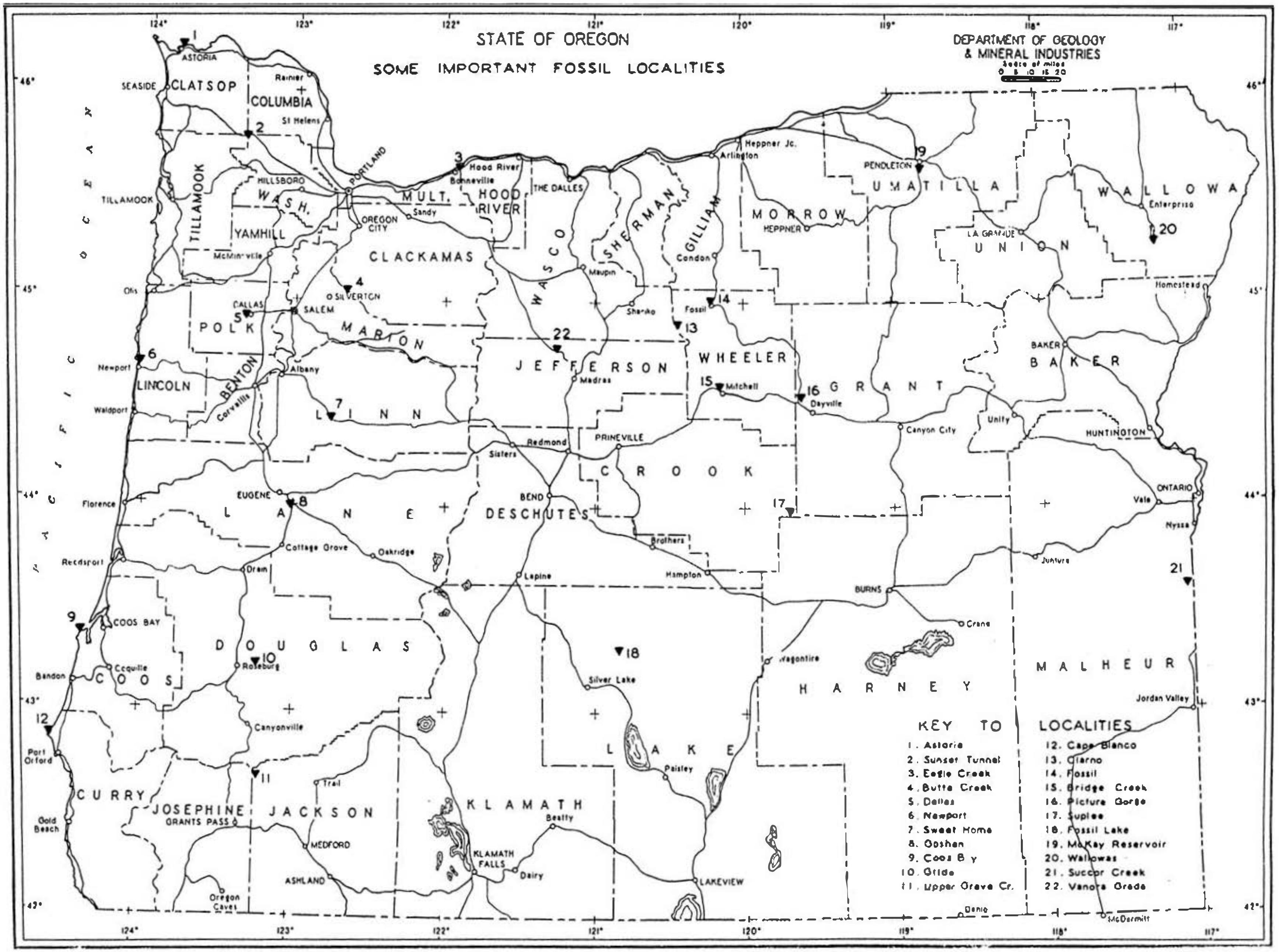
STATE OF OREGON
SOME IMPORTANT FOSSIL LOCALITIES
DEPARTMENT OF GEOLOGY
& MINERAL INDUSTRIES
Scale of miles
0 5 10 15 20
PACIFIC OCEAN
CLATSOP
COLUMBIA
TILLAMOOK
WASH.
MULT.
HOOD RIVER
YAMHILL
CLACKAMAS
WASCO
SHERMAN
GILLIAM
MORROW
UMATILLA
UNION
WALLOWA
POLK
MARION
LINCOLN
BENTON
LINN
JEFFERSON
WHEELER
GRANT
BAKER
CROOK
LANE
DESCHUTES
DOUGLAS
COOS
HARNEY
MALHEUR
LAKE
CURRY
JOSEPHINE
JACKSON
KLAMATH
KEY TO LOCALITIES
1. Astoria
2. Sunset Tunnel
3. Eagle Creek
4. Butte Creek
5. Dallas
6. Newport
7. Sweet Home
8. Goshen
9. Coos Bay
10. Glide
11. Upper Grave Cr.
12. Cape Blanco
13. Clarno
14. Fossil
15. Bridge Creek
16. Picture Gorge
17. Suplee
18. Fossil Lake
19. McKay Reservoir
20. Wallowas
21. Succor Creek
22. Vanora Grade

A SELECTED LIST OF PUBLICATIONS ABOUT FOSSIL LOCALITIES IN OREGON

Allen, John E.
1939 First aid to fossils, or what to do before the paleontologist comes: Oregon Dept. Geology and Mineral Industries Bull. 18, 1939

Chaney, Ralph W., and Sanborn, Ethel I. (Locality 8)[1/]
1933 The Goshen flora of west central Oregon: Carnegie Inst. Washington Pub. 439, 1933

Chaney, Ralph W. (Localities 3, 7, 8, 13, 14, 15, and 22)
1948 Ancient forests of Oregon: Oregon State System Higher Education, Condon Lecture, 1948

Condon, Thomas
1910 The two islands and what came of them: J. K. Gill, 1902; 2d edition, revised, 1910

Diller, J. S., and Kay, G. F. (Locality 11)
1924 Riddle Folio: U.S. Geol. Survey Folio 218, 1924

Hay, Oliver P.
1927 The Pleistocene of the western region of North America and its vertebrated animals: Carnegie Inst. Washington Pub. 322 B, 1927

Lowry, Wallace D.
1947 The extent of the Oligocene sea in northwestern Oregon: Geol. Soc. Oreg. Country News Letter, vol. 13, no. 1, Jan. 1947

Lupher, R. L.
1941 Jurassic stratigraphy of central Oregon: Geol. Soc. Am. Bull., vol. 52, no. 2, Feb. 1941

Martin, Bruce (Locality 12)
1916 The Pliocene of middle and northern California: Calif. Univ. Dept. Geol. Bull., vol. 9, no. 15, 1916

Merriam, C. W., and Berthiaume, S. A. (Locality 17)
1943 Late Paleozoic formations of central Oregon: Geol. Soc. Am. Bull., vol. 54, no. 2, 1943

Merriam, J. C. (Localities 13, 14, 15, and 16)
1901 A contribution to the geology of the John Day basin: Calif. Univ. Dept. Geol. Bull., vol. 2, no. 9, 1901

Merriam, J. C., and Sinclair, W. J. (Localities 13, 14, 15, and 16)
1907 Tertiary faunas of the John Day region: Calif. Univ. Dept. Geol. Bull., vol. 5, no. 11, 1907

Packard, E. L. (Locality 18)
1937 The Pleistocene mammals of Oregon: Geol. Soc. Oreg. Country News Letter, vol. 3, no. 21, 1937.

[1/] Locality numbers refer to numbers on map on opposite page.

Sanborn, Ethel I.
1937 The Comstock flora of west central Oregon: Carnegie Inst. Washington Pub. 465, Part 1, 1937

Scharf, David W. (Locality 21)
1935 A Miocene mammalian fauna from Sucker Creek, southwestern Oregon: Carnegie Inst. Washington Pub. 453, no. 7, 1935

Schenck, Hubert G. (Localities 2, 6, 8, and 9)
1928 Stratigraphic relations of western Oregon Oligocene formations: Calif. Univ. Dept. Geol. Bull., vol. 18, no. 1, 1928

Smith, W. D., and Allen, J. E. (Locality 20)
1941 Geology and physiography of the northern Wallowa Mountains, Oregon: Oregon Dept. Geology and Mineral Industries Bull. 12, 1941

Stock, Chester (Locality 16)
1946 Oregon's wonderland of the past - the John Day: Sci. Monthly, vol. 63, no. 1, July 1946

Turner, F. E. (Localities 9 and 10)
1938 Stratigraphy and mollusca of the Eocene of western Oregon: Geol. Soc. Am. Special Papers 10, 1938

Warren, W. C., and Norbisrath, Hans (Locality 2)
1946 Stratigraphy of upper Nehalem River basin, northwestern Oregon: Am. Assoc. Petrol. Geol. Bull., vol. 30, no. 2, Feb. 1946

Warren, Charles E. (Localities 1, 2, 6, and 9)
1942 Paleontology of the marine Tertiary formations of Oregon and Washington: Wash. Univ. Pub. in Geol., vol. 5, parts 1, 2, and 3, 1942

Weaver, Charles E. (Locality 9)
1945 Stratigraphy and paleontology of the Tertiary formations at Coos Bay, Oregon: Wash. Univ. Pub. in Geol., vol. 6, no. 2, 1945

Williams, Howel
1948 The ancient volcanoes of Oregon: Oregon State System Higher Education, Condon Lecture, 1948

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