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ABSTRACT

This guide introduces the study of fossils and means through which this study may provide clues to ancient environments and ecology. Presented are discussions about the origin of many types of organisms, origin of organic communities, evolution, and extinction of species. Suggestions are provided for likely collection sites, methods of collection, identification of fossils, and field techniques. Appendices, references, and a glossary are provided. (Author/RE)

field guide to FOSSILS

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The traces of ancient life—a burrow filling, a trail on a sandstone layer, the mold of a jellyfish's body, the skeleton of an ancient clam—are obviously clues to the history of life. But as this pamphlet shows, they also provide evidence for ancient environments and geography, and present challenging biologic problems about the origin of the major types of organisms, extinction, and the origin and evolution of organic communities.

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FIELD GUIDE TO

Fossils

James R. Beerbower

Series Editor: Robert E. Boyer

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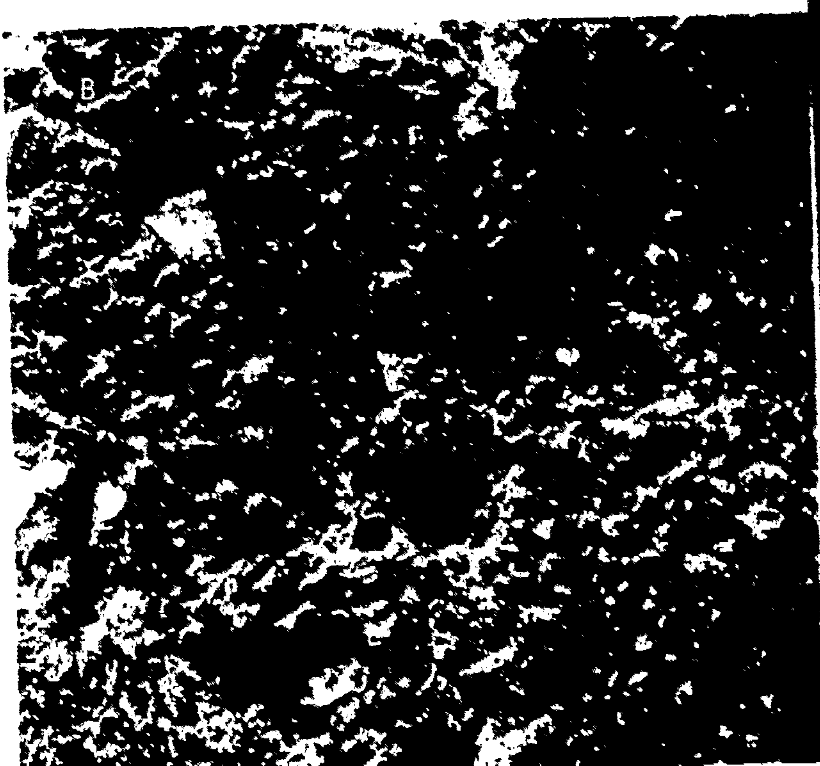
INTRODUCTION

A creek flows down over the hills southeast of Buffalo, New York, and then through a steep-walled valley toward Lake Erie. Here it has cut deeply into the horizontal layers of rocks that cover the area. Single, thin layers are exposed over hundreds of square yards in the stream bed. Each rock layer represents an accumulation of a layer of mud on a sea floor. So, when the stream is low, you can walk out across an ancient sea floor (Figure 1). Here you will see a coral that has tumbled on its side; there, a lamp shell, its shell tightly closed in the moment of death. A few moments' inspection on hands and knees reveals a variety of animal shells and skeletons, some similar to those a skin-diver would find today on the ocean floors, others quite strange and different. Perhaps you see a bit of broken shell in among many whole ones. Did a fish or a squidlike "nautiloid" crack it open to feed? And this creature rolled up like a pillbug—you can still see a pattern of pigment

Figure 1 (A) Fossil collecting along Cazenovia Creek near Buffalo, New York. Horizontal layers of mud rock represent deposits on ancient sea floor (B) Close-up of a fossil-bearing layer



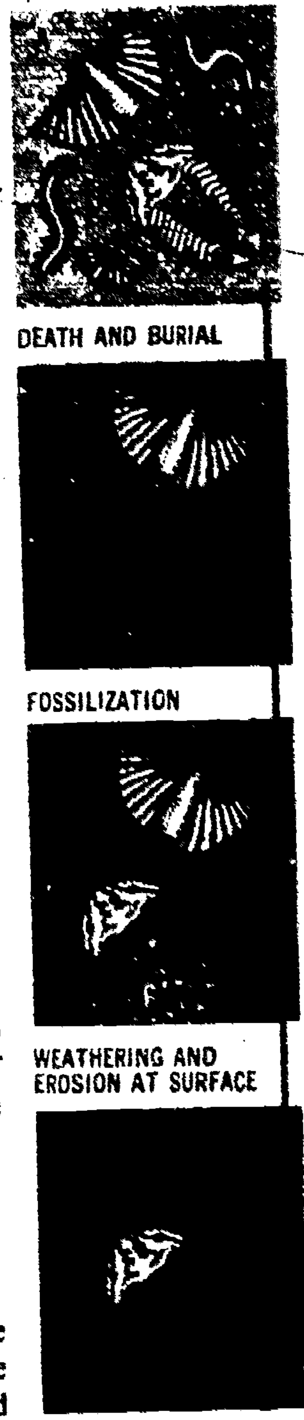


Figure 2. A fossil sample of the living world. (A) Organisms on the sea floor at one moment. (B) Organisms that died and were buried in a particular thin layer of mud. (C) Loss of soft organisms and preservation of others with resistant skeletons. (D) A single fossil remaining after the layer, now rock, is brought back to the surface and exposed. The student of fossils tries to reconstruct (A) from (D).

spots around the eyes and over the back. A sweep of shallow ridges and grooves reveals the presence of a worm probing for food in the mud.

All these things are *fossils*—traces of ancient life (Figure 2). These particular fossils lived and died over 350,000,000 years ago: some fossils have even been found in rocks over 1,500,000,000 years old. Fossil-bearing rocks are exposed at the surface over a major part of North America, so anyone willing to learn the proper methods of search, collection, and interpretation can join the sport.

THE SEARCH FOR FOSSILS

"Where do I look for fossils? How do I recognize one? What do I need to collect them?" These are probably among the first questions you would ask. Search and recognition may seem difficult if you have never collected fossils before, but a few general rules will make the task much simpler. "Where to look" is an obvious starting place.

Places to Collect

Not all rocks contain fossils. Begin by examining the right kind of rocks, those which began their existence as mud or sand on the earth's surface. Typically, these are layered rocks (though not all layered rocks form at the earth's surface) and have names as well as properties that reflect their origin —sandstone, mudstone, shale (a mud rock that breaks into thin plates), and limestone (a rock composed of calcium carbonate mud or sand). These rocks formed by settling of material (*sediment*) from water or air and are called "sedimentary rocks." Typically, limestones are the most likely to contain abundant fossils and may be composed entirely of shells and other kinds of fossil parts. Sandstones, particularly thick beds with few layers of mudstone or shale interspersed, are not likely to contain many fossils. Red-colored layers of rock generally have few fossils because these rocks are made of sediments which accumulated on land. But the fossils they do contain may be interesting and even unique. Shales are commonly good sources of fossils, though the fossils may occur in only a few of the many layers of exposed rock. Metamorphic rocks, such as slate, schist, and gneiss, transformed by great heat and pressure; igneous rocks like granite, formed at great depth in the earth by partial melting; and volcanic rocks, formed by the cooling of lava, rarely, if ever, contain fossils.

The general distribution of sedimentary rocks in North America is shown in Figure 3, but you should be able to obtain more detailed information from local sources about the location of sedimentary rocks and the kinds of fossils they contain. Books and maps that show the distribution of rocks in your state or region may be available in the city or school library. Natural history museums, the geology departments of universities and colleges, and many state (or provincial) and federal geological surveys offer special pamphlets on fossil collecting. Many of these are listed in *Sources of Earth Science Information*, in the References.

Figure 3 Distribution of Sedimentary Rocks in North America

1 Rocks formed under high temperature high pressure, and/or very ancient sedimentary rocks with few or no fossils

2 Rocks consisting largely of high temperature or high pressure types, also some fossil-bearing sediments

Rocks consisting largely of sedimentary layers - some bearing fossils

3 Ancient rocks (Paleozoic 600-230 M years old) principally marine in origin

4 Ancient rocks (late Paleozoic 310-230 M years old) include stream, lake and swamp as well as marine deposits

5 Intermediate age rocks (Mesozoic 230-65 M years old) largely marine but include stream, lake and swamp deposits particularly in Rocky Mountain area

6 Young rocks (Cenozoic less than 65 M years old) largely marine near coast, river and lake deposits in interior

Over most of the continent, the rocks are extensively covered by soil and vegetation. Therefore, you must look for natural or man-made excavations such as cliffs, stream gulleys, road cuts, and quarries. Beware of dangers such as steep slopes, falling rock, and traffic. Always obtain the owner's permission before going on private property. State, national, and provincial parks have definite rules about collecting; learn and obey them.

The Appearance of Fossils

Once you have found the right rocks, what should you look for? Remember that usually only the tougher parts of plants and animals are fossilized. Pieces of bark or durable stem are common plant fossils. Abundant leaf impressions may be found in shales formed as muds in ancient swamps or lakes. Animal skeletons, like the hinged shells of a clam or the hard, supporting structure of corals, are the most common kind of fossils. Furthermore, fossils of animals like clams or corals that lived on the bottom of the sea are far more common than those of fish that swam actively above the bottom, or those of dinosaurs that roamed across the land. In some fossils the original bone or shell is preserved without changes; most fossils, however, have been variously transformed. Soft parts—those without any original mineral content—commonly decay and disappear, but particularly tough organic materials like cellulose and lignin in plants and chitin in insects resist decay. These may be left as streaks or prints of carbon on the surface of the rock layers. Porous bone or wood may be filled by minerals precipitated in the holes after burial in sediment. Thus dinosaur bones in the Colorado Plateau may be rich in uranium minerals, and many "trees" in "petrified forests" are preserved as opaline silica (silicon dioxide). In other fossils the original minerals have dissolved, leaving a void (*mold*) within the rock. Many molds are filled—

either by squeezing in of sediment to make a *cast*, or by chemical precipitation of other minerals (*replacement*). These various kinds of transformations can be clues to the physical and chemical history of the enclosing rock.

Obviously, then, to find fossils you must know what skeletons look like. Appendices I and II provide representative examples of the more common kinds of fossils; the reference books listed at the back of this guide and the state geological survey pamphlets on fossil collecting give many more examples. Museum displays may provide a better impression of "the fossil in the rock." However, you must examine the rock exposures with great care, alert for unusual shapes or patterns that suggest animal or plant forms.

Ready for the Field

You have taken two of the three steps: learning where to begin your search and what to look for. To make the final preparations for collecting, you need the following materials:

Map to help you locate collecting sites and to describe and re-locate sites once found. A road map may be sufficient, but a large-scale map like those prepared by the U.S. Geological Survey (see References) or your state geological survey is desirable.

Hammer, if possible one with a point or chisel at one end. Some hardware stores sell "geologist's hammers" or "prospector's picks"; an ordinary "mason's hammer" with a chisel at one end is equally useful and commonly less expensive.

Cold chisel, especially if the rock is hard

Large, thin-bladed knife to wedge apart thin layers of rock

Pocket knife, small paint brush and small, powerful magnifying glass

Paper towels or toilet tissue for wrapping small and delicate fossils
Newspaper to wrap large slabs
Paper sacks, a knapsack, or a canvas bag to carry the fossils
Pocket notebook, slips of paper or cardboard for labels, small ruler, and pencil or ball-point pen
Glasses or goggles for eye protection

COLLECTING THE PAST

You may now search for sedimentary rocks in a gully, a quarry floor, or a road bank. After diligent work you may find the shells and skeletons of ancient animals or the leaves of ancient plants. Then you can simply take, wrap, and carry them home for your specimen display.

Or is it this simple? Most fossils must be worked from the rock and wrapped carefully to protect them from the jolts and bangs of transportation. Collection requires care in another sense, for much of what fossils reveal about the past comes from the rock layer in which a particular fossil is found and the other fossils associated with it. Observation of the fossil environment can be important, so all collection begins and ends with careful observation.

Observation in the Field

Field observation revolves about six general questions: Where found? When deposited? With whom? In what rocks? What are they? How did they form? If you answer Where found? carefully enough, you can return again and again to the same fossil layers with new questions. Begin by carefully noting the location. If you have a good, large-scale map, you can number the fossil location on the map with a description of it in your notebook. If fossils occur at a single place in a long road cut or in a quarry wall, estimate the distance and direction from some easily located point such as a building or a distinctive rock formation. The simplest rule is to record *all* the information necessary for anyone else to find the place easily; then you are certain of finding it again yourself.

It is also desirable to determine which rock layers contain the fossils. If your collection is made from loose specimens, note this distinctly and, if possible, determine the layers from which they came. If only a single fossil-bearing layer is present, the place description itself may be adequate, although even then you may wish to note where along the layer fossils were collected. If several separate layers containing fossils are present, be more precise; the fossils from upper layers lived at a later time in earth history than those from lower layers. Only by separating the fossils layer by layer while you are collecting can you determine which life forms lived at the same time. If individual fossil layers have a distinctive color or appearance, note this; if the beds are not so easily separated, measure the distance from the top or bottom of a distinctive layer to the fossil-bearing layer.

Since layers of sediment are deposited in succession, the position of a layer in the succession gives a partial answer to the second question, When deposited? Do you find that different layers yield different fossils? Then you have taken the first step in determining the history of life in this particular place. On the other hand, the different kinds of fossils found in the same layer tell you With whom? and your observations on the kind of rock composing the layer answer In what rocks? What are they? and How did they form? are questions which involve somewhat more study and knowledge than you can expect to apply in this first collecting trip; they will be dealt with later.

Bagging the Game

Field observation is essential to understanding fossils; but collecting the fossils is also important. Put aside your notebook and begin the job.

If you do find interesting loose specimens on the outcrop, the task is as simple as wrapping each one. However, be sure that the specimen or its package carries a label keyed to your notes on the collecting site. In general, a site name or number, a designation of the fossiliferous bed by name or number, and a few words summarizing the location of the site and the position of the bed in the series are adequate. If possible, note which fossil surface originally faced up in the rock layer.

To get good fossil specimens may be more difficult—this is the reason for the hammer and chisels in your collecting kit. The amount of rock breaking and the care with which it is done varies, but remember to protect your eyes with glasses or goggles. Collecting methods depend on the size and abundance of the fossils, their fragility, the way the rock tends to break, and the extent to which you wish or need complete specimens.

Modify your collecting method to suit individual circumstances. However, the following general guidelines will be helpful. If no fossils are visible on the rock surface, break the rock into successively smaller pieces, following the original layers if possible. The rock may actually break around a fossil; if the fossil breaks, you can bundle the pieces, including the attached rock, together in the same labeled package. The pieces can be glued back together later.

If fossils are visible on the rock surfaces, you can take a somewhat different approach. If they are abundant and you are not interested in preserving any particular one, simply break the rock out in large slabs, saving those that contain the best fossils. Label each slab; if the fossils are delicate or the slabs are to be packed together, wrap them individually. On the other hand, if the fossils are rare, unusual, or particularly complete or well preserved, you may wish to collect them as individual specimens. If the fossils are delicate, you will need to use a "hardener" (page 12) before attempting to remove them. Then you can use your hammer (and chisel, if necessary) to loosen the block of rock containing the specimen. Follow natural breaks in the rock as much as possible. Then carefully chip away the corners of the block to reduce it to manageable size. If fossils are delicate, you will want to wrap them in tissue before you bundle them into newspaper or paper toweling.

In general, expect to bring in a considerable bulk of rock with each fossil. This rock is more easily and safely removed in a workshop or laboratory than in the field. In addition, it is often best to leave the fossil in the rock, which acts as a protective cast. Since molds and impressions are actually part of the rock, the rock in which they are found becomes the specimen. With the fossils collected and packed, you can start home and go on to the next step in your study.

Remember one caution, however! Some fossils, particularly the rare ones, have unique scientific value which overenthusiastic collecting by a beginner may destroy, and must be collected and studied by professional scientists. For example, the bones and teeth of vertebrates (fish, amphibians, reptiles, birds, and mammals) generally fall into this category, as do some shells and other types of skeletons. If you find vertebrate fossils, you should contact a professional geologist at your state geological survey or at the nearest college or university before you attempt to collect them. As a rule of thumb, shells and other invertebrate skeletons can be collected without this caution, unless you find something that you think may be rare or unique.

PREPARING FOSSILS FOR STUDY

Removing rock from fossils can be rather complicated. The most direct method is to use a hammer and chisel—a light hammer and small chisel are generally most useful. Used dental scrapers, picks, and chisels obtained at low cost from a dental supply company or a local dentist are excellent for delicate work close to the fossil. A "pin vise" obtained at a hardware store, a box of old-fashioned steel phonograph needles, and a small hammer provide effective and inexpensive tools for delicate work. A small hand grinder equipped with carborundum disks and burrs can also be used if one is available.

The object is to locate natural planes of weakness within the rock, such as fractures paralleling the sediment layers, often found in shale. If rock and fossil are of different composition and structure, the rock will tend to split away from the fossil. If they are similar, however, or if the fossil is softer than the rock, you may not be able to remove rock chips without damaging the fossil. In such cases, you may find a grinding tool essential. You may be able to accentuate natural differences and toughen the fossil by soaking or painting it with a hardener. Shellac thinned with alcohol is very good for this purpose and penetrates deeply. However, it dries rather slowly, and the fossil may be damaged by water and acids in chemical preparation. (See Identifying the Fossils.) Plastic cements thinned with acetone or benzene dry rapidly and resist water and acids. Most of these penetrate only a short distance into the fossil, however, and do not harden a large specimen to any depth.

Chemical preparation can frequently assist or replace mechanical methods, but careful experimentation on fragmentary specimens should precede any application of acid or even water. Some clay or mud rocks will yield simply to overnight soaking in water supplemented by vigorous scrubbing with a stiff brush. You can also try soaking the rock in kerosene for several hours and then placing it in water. Dilute (about 5-10%) hydrochloric acid readily attacks calcium carbonate, the principal constituent of limy rc .s: Unfortunately most fossils are also composed of calcium carbonate, and hydrochloric acid (or weak organic acids like acetic, citric, or formic) can be used only in special cases. When you use acid, be careful not to get it on your hands or clothes.

In addition to the large, easily visible fossils, many rocks contain tiny *microfossils*. If the rock is quite soft, you may be able to prepare and study microfossils by crushing a quantity of the rock, soaking it in water, and then washing the sample by repeatedly removing the mud that remains suspended in the water after the sample is stirred. After washing, dry the sample, sieve it through a fine (20-mesh) screen, and examine it with a low-power microscope. Throughout this process, remember to keep the identifying label with the specimen.

When work is completed, you can number the larger fossils directly with India ink—you may have to place a spot of fast-drying white enamel on the rock or fossil for the ink. Small specimens can be kept together in a plastic vial or in a box that can also carry the number and label. You can then insert the same number on the label and at the proper place in your notes.

IDENTIFYING THE FOSSILS

You may collect scores of fossils from the surface of a single rock layer (Figure 1B). Careful inspection will reveal, however, that many of them are quite similar to one another, and probably only three or four different kinds of fossils occur in the layer. It also demonstrates that the kinds of fossils found may be similar to the kinds of plants and animals living today. This similarity of organisms within a group and the differences between groups result from biologic evolution. They also reflect the adjustment or adaptation of plants and animals to different ways of life. Each kind of organism has a distinct kind of food, a particular place to live, and a unique set of enemies. Your next task, therefore, is to bring this order to your own fossil collection by identifying the fossil type and applying the proper name.

Classification

Many specimens in your collection will be nearly identical. They may vary slightly in shape and considerably in size, but they resemble each other as closely as house cats resemble one another and are distinct in form from the other fossils from the same layer. Such a group represents, or is a sample of, a distinct population of plants or animals that lived at some time in the past, just as the goldfish in a bowl are a sample of a distinct population living at present. Such a population is called a *species;* its members look alike and live the same way largely because they are members of an interbreeding unit and have a common inheritance.

In the same collection or in one from a nearby layer you may discover other specimens that resemble the first species but are sharply distinct in one or more features (other than size). This distinctiveness means that they belong to a different species. The similarity, however, suggests that the two species have a similar inheritance from a common, ancestral interbreeding unit. Figure 4 is an example of two such fossil species of lamp shell (brachiopod). From clusters of such similar species it is possible to hypothesize that the cluster represents an evolutionary history of divergence from a common ancestor.

In the cat family, for example, cheetahs are distinct from other kinds of cats, but are more like cats than like any kind of dog. Dogs and bears each form a distinct species cluster, but the dog and bear clusters are closer to each other than either is to the cat cluster. However, the dog, bear, and cat clusters resemble each other (form a "supercluster") more than they do sheep or whale or monkey species clusters. In the same way all lamp shell species form a cluster quite distinct from the clam species cluster. If very similar species share a considerable inheritance from an immediate common ancestral population, evidently the members of a "supercluster" have a more distant common ancestry and share a smaller inheritance. Thus, in a very broad way the similarities among species define their closeness in time and way of life to a common ancestry: the differences between species chart their divergence.

The classification of plants and animals, both fossil and living, attempts to map the pattern of similarities and differences regardless of its probable evolutionary implication. The basic unit is the *species*. A cluster of similar species is called a *genus* (plural, *genera*). Similar genera are allocated to the same *family;* similar families to the same *order;* orders to the same *class;* and classes to the same *phylum* (plural, *phyla*). Intermediate groups are identified with prefixes such as *sub-* (less than) or *super-* (more than), so a classification might include *subphyla* and *superorders*.

A system of naming organisms has been set up to correspond to the classification scheme. The name of a species includes the name of the genus to which it belongs and an adjective specifying which species within the genus. For example the species *Homo sapiens* (present-day man) and *Homo erectus* (an extinct species known only through fossils) belong to the genus *Homo*. The family is given the name of a representative genus plus the distinctive suffix "-idae," for example Hominidae for the family containing the genera *Homo* and *Australopithecus* (fossil ape-men). The name of an order may be made up from a generic name, as Spiriferida for an order of lamp shells containing *Spirifer*, or a separate term may be applied, as "primates" for the order containing monkeys, apes, and man. Higher groups—classes and phyla—typically have distinct names not derived from genera, as "Mammalia" for the class of warm-blooded, fur-bearing animals, "Aves" for the class containing the birds, and "Brachiopoda" for the phylum that includes the lamp shells.

Identification and Names

Look back now at your specimens. If you collected from rocks 350 million years old, you might encounter fossils like those in Figure 1. In sorting them out, you recognize several species, some quite similar and possibly belonging to the same genus or family (Figure 4); others come from different orders or phyla and because of this are more distinct (Figure 5).

Thousands of fossil species, genera, and even families have been recognized and named. The fossils you have collected will probably belong to one of the more common kinds; your problem is to determine which names among these thousands go with your specimens. The best way to make the identification is to work from the phyla and classes, which are few in number and quite distinct (Appendices I and II), toward genera and species, which are numerous and differ only in subtle features. Thus comparison of a fossil in Figure 4B with the description in Appendix II indicates that the species, whatever it is, must belong to Phylum Brachiopoda. This may be all you need or wish to know. If, however, you wish to identify the fossil to species level, you will find that this phylum contains a large number of genera and species. Fortunately, only a few occur in rocks of a particular age. Appendix III tells what fossils may be found

Figure 4. Two species of lamp shell (brachiopod) from shale in Cazenovia Creek, Erie County, New York. (A) *Mediospirifer audacula*. (B) *Mucrospirifer mucronatus*. The most striking difference appears when the shells are viewed from the hinge margin (lower photos). Further examples of each species are shown below the line.

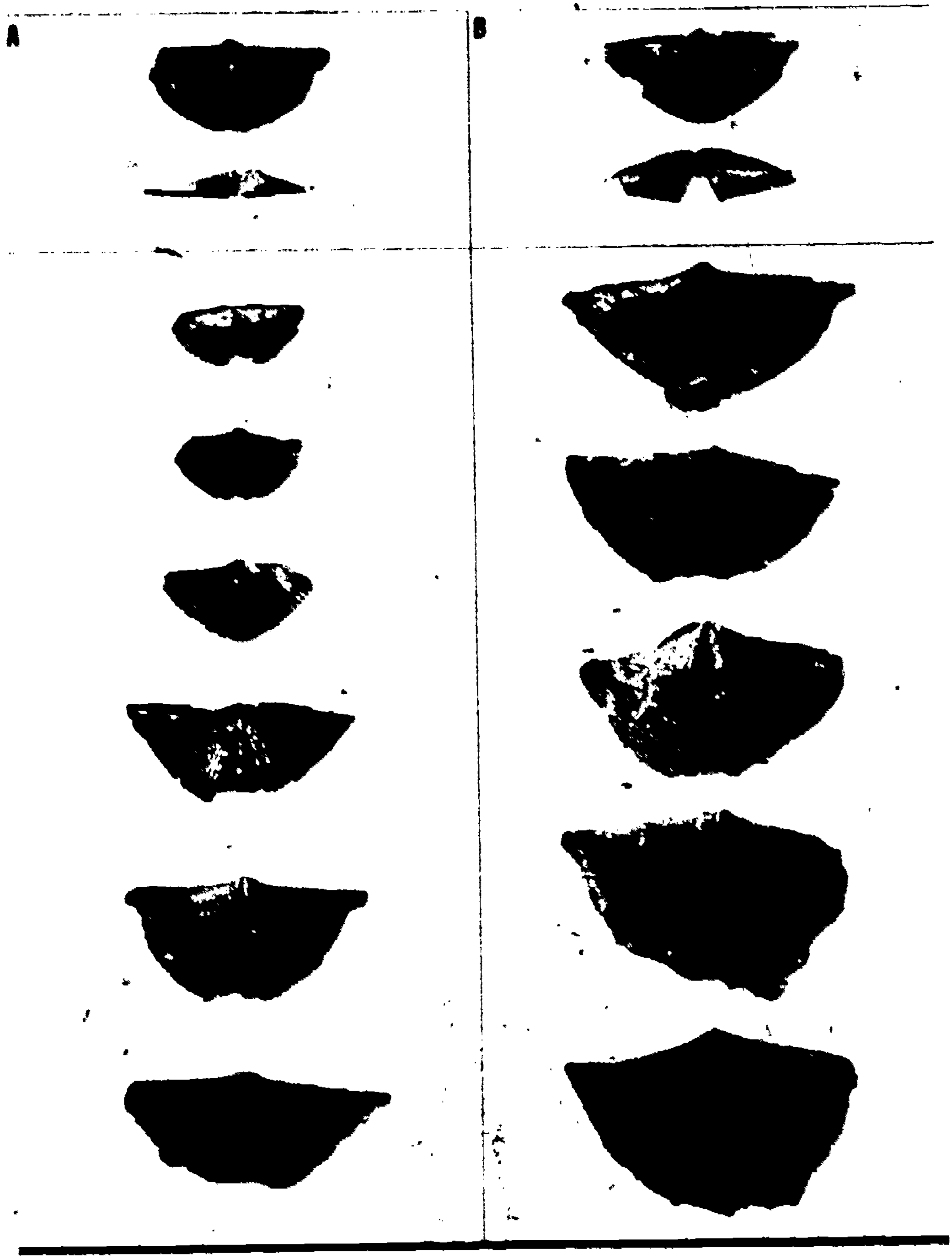


Figure 5. Samples of relatively different species.

in rocks of different ages. The specimens shown in Figure 4B were collected in rocks of Devonian age in western New York. Comparing them with the descriptions and illustrations in a source book (see References) indicates that they are very similar to the genus *Mucrospirifer* and, particularly, like the species *Mucrospirifer mucronatus*.

Clearly, to make an identification you must know the general kinds of fossil plants and animals and the overall forms of their skeletons (Appendices I and II). In addition, you will need to know some of the names of various skeletal forms and parts. Some good sources are listed in the References. Some state geological surveys offer pamphlets on common fossils of that state. If you can tell the geologists of the state survey or the nearest college or university the general kinds of fossils you have, precisely where you collected them, and the age of the rock layers (if you know), they may be able to help.

Then, knowing the kinds of animals or plants, the What are they? you are ready to answer the final and most interesting question, How did they form?

UNRAVELING THE MYSTERY

Each fossil represents a plant or animal that lived in a particular place in a particular way, had distinctive associations with other organisms, died and was preserved in some fashion, and represented the products of a long period of biological evolution. Much of this history is permanently lost, but with skill and patience you may be able to learn much about it. The problems discussed in this section can be tackled by beginners in the study of fossils; as you learn more, you will find additional questions that require an extensive knowledge of living plants and animals, of the deposition of sediments, and of the processes that produce fossils.

Impressions in the Rock

Before thinking about fossils as living animals or plants, it helps to understand them as fossils. In other words, a fossil is an object in a rock, thousands or millions of years distant from the living organism. Its present condition—shape and chemical composition--reflects events that have occurred since its death as well as while it lived.

The first question to ask is, How is the fossil preserved? Is it a mold or cast? If it is either, then some time during its history the environment within the sediment or rock must have destroyed the original materials. Organic compounds, those composing the flesh or soft tissues of organisms, can be destroyed by scavengers, bacterial decomposition, and chemical decay. Thus, soft-tissue preservation is rare and typically occurs as tightly compressed molds or casts, sometimes called *impressions*. The fossilization of soft tissues implies rapid burial away from scavengers and relatively little oxygen in the sediment. Traces of relatively resistant organic compounds may be preserved as carbon and simple carbon compounds. Coal is a fossil aggregate of this sort. The inorganic compounds, such as the calcium carbonate and silica composing skeletons and shells, are more stable chemically and are largely indigestible to either bacteria or scavengers. Even resistant minerals, however, may be destroyed. The commonest skeletal material, calcium carbonate, dissolves in weak acids. In the shales of western New York described in the Introduction, shells of the brachiopods (lamp shells) are preserved without obvious modification even in microscopic structure. On the other hand, many of the mollusks—snails, clams, and cephalopods—have no trace of the original skeleton; they occur as molds.

Solutions percolating through the rock or sediment may add new minerals or replace the original minerals in the skeleton. Thus the fine pores in wood may be filled with silica; the wood may later decay and leave behind its fine structure preserved solely in silica Replacement may occur on a fine scale, preserving delicate details of the original skeleton, or may be so coarse that the result is simply a cast representing the gross external structure. Perhaps the most common type of chemical replacement is the replacement of the original carbonate by calcium carbonate. Other minerals, such as silica or iron sulfide, may be involved.

Physical alteration of form also occurs, either through the compacting weight of sediment accumulating on top of the fossil-bearing layer, or through the stress imposed on the rock in later bending and folding. In the latter case, the direction in which the fossils are stretched or deformed may indicate the direction of stress; in the former, the amount of flattening may reveal something of the original properties of the sediment. Muds with much original pore space will compact greatly and the entombed shells may be highly deformed; those with little pore space will contain fossils that show only a little flattening.

Reconstruction of the Living

The most complete fossil records are traces of soft parts—muscles, sense organs, blood vessels—indicated in details of the skeleton. These in turn reveal something of the activities of the organism. Making a reconstruction requires knowing something of the organization of living plants and animals. The clam shells illustrated in Figure 6 serve as an example. The round scars on the inner surface of the shell indicate attachment of the muscles which close the shell; the "teeth" at the top of the shell form the joint about which closure is made. In some clams that live in burrows, the muscles and

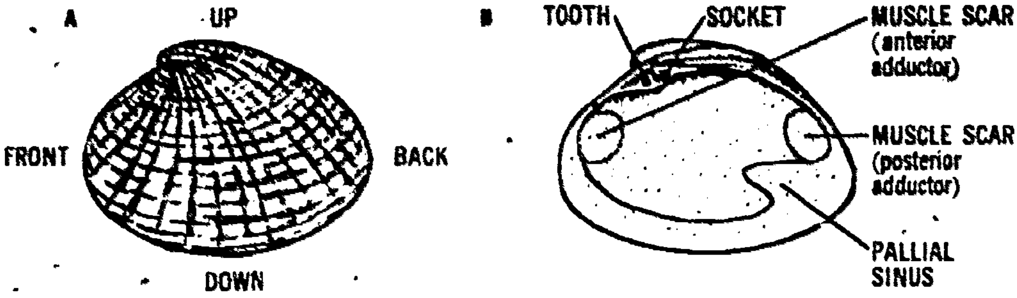


Figure 6. Interpretation of mode of life from skeletal form: clams. (A) Exterior of left portion (valve) of a clam shell. (B) Interior of right portion (valve) of a clam shell.

"teeth" are small because the burrow walls restrict movement of the shell: in other clams that crawl or burrow actively along the sea bottom, the muscles and "teeth" are strongly developed. Similarly, a shallow groove on the inner surface of the shell (the "pallial sinus" of Figure 6) marks the attachment of the tube, the *siphon*, through which the clam draws water into its shell. The size of the groove reflects the size of the siphon; that in turn is related to how deep the animal burrows.

In older rocks *trilobites*, distant relatives of living crustaceans, are relatively common. Most have a broad, flattened body, a shape common to animals that swim or crawl along the sea floor. Thus one might hypothesize such a way of life for trilobites. An interesting check on this interpretation is the form of the trilobites' eyes. Like their living relatives, trilobites had compound eyes consisting of narrow tubes with lenses at the outer ends. Since the individual tubes could accept light from only a narrow angle, the direction of the tube defined the field of vision, or the direction in which sight was possible. For example, tubes pointing upward from the head would "see" above; those pointing forward would "see" forward. Since Figure 7 shows that the lenses and tubes of a trilobite point forward, to the sides, and to the back, it almost certainly lived on the bottom of the sea floor. The limited upward vision further suggests that its enemies and food must also have been largely on the bottom rather than in the water above.

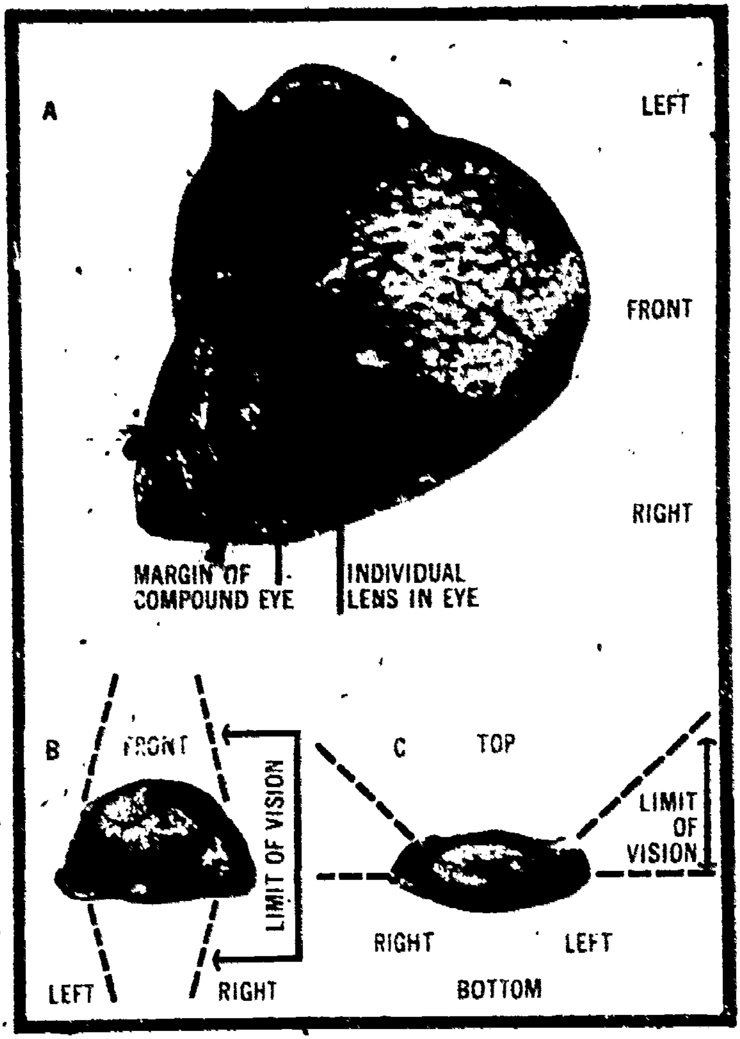


Figure 7. Interpretation of mode of life from skeletal form: trilobites. (A) General form of head viewed from upper right. (B) Head, from above. (C) Head, from front.

Fossil Calendars

Many animals such as clams, brachiopods, and corals preserve traces of their growth in their shells or skeletons. For example, a brachiopod periodically adds a layer of material along the edge of its shell. Its shell consists of a series of growth rings separated by fine lines called *growth lines* (Figure 8) similar to the rings of a tree trunk. When the animal is growing rapidly, the rings are wide and the lines widely spaced; when it grows slowly, the lines are closely spaced. How might you use such information in order to determine whether

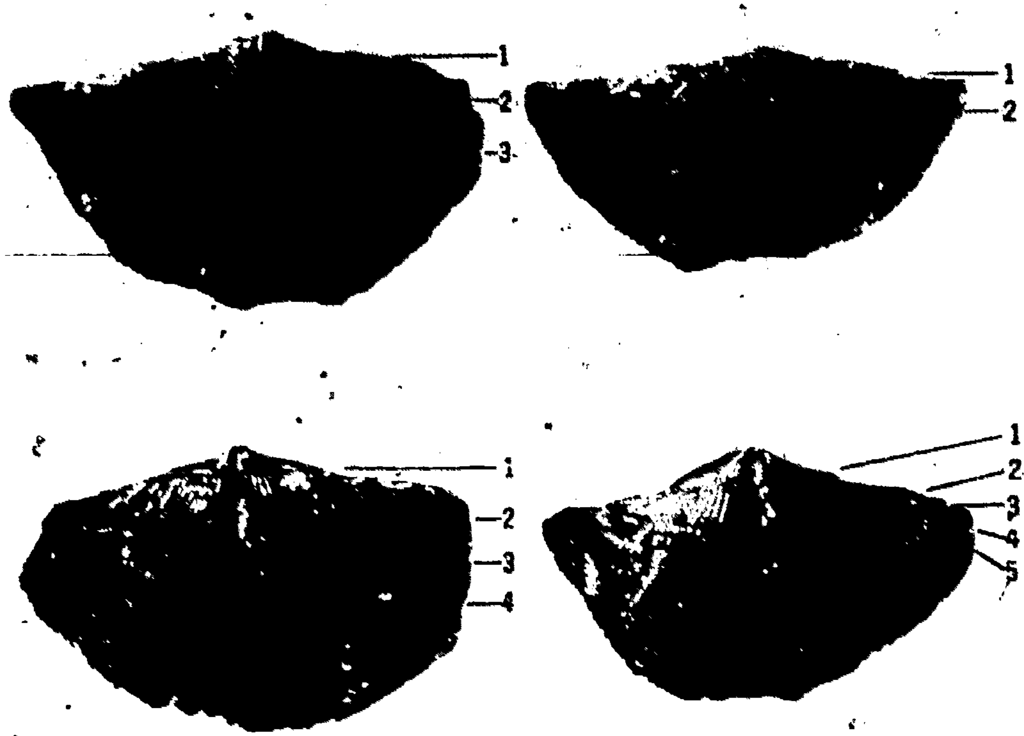


Figure 8. Growth lines in brachiopods. Specimens of *Mediospirifer audacula* from Cazenovia Creek, Erie County, New York. Note very strong "growth lines" indicated by numbers that suggest prolonged interruptions in growth.

the environment remained constant all year or showed seasonal variation? Could you determine the ages of animals at death? Some animal skeletons apparently show daily growth layers: studying them may enable paleontologists to determine whether the number of days in a month or in a year has remained constant for the last several hundred million years.

Taking a Census

The fossils you find may have been transported into the sediments in which they are found after the animals' deaths. Some of the shells may have been washed away before sediment buried them; or the smaller skeletons or those made of more soluble minerals may have been dissolved rather than preserved. If you wish to make a census of ancient populations, you will need to determine how important all these factors are.

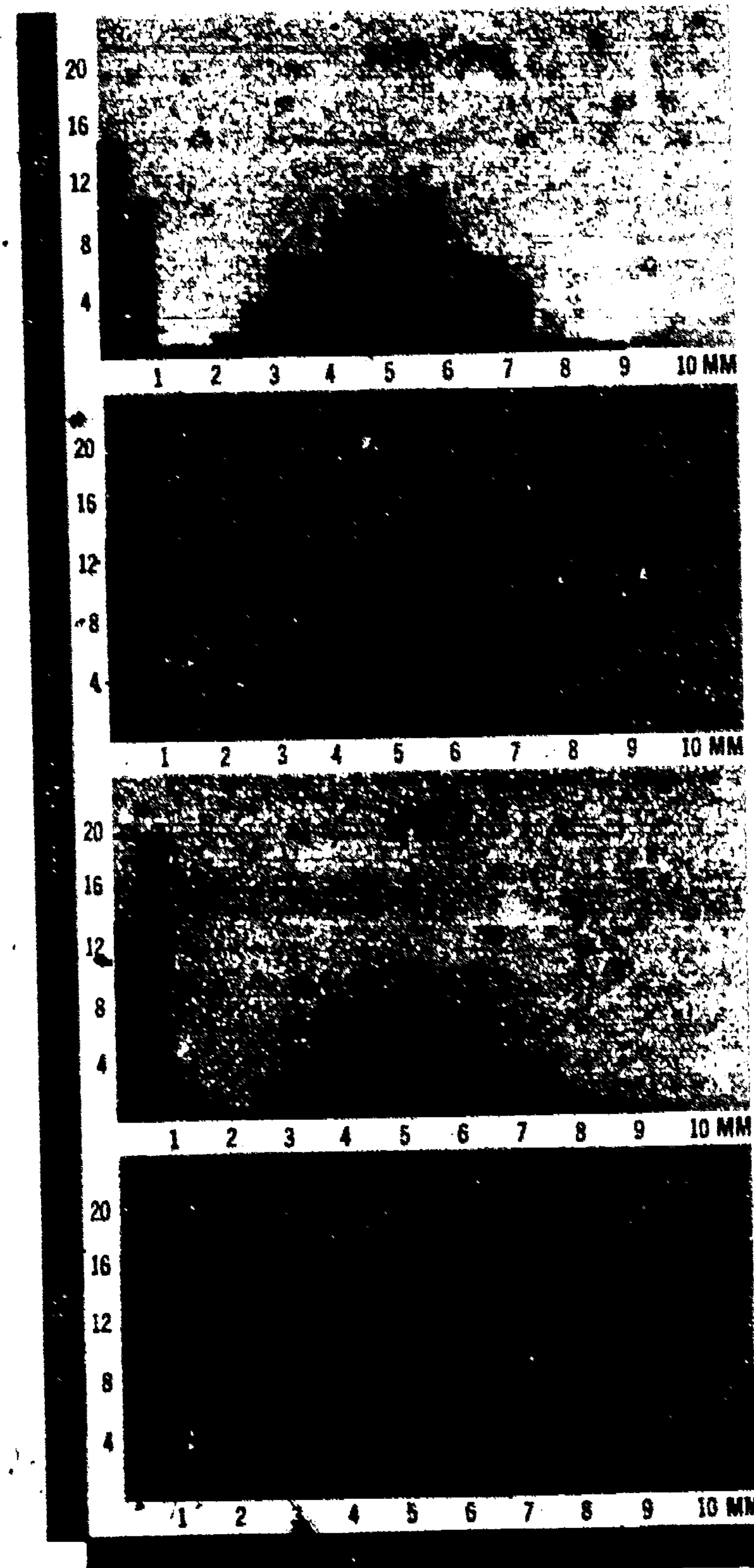
What questions might you ask to settle these problems? Are many of the shells broken or worn and polished? Are delicate spines broken off or etched away? Are all the fossils about the same size and shape, as if sorted? A careful study of your collection will permit you to make other tests. For example, the shells of clams and brachiopods are hinged together and, after the death of the animal, may separate. Count the shells and determine the number still fastened together as against the number separated. Are the two halves present in equal numbers? If moved by a current, the shell should have its flat or hollow side down. Since most brachiopods lived "beak" or round side down, you might study their position if you have any in your collection.

Figure 9 shows the length measurements made on a large number of brachiopods from a small area in very thin layers of sediment. The shell size must have some relationship to the age of the animal at death—on the average, larger individuals must have been older. In general, the relatively great abundance of small individuals suggests that initial death rates were high. Few individuals died in the "adolescent stage." The abundance of mature individuals evidently results from slow growth and probably increased mortality after reproduction. Note the differences in relative mortality among the successive layers of sediment. What might this indicate about the environment?

Measuring the Past

If you can establish that your collection represents a considerable part of some ancient animal community, not strongly modified by transport of shells, then you can make some reasonable conclusions about the environment of that community. In general, the greater the number of different

Figure 9. Census of successive fossil brachiopod populations. Graph of the percentage of fossils of a particular size from each of four successive thin layers of sediment. D is the bottom and oldest layer in the series, A the top and youngest.



kinds of fossils relative to the number of fossils, the better the environment was. Today the maximum variety of types occurs in warm, shallow, clear sea water with normal salt concentration. If the water is too fresh or too salty, too cool, too deep, or too muddy, not as much variety will occur. Some animals, for example brachiopods, sea urchins, sea lilies, trilobites, and corals, apparently lived only in water with near-normal salt concentration. Others like clams and snails ranged into fresh water (low salt) streams and lakes. An abundance of corals and bryozoans ("moss animals") probably also means warm, shallow, clear water.

If you can collect fossils from a series of layers one on top of another, you may be able to observe progressive changes in environment as the diversity increases or decreases and as certain kinds of fossils appear or disappear in the sequence.

Fossil Clocks

One timekeeping aspect of fossils—their growth—has already been discussed. The other and more important is the use of fossils to establish the age of the rocks in one place relative to those in another. Evolution, the change of plant and animal populations along unique paths through time, provides the mainspring of this fossil clock. The dial of the clock is calibrated by observing the sequence of fossil animals and plants that occur in a sequence of rock layers deposited one atop another. When a part of this sequence is found elsewhere, it is concluded to represent about the same time interval (Figure 10). The clock is not perfect, but it is commonly the best way to determine geologic age.

Your preliminary work on identifying fossils should give you a guide to the age of your collection by the standard Geologic Time Scale (Appendix III).

For example, the set of fossils in Figure 1B includes trilobites, brachiopods, and bryozoans.

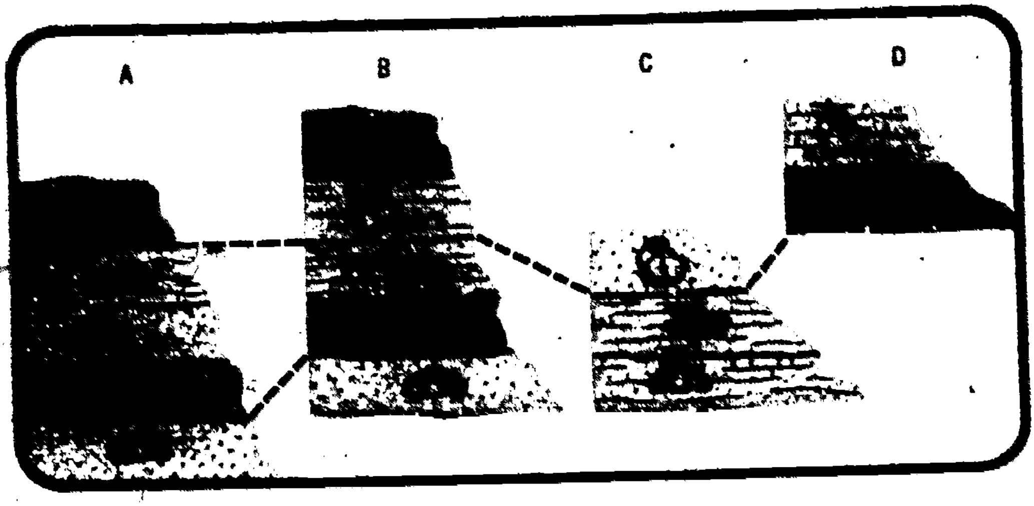


Figure 10. The fossil sequence. Diagrammatic illustration of the fossil sequence in four different places, e.g., different quarries and road cuts. A similar sequence occurs in each series of sedimentary layers. The layers are matched from place to place on the basis of this sequence

From Appendix III, you can see that trilobites are limited to rocks 600 to 230 million years old; brachiopods extend from about 600 million years to the present; bryozoans from about 520 million years to the present. The fossils, and their rocks, must therefore be older than 230 million years (older than Triassic) and younger than 520 million (younger than Precambrian). The trilobite is actually *Phacops rana*, and one of the brachiopods is *Mucrospirifer mucronatus*, both species known only from rocks of Devonian age. From Appendix III, this makes them between 350 and 400 million years old.

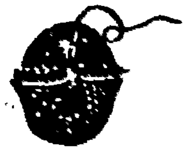
As you gain experience, you may be able to construct a refined clock for your local area by observing the sequence of fossils in a well-exposed series of layers. You can then use this sequence to date other rock layers in adjacent areas. However, always remember that you may be observing a sequence of *environments* rather than a sequence of *evolution*.

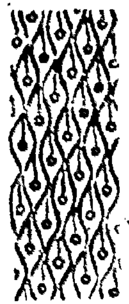
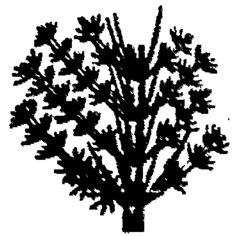
Meaning of the Past

Fossils are the ultimate evidence for the pattern of organic evolution; since any theories of evolutionary process must conform to this evidence, the study of fossils is critical to continued refinement of evolutionary theory. Fossils are equally critical to the determination of time relationships for the physical and chemical history of the earth and provide evidence for changes in climate, the atmosphere, and the oceans. Fossils are one of the principal keys to the earth's past, and any thoughtful collection and study of fossils can contribute to our understanding of that past. You can become a partner in this endeavor.

8 APPENDICES

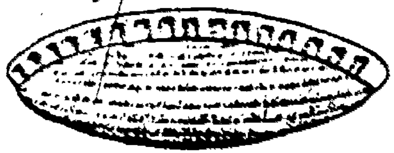
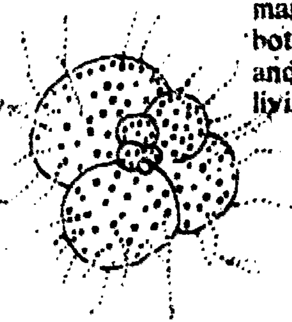
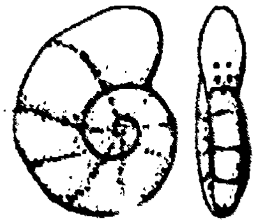
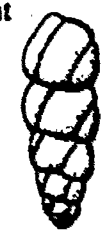
I—Major Groups of Plants Represented by Fossils

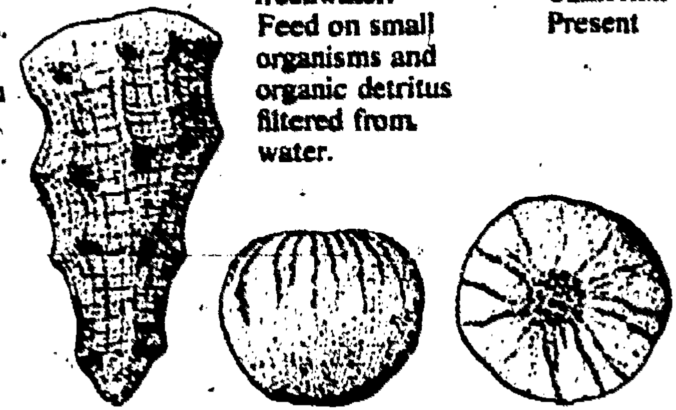
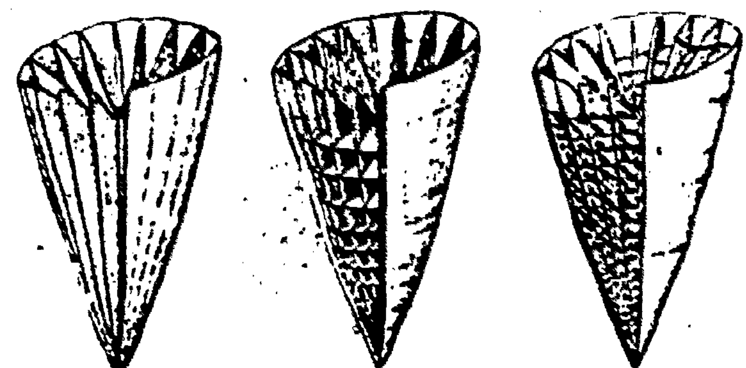
Group	Characteristics	Appearance of Typical Species	Habits and Habitat	Geologic Occurrence
Cyanophyta (phylum)	Blue-green algae—single cells or simple colonies. Most common fossil occurrence as sheetlike, laminated deposits of calcium carbonate trapped on algal mat.		Marine and freshwater. Bottom-living and floating.	Early Precambrian to Present
Pyrrophyta (phylum)	Dinoflagellates—microscopic, unicellular plants with spiny skeleton of cellulose.	 		Jurassic to Present
Chrysophyta (phylum)	Diatoms—microscopic unicellular plants with disklike skeleton of calcium carbonate.		Marine and freshwater. Predominantly floating.	Jurassic to Present
Psilopsida (phylum)	Simple vascular plants with upright branches arising from a horizontal stem without leaves or roots. About 30 cm.		Terrestrial.	Silurian to Present

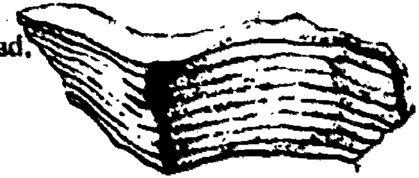
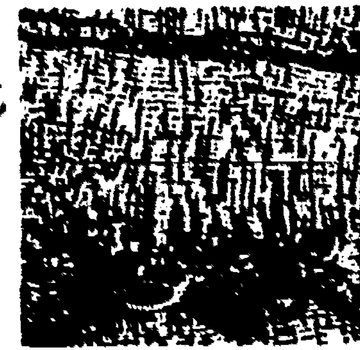
Lycopsida (phylum)	Club mosses—plants with simple strap-like leaves. Leaves typically form scars on stem and result in a scale-like pattern.		Terrestrial.	Devonian to Present
Sphenopsida (phylum)	Horsetails—plants with slender leaves arranged in whorls around segmented stem. About 10 cm.		Terrestrial.	Devonian to Present
Pteropsida (phylum)	Ferns.		Terrestrial.	Devonian to Present
Spermopsida (phylum)				
Cycadophytae (class)	Cycads—plants with generally palmlike form and foliage but without flowers.		Terrestrial.	Triassic to Present

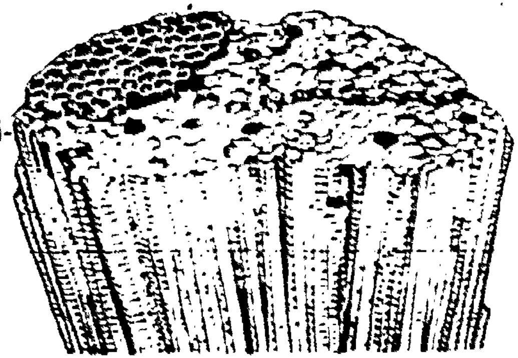
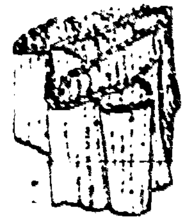
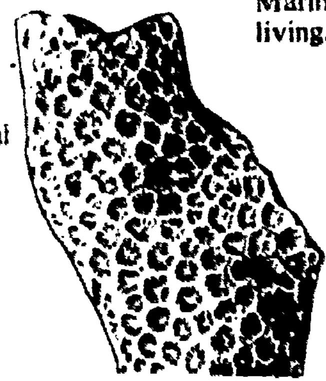
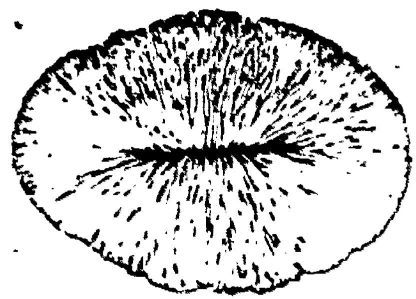
Group	Characteristics	Appearance of Typical Species	Habits and Habitat	Geologic Occurrence
Peridospermae (class)	Seed-ferns—plants with fernlike foliage but bearing seeds.		Terrestrial.	Devonian to Jurassic
Coniferophyta (class)	Conifers—needlelike leaves and cones.		Terrestrial.	Pennsylvanian to Present
Ginkgophyta (class)	Ginkgoes—distinctive fan-shaped leaf about 3 cm across.		Terrestrial.	Permian to Present
Angiospermae (class)	The flowering plants. Seeds enclosed in fruit.		Terrestrial.	Jurassic to Present

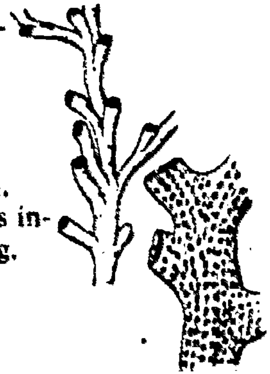
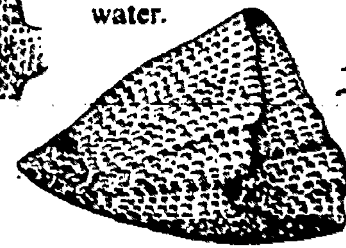
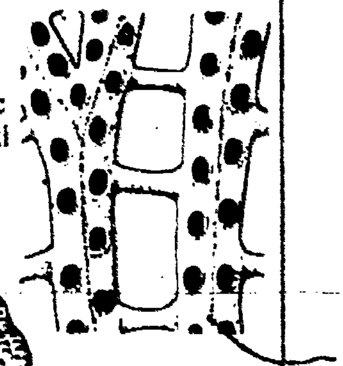
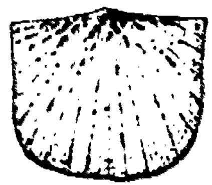
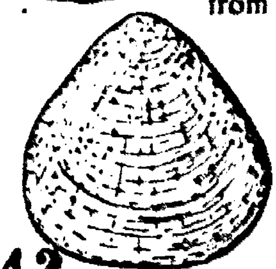
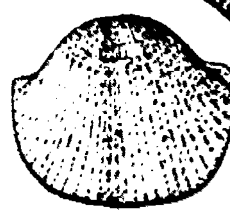
II—Major Groups of Animals Represented by Fossils

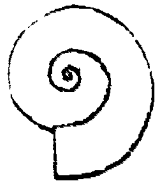
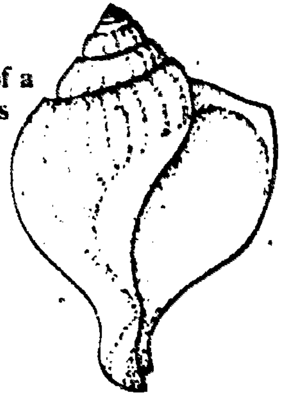
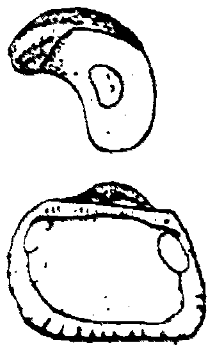
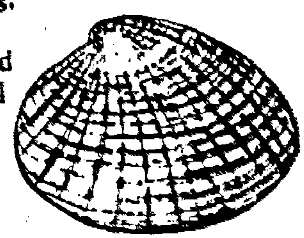
Group	Characteristics	Appearance of Typical Species	Habits and Habitat	Geologic Occurrence
Protozoa (phylum)				
Sarcodina (class)				
Foraminifera (order)	Single-celled animals. Largely microscopic, although a few range up to 25 cm or more in length. Skeleton typically of calcium carbonate consisting of one or more chambers connected by pores (foramina) and opening externally through one or more apertures. Chambers may be variously arranged—serially or coiled. 	  	Principally marine. Include both floating and bottom-living types.	Cambrian to Present
Radiolaria (order)	Single-celled microscopic animals. Skeleton of silica "rays" arranged in complex latticework with some degree of spherical symmetry.		Marine, largely floating.	Cambrian to Present

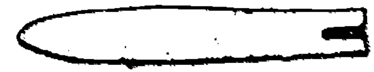
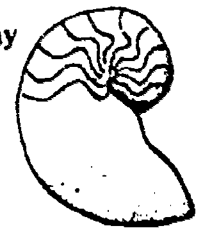
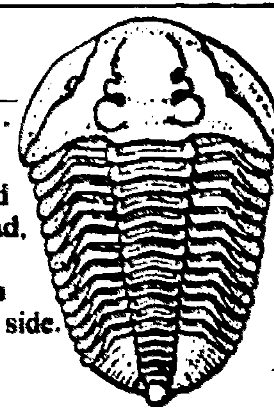
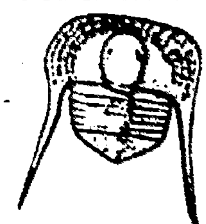
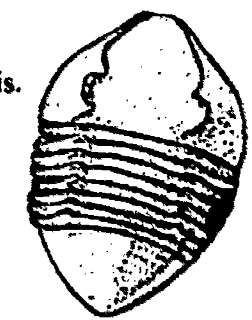
Group	Characteristics	Appearance of Typical Species	Habits and Habitat	Geologic Occurrence
Porifera (phylum)	The sponges. Multicellular, but cells not organized into tissues. Canal system with numerous tiny external pores. Skeleton of fibers or spines (spicules) of calcium carbonate, silica, or spongin (an organic material). Spicules may be loose or bound into a rigid skeleton. Overall form radially symmetrical or asymmetrical. About 10 cm.		Marine and freshwater. Feed on small organisms and organic detritus filtered from water.	?Precambrian. Cambrian to Present
Coelenterata (phylum)	Multicellular animals with cells organized into tissues.			

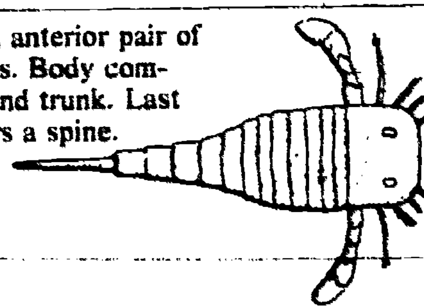
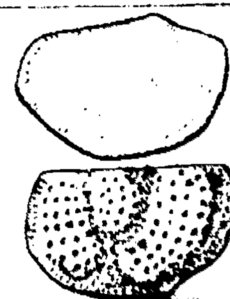
Hydrozoa (class)			
Stromatoporoidea (order)	Extinct. Skeleton of calcium carbonate built by colony of small individuals (polyps). Skeletal structure consists of horizontal sheets (lamellae) connected by vertical rods (pillars). Broad, domal masses of more or less hemispherical form.  	Marine, bottom-living, sessile (fixed).	Cambrian to Cretaceous
Anthozoa (class)			
Rugosa (order)	Extinct order of corals. Lived in colonies. Basic skeletal plan comprises cone divided internally by radial vertical plates (septa) typically including numerous large or small horizontal plates. May be solitary or consist of closely packed individuals in colony. Septa show a four-fold symmetry in development. About 3 cm long. 	Marine, bottom-living, sessile.	Ordovician to Permian

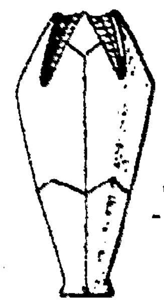
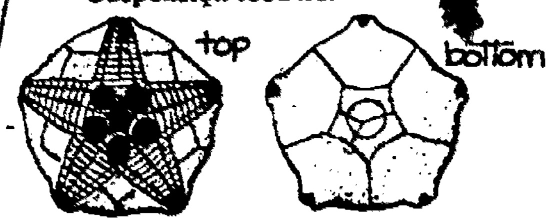
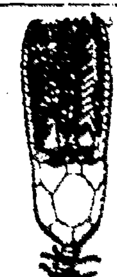
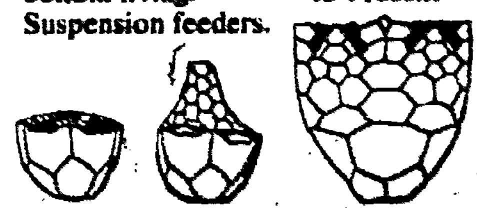
Group	Characteristics	Appearance of Typical Species	Habits and Habitat	Geologic Occurrence
Tabulata (order)	Extinct order of corals. Lived in colonies. Basic skeletal plan consists of attached calcium carbonate tubes (typically 2 mm or more in diameter) each built by a single individual. Tubes typically connected by pores and divided by horizontal partitions. Vertical partitions (septa) rudimentary or missing.	 	Marine, bottom-living, sessile.	Ordovician to Permian
Scleractinia (order)	The stony corals. Calcium carbonate skeleton consisting of cone with radial vertical plates (septa). Development of septa shows a six-fold symmetry. Include a variety of colonial and solitary types. About 10 cm.	 	Marine, bottom-living, sessile.	Triassic to Present

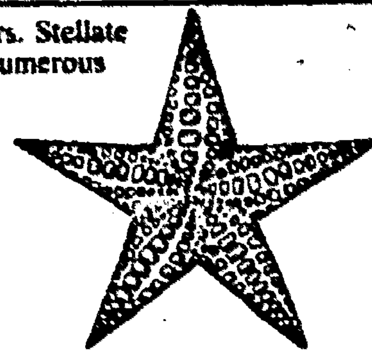
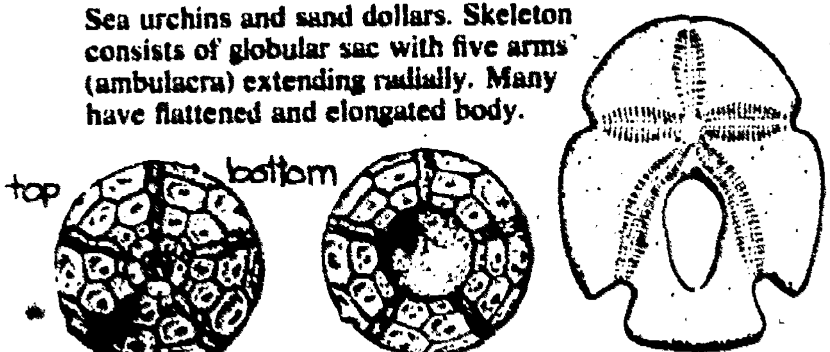
Bryozoa (phylum)	The "moss animals." Always colonial; skeleton consists of attached calcium carbonate tubes (typically 1 mm or less in diameter), each built by a single individual. Tubes may have various types of internal, horizontal partitions. Colony forms include branching, "lacy," encrusting, or massive hemispherical.	  	All with calcareous skeleton are marine. Bottom-living, sessile. Filter suspended organic particles and small animals from water.	Ordovician to Present
Brachiopoda (phylum)	The "lamp shell." Skeleton of two plates (valves) that cover the body above and below. Each valve is bilaterally symmetrical. Valves close and open by muscles which typically leave attachment scars on inner surface: in most the valves are articulated by a tooth and socket hinge. Presence, typically, of an attachment "stalk" (pedicle) indicated in the skeleton by a circular or triangular opening along the hinge line. One valve always convex, but other may be flat or concave instead. About 3 cm.	   	Marine. Bottom-living, sessile. Filter suspended organic particles and small animals from water.	Cambrian to Present

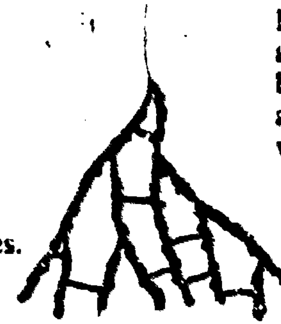
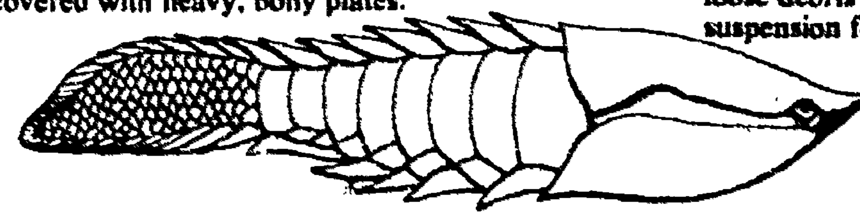
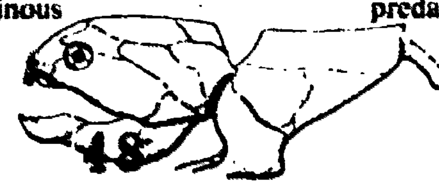
Group	Characteristics	Appearance of Typical Species	Habits and Habitat	Geologic Occurrence
Mollusca (phylum)				
Gastropoda (class)	The snails. Basic skeletal plan consists of an unpartitioned conical calcareous tube coiled on the surface of a cone. In a few the cone of the coil is almost flattened into a plane.  		Marine and freshwater. Primarily bottom-living. Various types feed on plants, on loose debris, and on other animals.	Cambrian to Present
Bivalvia (class)	The clams, oysters, etc. Basic skeletal plan consists of two calcareous plates (valves) hinged above the body and covering either side. Typically the two valves are mirror images of each other, but neither can be divided into symmetrical halves as can brachiopod valves. Commonly the interior shows muscle attachment and tooth-and-socket arrangement for a hinge between valves.		Marine and freshwater. Bottom-living—sessile, crawling, and burrowing. Filter suspended organic material from water or collect bottom debris.	Ordovician to Present 

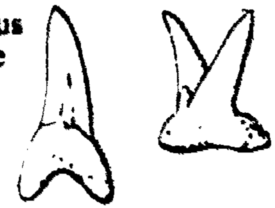
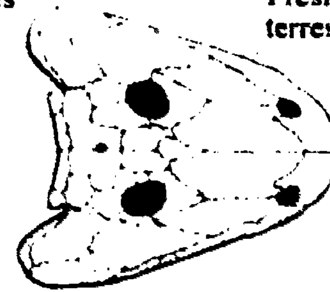
Cephalopoda (class)	Include present-day squids and octopuses. Basic skeletal plan consists of a straight to coiled conical tube divided by internal partitions (septa) which attach to the tube along a suture line. Include many fossil forms with tube coiled in a plane. Skeleton may be covered with nodes and/or ribs, and suture line may be elaborately contorted. One group related to recent squids has a solid calcareous cone similar to a bullet.	    	Marine. Largely active, swimming, carnivorous.	Cambrian to Present
Arthropoda (phylum)				
Trilobita (class)	Extinct. Primitive arthropods with antennae, simple two-branched appendages: no appendages specialized as mouth parts. Body comprises head, multisegmented trunk (thorax), and tail. A central lobe runs along length of body with a flatter lobe on either side.	   	Probably marine and bottom-living. Swam or crawled. Fed on loose debris.	Cambrian to Permian

Group	Characteristics	Appearance of Typical Species	Habits and Habitat	Geologic Occurrence
Merostoma (class)				
Euripterida (subclass)	Extinct. No antennae, anterior pair of appendages bear claws. Body comprises a head region and trunk. Last segment of trunk bears a spine.		Apparently both marine and freshwater. Swam or crawled on bottom. Probably predatory.	Ordovician to Permian
Crustacea (class)	Includes lobsters, crabs, crayfish. Most common fossils are the ostracods, which have a calcium shell (plates on either side of the body and hinged over the back). Ostracods are typically small, 2 mm or less, although a few are over 10 mm long.		Marine and freshwater. Live in a variety of conditions and feed in a great variety of ways.	Cambrian to Present
Insecta (class)	Paired appendages of head specialized as antennae and mouth parts. Body consists of head, thorax, and abdomen. Thoracic segments bear three pairs of walking legs. Most have wings on second and third thoracic segments. Relatively rare as fossils.		Terrestrial and freshwater.	Devonian to Present

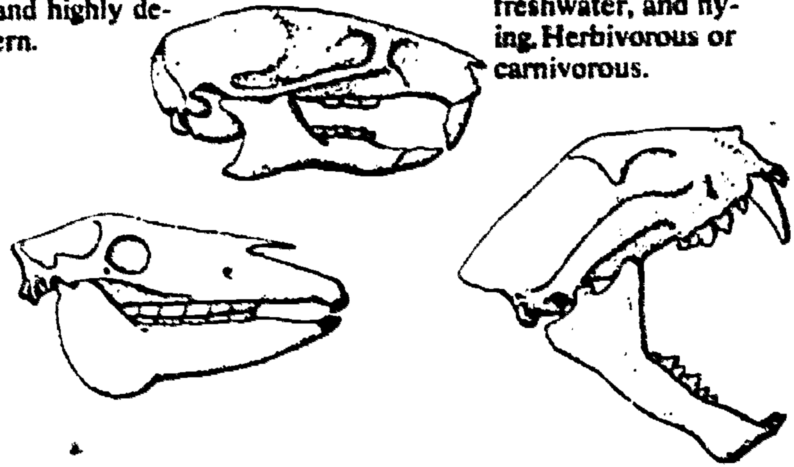
Echinodermata (phylum)				
Cystoidea (class)	Extinct. Skeleton consists of subspherical sac (theca) of irregular, calcareous plates surrounding viscera—typically with stem of stacked calcareous disks. Surface of theca bears one or more "arms" or ambulacra. In well-preserved specimens, short "brachioles" extend up from ambulacra.		Marine, sessile, bottom-living. Suspension feeders.	Ordovician to Devonian
Blastoidea (class)	Extinct. Skeleton consists of globular theca with regularly arranged calcareous plates and stem of stacked disks. Armlike tracts (ambulacra) arranged in five rays about crown of theca.	 	Marine, sessile, bottom-living. Suspension feeders.	Ordovician to Permian
Crinoidea (class)	The "sea lilies." Skeleton consists of globular structure (calyx) bearing long arms and typically carried on a stem. Plates of calyx arranged in regular pattern with five-fold symmetry. Arms missing from many fossils, but bases indicate their presence.	 	Marine, sessile, bottom-living. Suspension feeders.	Ordovician to Present

Group	Characteristics	Appearance of Typical Species	Habits and Habitat	Geologic Occurrence
Asteroidea (class)	The starfishes and brittle stars. Stellate body—skeleton consists of numerous small plates.		Marine, active bottom crawlers. Predatory, loose debris or suspension feeders.	Ordovician to Present
Echinoidea (class)	Sea urchins and sand dollars. Skeleton consists of globular sac with five arms (ambulacra) extending radially. Many have flattened and elongated body.		Marine, burrowing or crawling on bottom. Loose debris feeders or herbivores.	Ordovician to Present
Protochordata (phylum)				

Graptolithina (class)	Extinct group—graptolites. Colonial forms—skeleton consists of one or more tubes (stipes) of chitinlike material 1 mm wide with small lateral openings (theca) housing individual animals. Stipes may show complex branching and interconnections or consist of two to four simple branches.  	Marine, sessile, attached to bottom, or floating attached to seaweed or "float."	Cambrian to Mississippian
Chordata (phylum)			
Agnatha (class)	"Jawless" fish—represented by lampreys. Elongate, fishlike, but without paired fins or jaws. In most the head is covered with heavy, bony plates. 	Freshwater and marine. Probably largely sluggish, loose debris and suspension feeders.	Ordovician to Present
Placodermi (class)	Extinct. Early jawed fish. Elongate, fishlike, with bony or cartilaginous skeleton. Most fossil occurrences are of teeth. 	Largely marine, predaceous forms.	Silurian to Permian

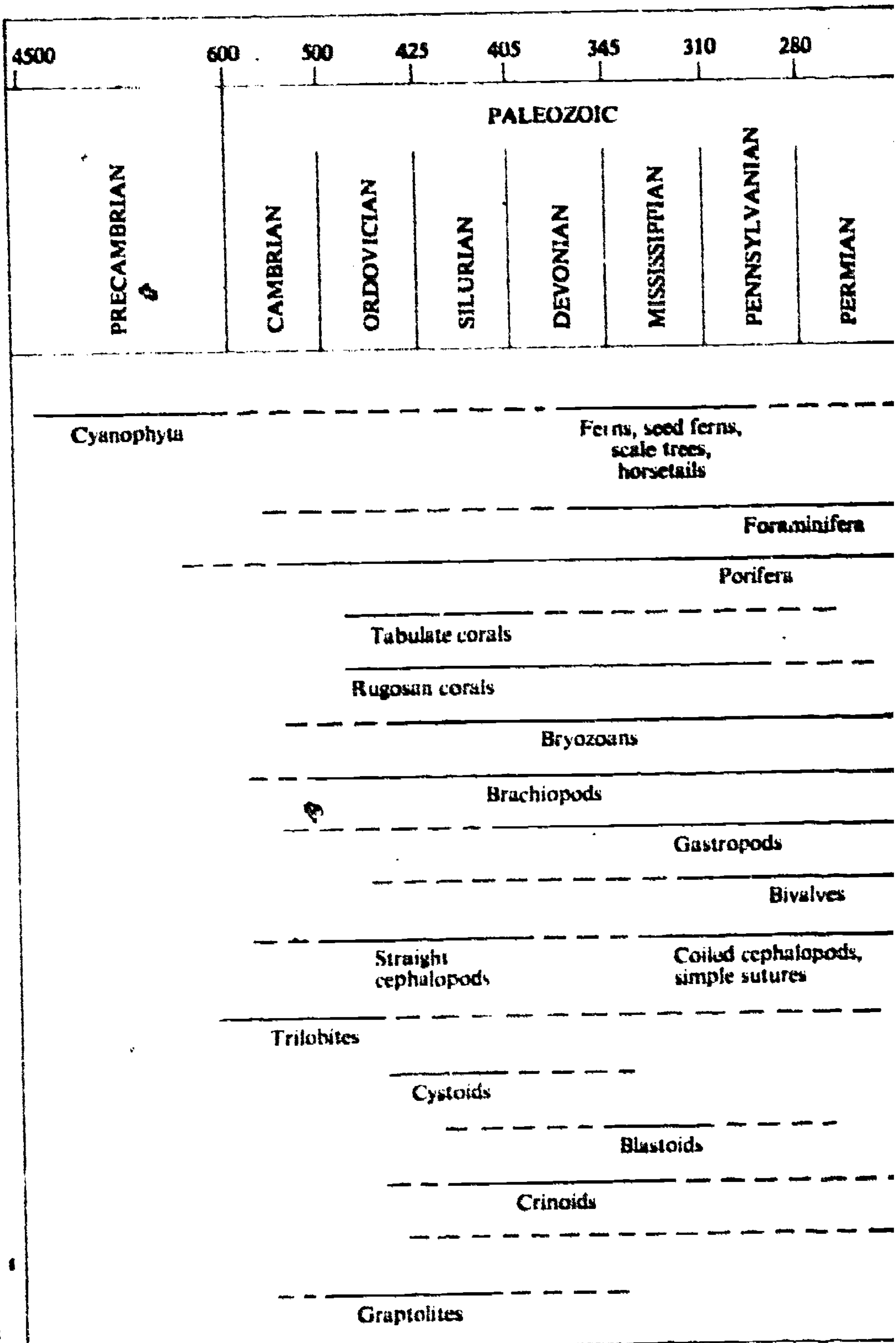
Group	Characteristics	Appearance of Typical Species	Habits and Habitat	Geologic Occurrence
Chondrichthyes (class)	Sharks and rays. Internal cartilaginous skeleton. Most fossil occurrences are of teeth.		Primarily marine, predaceous forms.	Devonian to Present
Osteichthyes (class)	The true, bony fishes Bony skeleton; external bone reduced to thin scales and skull plates.		Marine and fresh-water. Predators, herbivores.	Devonian to Present
Amphibia (class)	The amphibians. Fossil representatives typically have heavy, bony skulls.		Freshwater and terrestrial predators.	Mississippian to Present
Reptilia (class)	Include numerous extinct groups such as dinosaurs, as well as snakes, lizards, alligators, and turtles.		Terrestrial—more rarely, marine or freshwater. Herbivorous or carnivorous.	Pennsylvanian to Present

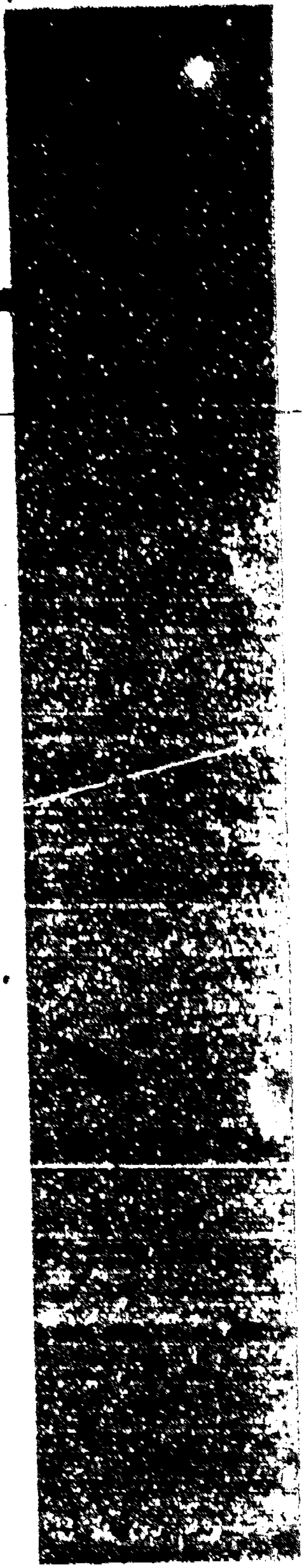
Aves (class)	Birds. Very rare as fossils.	Flying and terrestrial.	Jurassic to Present
Mammalia (class)	Marsupials, placentals, and some extinct groups. Particularly marked as fossils by complex and highly developed dental pattern.	Terrestrial—more rarely, marine, freshwater, and flying. Herbivorous or carnivorous.	Triassic to Present



III—Geologic Time and Fossil Occurrence

Solid line indicates abundant and varied; dashed line indicates abundant but less varied.





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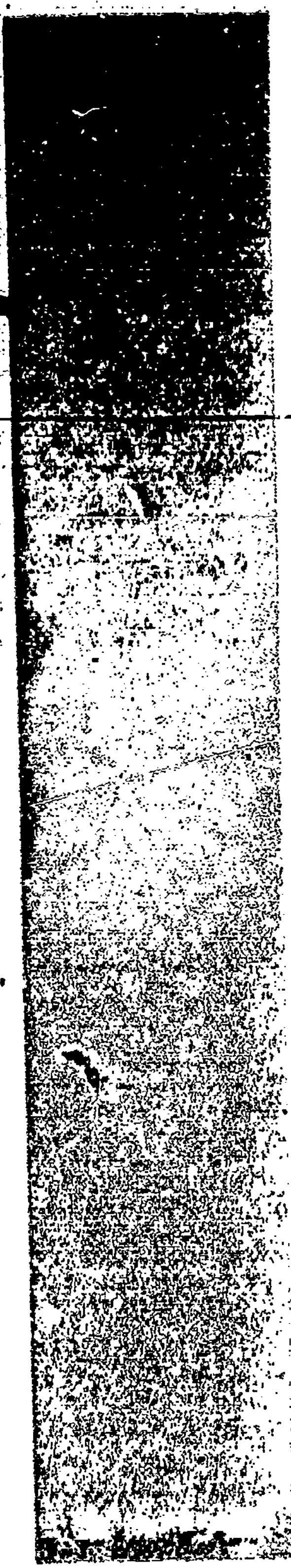

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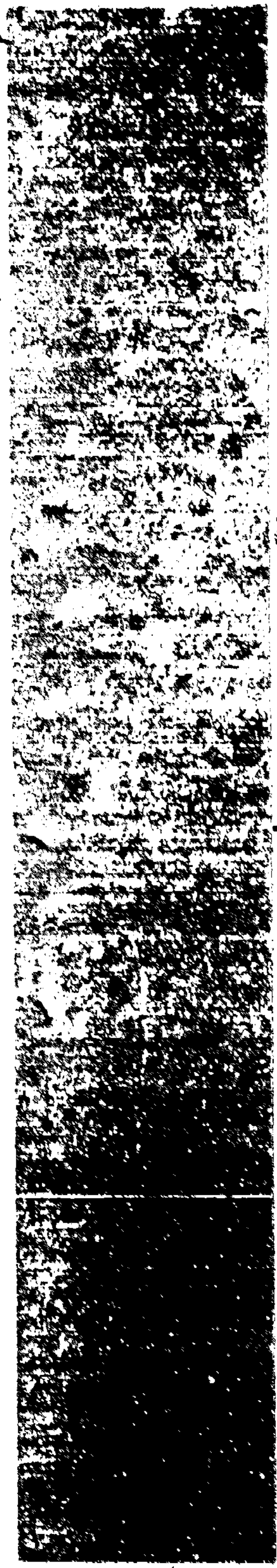

Glossary

brachiopod—the technical name for a group of organisms having an external skeleton consisting of two large plates or valves, one above and one below the body. Brachiopods are also called lamp shells.

bryozoan—the technical term for a group of organisms having a compound skeleton of calcium carbonate tubes built by large numbers of tiny individuals. Bryozoans are also called moss animals.

cast—fossil preservation by material filling the void in a rock left by dissolution of the original skeletal material.

clam—the popular term for a group of organisms having an external skeleton consisting of two large plates or valves, one on either side of the body.

classification—in biology and paleontology, the arrangement of organisms or fossils into groups and subgroups on the basis of overlapping biological properties—commonly physical resemblance. Presumably such arrangements correspond in some way to their evolution.

fossil—some evidence of ancient life, including "body fossils" representing a part of an organism and "trace fossils" representing some activity such as a track or burrow.

fossilization—the various processes by which all or part of an organism is transformed when it becomes a fossil.

genus—a collection of one or more biological or fossil populations, or species, which resemble each other more than they do other such collections and presumably have a common ancestral population in the not-too-distant past.

microfossils—body fossils of very small organisms such as protozoans and plant spores and pollen.

mold—a type of fossil preservation consisting of the impression in the sediment surrounding the original skeletal material.

replacement—a type of fossil preservation in which crystal grains in the skeleton or molecules comprising the tissues of an organism are removed and other grains, of similar or different composition, are substituted.

species—biologically, a population of organisms in which exchange of genetic material occurs through interbreeding; paleontologically, a "population" of fossils sufficiently similar in form to correspond to the similarity observed within a biological species. Each species is given a unique name consisting of a "generic noun" and a "specific adjective"—as *Homo sapiens*.

trilobite—an extinct group of sea-floor inhabiting animals related to crustaceans, insects, and spiders which typically consist of a flat body with a large head, a multisegmented trunk, and a large tail.

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