12

Fossil Indicators of Age, Environment, and Correlation

Fossils and Age Determinations

Perhaps the most important value of fossils to geology is the means they provide for differentiating and recognizing units of rock deposited during particular increments of geologic time. Because fossils change or evolve through time, they serve as distinctive and nonrepetitive markers in vertical successions of sedimentary rocks. However, in order to make use of this attribute of fossils, geologists must determine the total time span or **geologic range** during which particular organisms lived. The geologic range of an organism is not known *a priori,* but is determined by experience. Only after collections of fossils are made from successively higher (and thus younger) beds in many geologic sections will the total geologic range of organisms be disclosed. In practice, the determination of geologic ranges can become quite involved. However, the general principle is illustrated by the situation depicted in Figure 12.1.

Study Questions

1. Using the "Law of Superposition," arrange the letters representing the geologic systems in proper vertical order in the geologic column on the left side of Figure 12.1.
2. By means of vertical arrows or heavy lines, plot the vertical ranges of fossils F-1 and F-2 in the space to the right of the standard geologic column.
3. During which of the geologic periods were the rocks in unexplored region IV deposited?

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4. During which geologic periods were the rocks in unexplored region V deposited?

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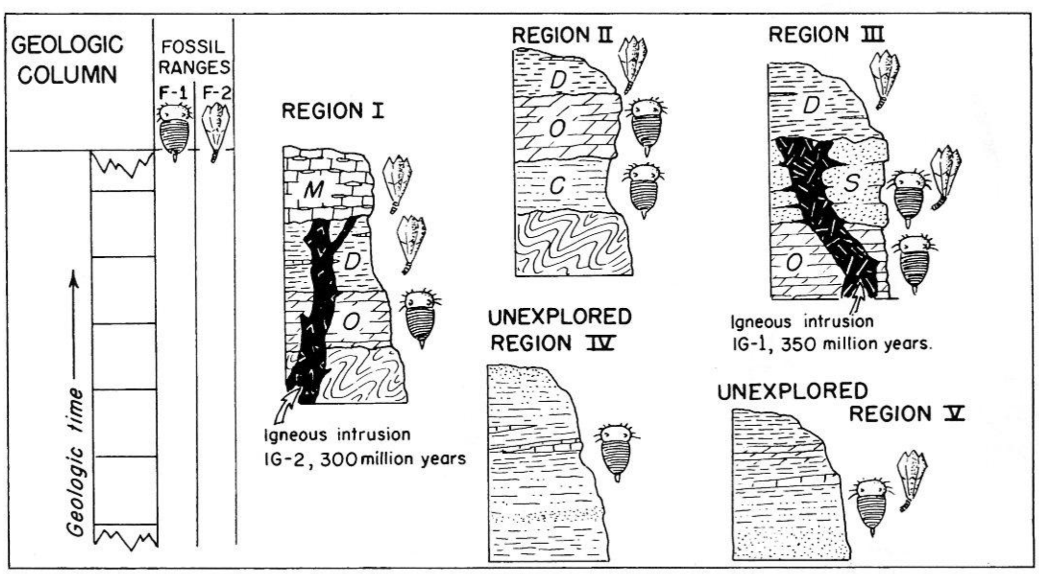
Figure 12.1 Problem illustrating the determination and use of geologic ranges of fossils. Capital letters on the sections of different regions represent rocks deposited during hypothetical geologic periods analogous to, for example, the Silurian Period.



5. What statement can be made about the age of rocks in unexplored region IV?

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6. What statement can be made about the age of rocks in unexplored region V?

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7. The following questions refer to Figure 12.2. The figures in Chapters 10 and 11 will be useful in answering these questions.

   a. On limestone slab A, note the branching twig bryozoa, trilobite pygidia, and strophomenid brachiopods. What is the age of this limestone?

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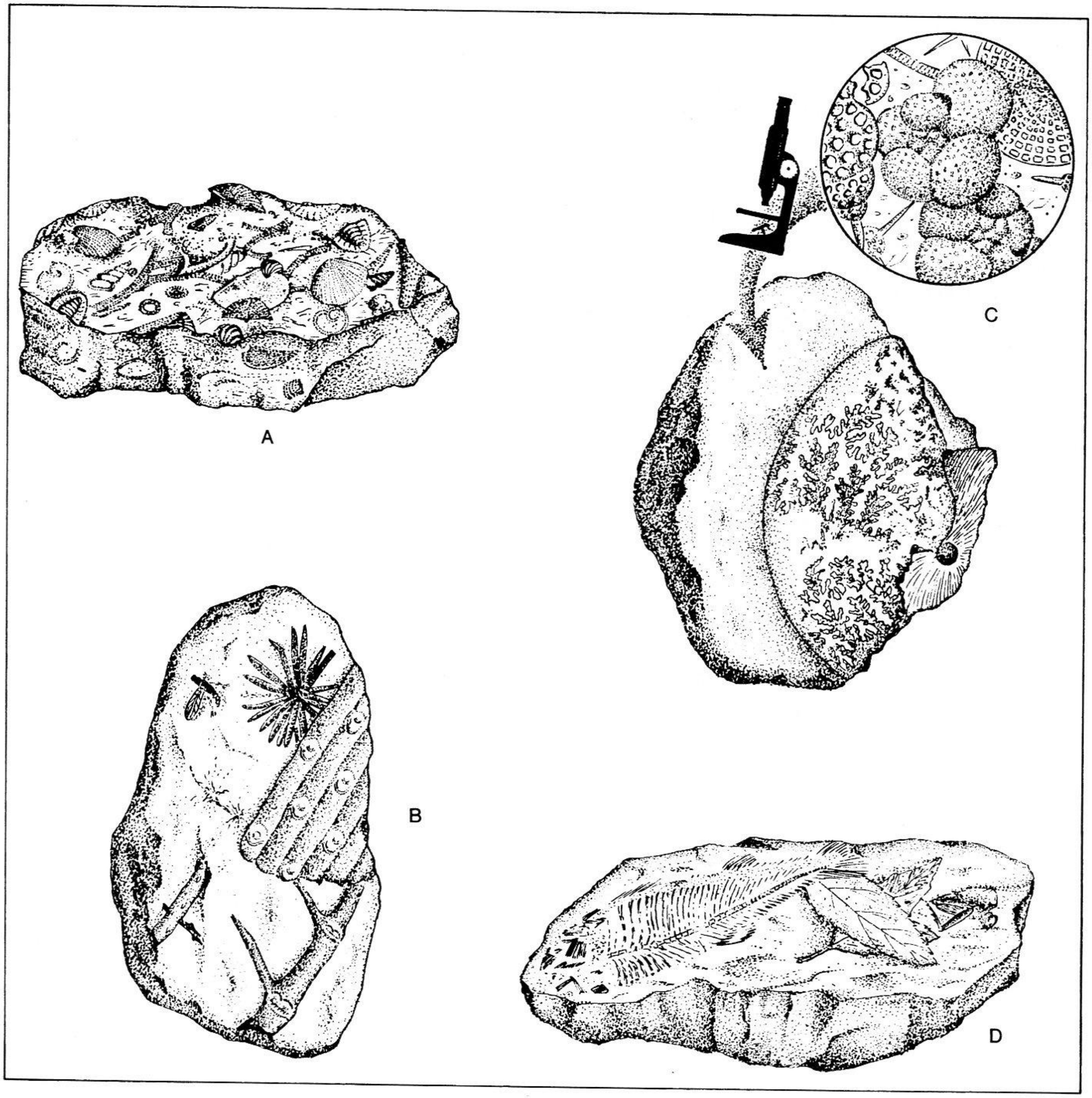


Figure 12.2 Geologic age and depositional environment. Identify as many of the fossils as you can on each rock slab shown. Beneath each slab, write the geologic age (era or period) during which the fossils lived and the probable environment (marine, nonmarine, water depth, climate).

b. Two fossil plants (and an obscure insect) are visible on the surface of slab B.

1. What are the names of the two plants (see Fig. 11.43)?

2. What is the age of the rock?

c. Rock C is a limestone containing a large cephalopod and various microfossils (visible on microscopic examination).

1. What groups of microfossils are present?

2. What type of sutures are visible on the fossil cephalopod?

3. What is the age of this rock?

d. Rock D is a shale.

1. Define the age or age range of this rock as closely as you can. State what criteria you used to make this determination.

2. What is the probable environment of deposition?

The geologic ranges of major groups of invertebrate fossils that have left good fossil records are illustrated in Figure 12.3. Knowledge of the time interval during which even such large taxonomic groups lived can serve to determine the geologic system in which particular strata belong. Smaller taxonomic divisions, such as orders, families, genera, or species, can provide the necessary information for identifying correspondingly smaller time-rock units, such as series or stages.

Study Questions

Answer the following questions by referring to Figure 12.3.

1. If the belemnites and trilobites (not identified as to genera or species) are found together in a rock unit, within what limits may the age of the rock be stated? (That is, what is the maximum and minimum age of the rock?)

2. If belemnites, trilobites, and graptolites (not identified as to genera or species) are found together in a rock unit, within what limits may the age of the rock be stated?

3. If trilobites (not identified as to genera and species) are found in a rock unit, within what limits may the age of the rock be stated?

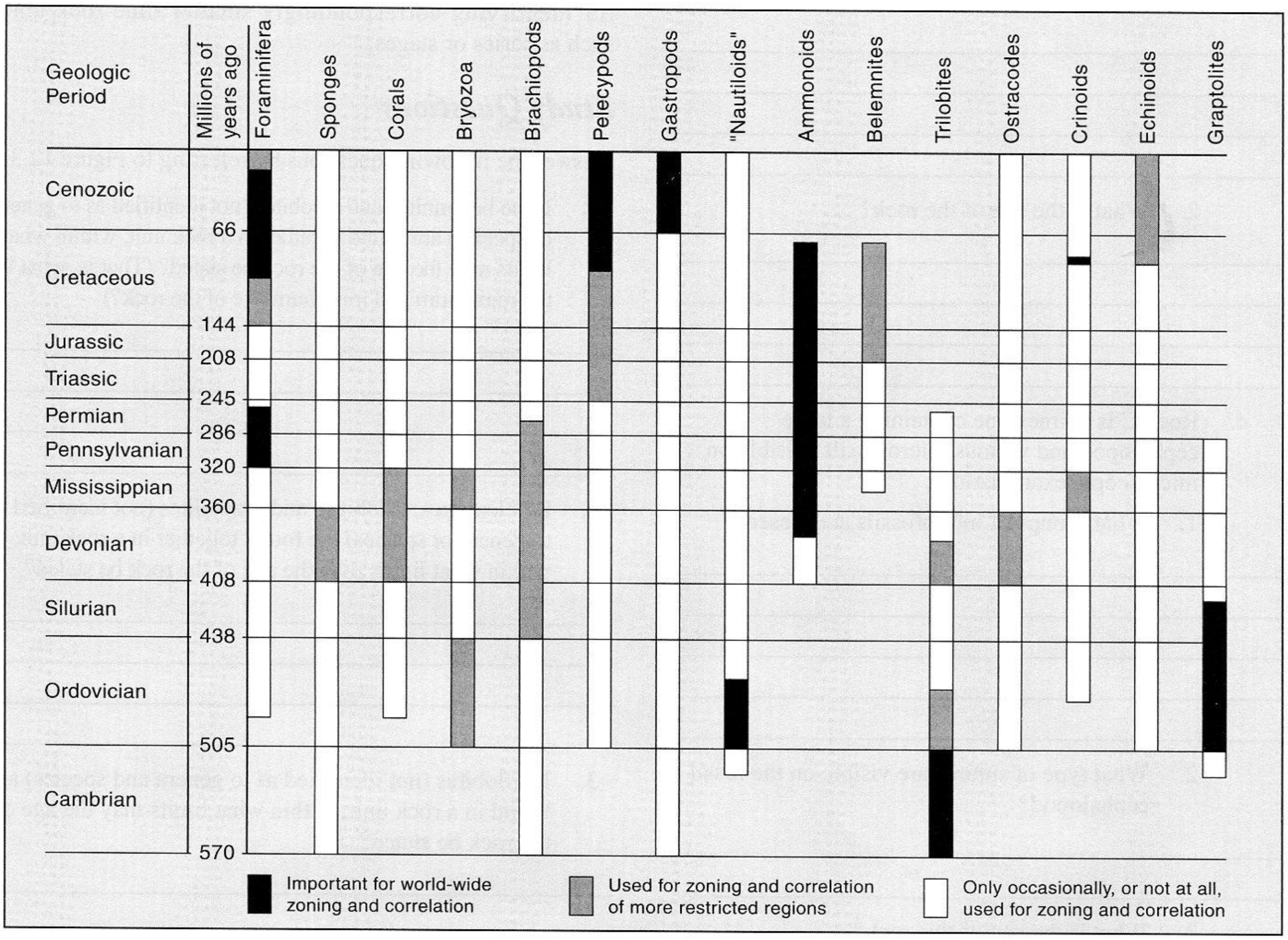
4. For age determination of a rock unit, what are the advantages of an assemblage of **index fossils** over a single kind of index fossil?

BIOZONES AND BIOSTRATIGRAPHY

Recognizing and correlating rock units on the basis of the fossils they contain is called **biostratigraphy,** and the fundamental unit used in biostratigraphy is the **biozone.** A **biozone**

Figure 12.3 Geologic ranges of some major groups of marine invertebrates and the relative importance of each group as currently used for correlation and age determination.

Updated from Teichert (1958), *Geol. Soc. Amer. Bull.*, **69**:99–120.



is a body of rock that is identified strictly on the basis of its contained fossils. Without naming them, we have already described two kinds of biozones: the range zone and the assemblage zone. The **taxon range biozone** is a body of rock representing the total geologic life span of an organism. The range zone consists of the interval between the first (lowest) occurrence of the organism and its point of extinction and is named after the fossil itself. Thus, the total range of the organism *Robulus crassus* would be called the *Robulus crassus* range zone.

One may also designate an **assemblage biozone,** selected on the basis of several coexisting species and named after one common and abundant member. A variation of the assemblage zone is the **concurrent range biozone,** recognized by the overlapping ranges of two or more taxa (sing. *taxon*). (The term *taxon* refers to a group of organisms that constitute a particular taxonomic category, such as species, genus, or family.)

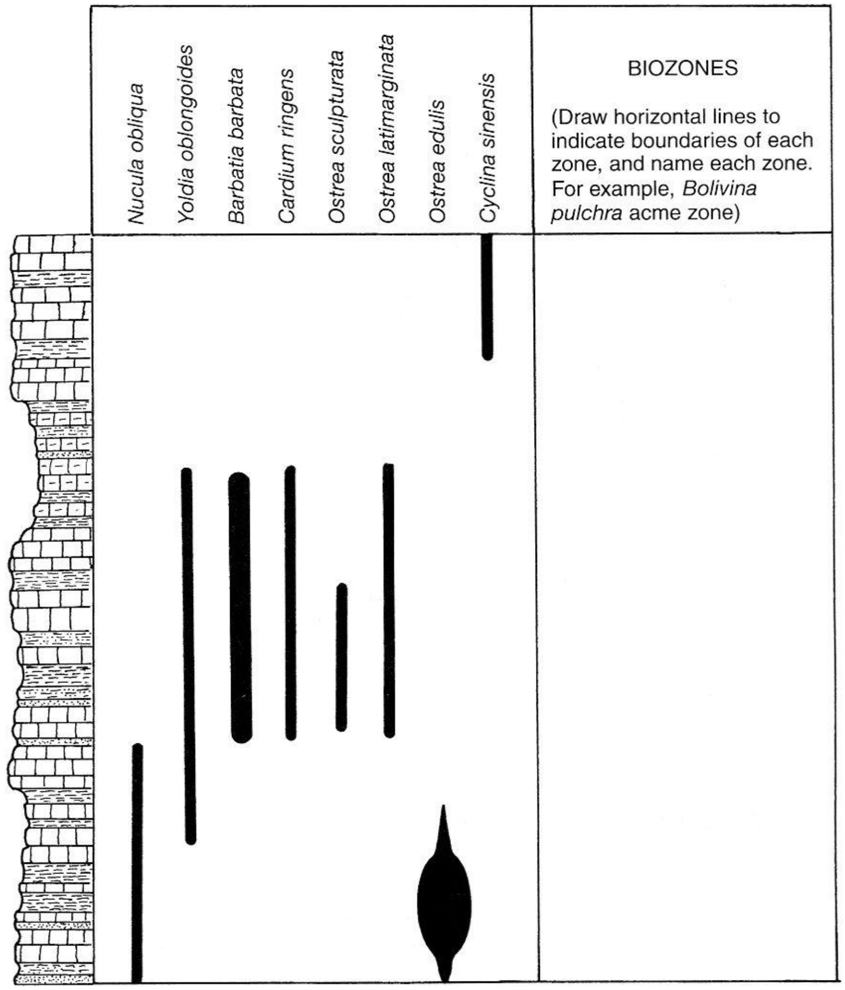
Some other frequently used kinds of biozones are the **acme biozone,** which consists of a body of rock represented by the maximum abundance of some species, genus, or other taxon (and named after that abundant taxon), and the **intrazone,** which represents an interval that lacks diagnostic fossils between two identifiable biozones. The interval zone would have a hyphenated name, including the organism that became extinct below the barren interval and the organism that made its first appearance above the barren interval (e.g., the *Globigerina sicanus-Orbulina suturalis* interval zone).

Once biozones have been identified in sections of rock at many different locations, one can correlate the biozones from place to place. Such correlations are the ultimate reason for designating biozones.

Study Questions

1. On Figure 12.4, identify, name, and draw in the boundaries of a *concurrent range biozone,* an *acme biozone,* an *intrazone,* and an *assemblage biozone.*

Figure 12.4 Designating biozones.



2. On attempting to correlate the biozones you have recognized, you find that you cannot identify the same biozones in rock sections of the same age at distant locations. What may be the reason?

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A GRAPHIC METHOD OF CORRELATION

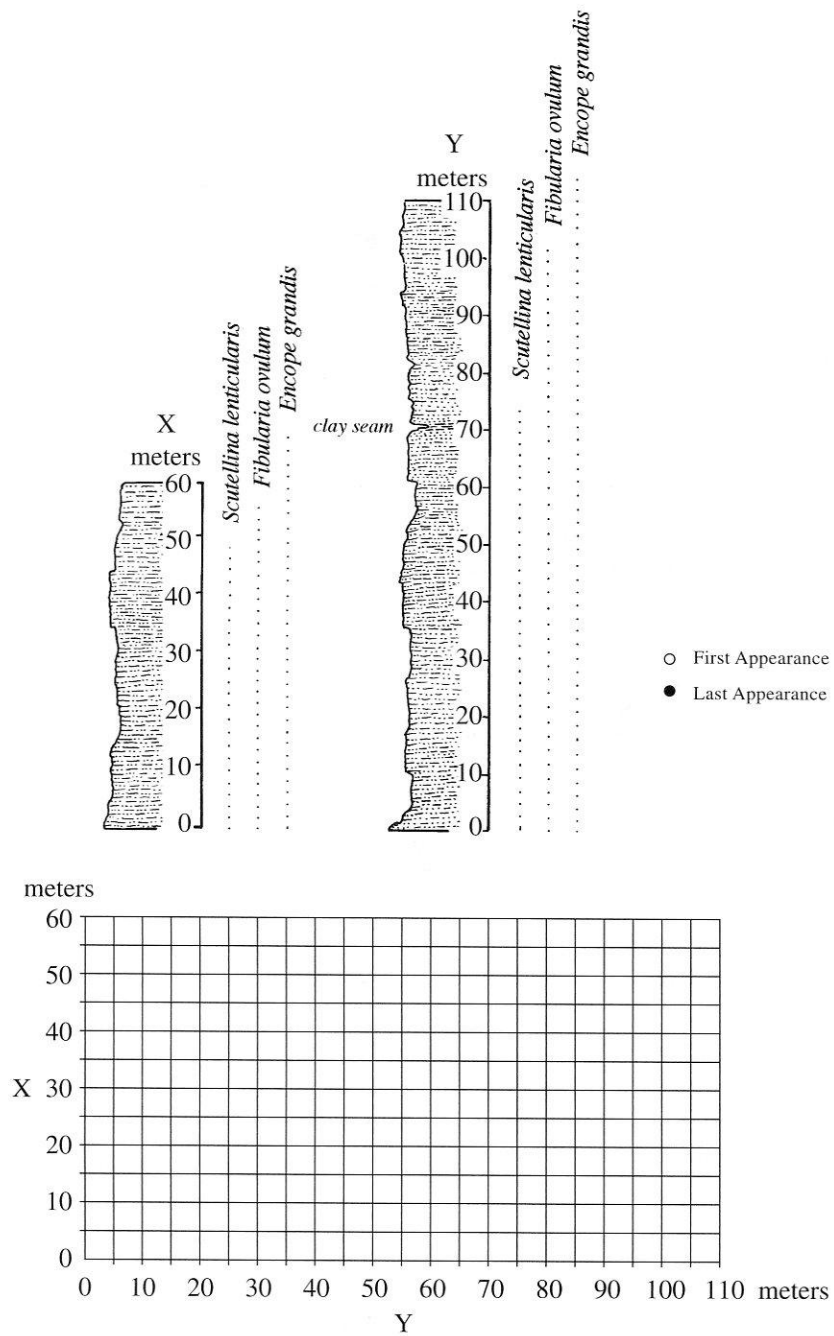
Even where fossils are present, it is sometimes difficult to precisely correlate a point in one section to a point in another section at a distant location. One interesting way to solve this problem was devised by geologist Alan B. Shaw. The Shaw method involves the following steps:

a. A geologic column is prepared for the two sections that require correlation. One of these, designated section X, is the standard section to which others are to be compared. The second section is designated section Y (Fig. 12.5A).

b. Geologic ranges of the fossil species are drawn next to each section, with lines that extend from the first appearance of the species to the last, as measured from the base of each section.

c. A graph is then prepared with the standard (X) section on the horizontal axis, and the section being compared on the vertical axis (Y). Points representing the first appearance of a species (use small open circles) and the last appearance of a species (use small filled circles) are plotted on the graph.

Figure 12.5A Graphic method of biostratigraphic correlation.



d. A line is drawn through the points plotted on the chart. It is called the *line of correlation.* By using the line of correlation, any point in one section can be correlated to a point in the other. (The example used here is greatly simplified. In practice, there would be many species and a cluster of points, so that one would have to statistically determine the best fit for the line of correlation.)

Correlation Exercise

1. Using the data provided on the accompanying chart (Fig. 12.5B), draw vertical lines next to the geologic columns for sections X and Y, indicating the geologic range of each of the three species used in this example.
2. Plot the correlation line indicated by first and last occurrences by using X and Y data for each point.

Figure 12.5B First and last appearances of species in sections X and Y, Figure 12.5A.

	Section X		Section Y	
	First Appearance	Last Appearance	First Appearance	Last Appearance
Scutellina lenticularis	5 m	30 m	10 m	60 m
Fibularia ovulum	10 m	42 m	20 m	85 m
Encope grandis	25 m	50 m	50 m	100 m

3. Section Y has a 10-cm seam of clay 70 m above the base of the section. To what point above the base of section X would this seam correlate?

4. In which section, X or Y, was the rate of deposition greatest?

Interpretation of an Outcrop in Southern Illinois

The following questions provide an opportunity to interpret an actual outcrop in southern Illinois. Answer these questions by referring to Figure 12.6.

1. Draw the upper and lower contacts of the Tar Springs Formation on the photograph (Fig. 12.6A).
2. The rocks in this outcrop were deposited during the same geologic period. What was the geologic period?

3. Name two fossils present in the rock slabs that are the basis for your answer to the previous question.

4. Describe the probable depositional environments of the Vienna Formation.

5. What can be inferred about the movement of the shoreline during the time that the formations in this bluff were being deposited?

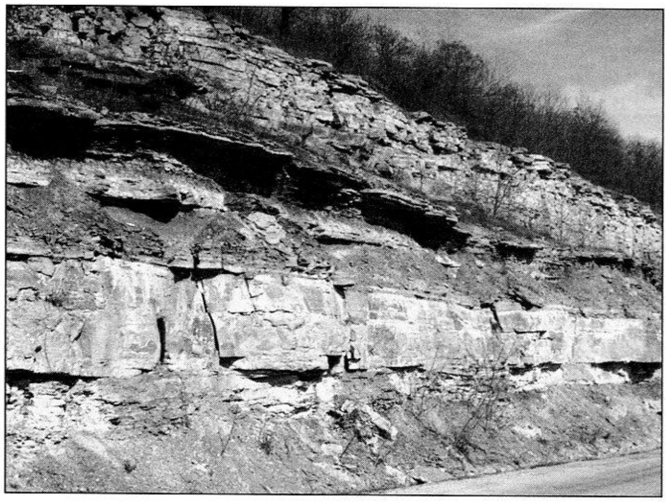
6. In reference to Question 5, for the movement of the shoreline, would reasons other than sea-level fluctuation explain the assemblages and sediment types? Explain.

Interpretation of an Outcrop in Central Illinois

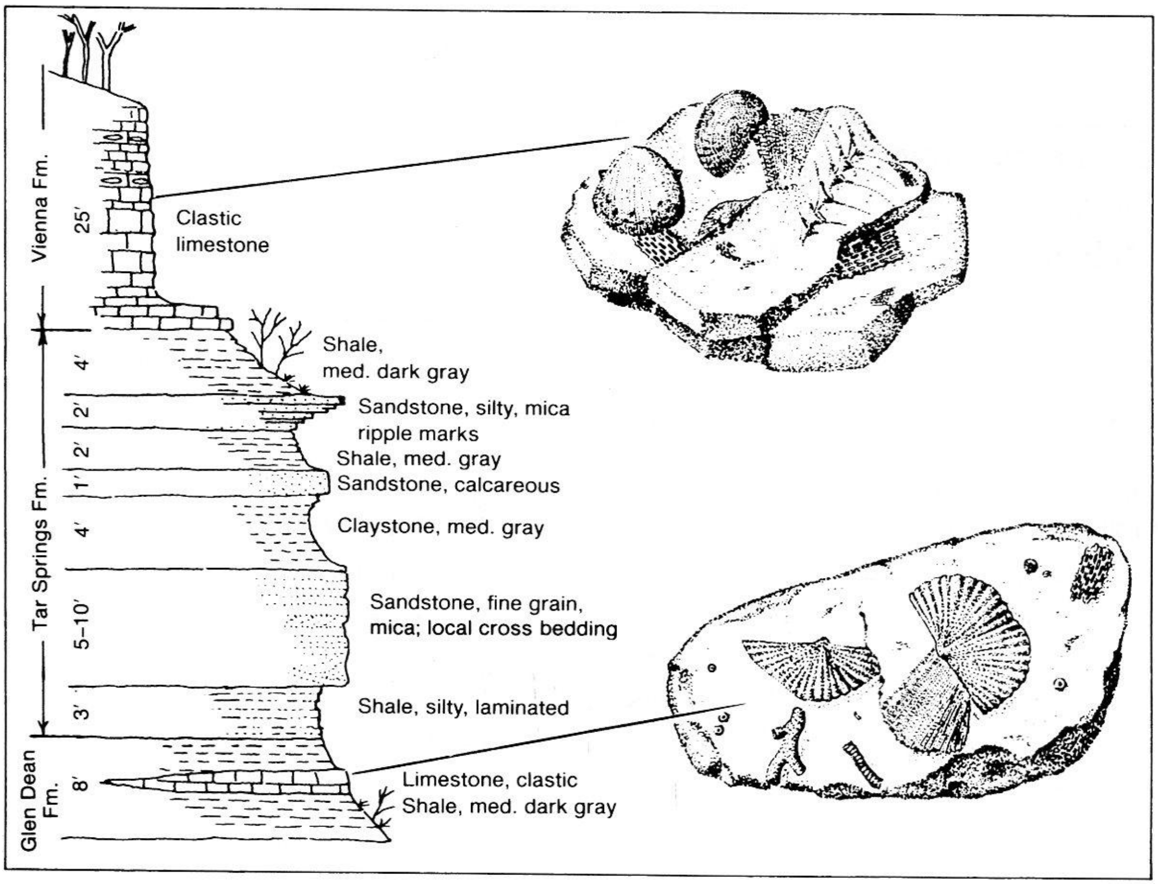
For the following questions, you are asked to interpret an outcrop in central Illinois. Answer the questions by referring to Figure 12.7.

1. By comparison with drawings in "Fossils and Their Living Relatives" (Chapters 10 and 11), identify each fossil as to major group (phylum or class) and subgroup (genus and/or species). Write the name of the fossil beneath it on Figure 12.7, and plot its range by a vertical arrow on the range chart.
2. What is the geologic age of the outcrop, assuming that all units belong to the same geologic system?

Figure 12.6 (A) Bluff along the Mississippi River at Chester, Illinois. (B) Columnar section of bluff.

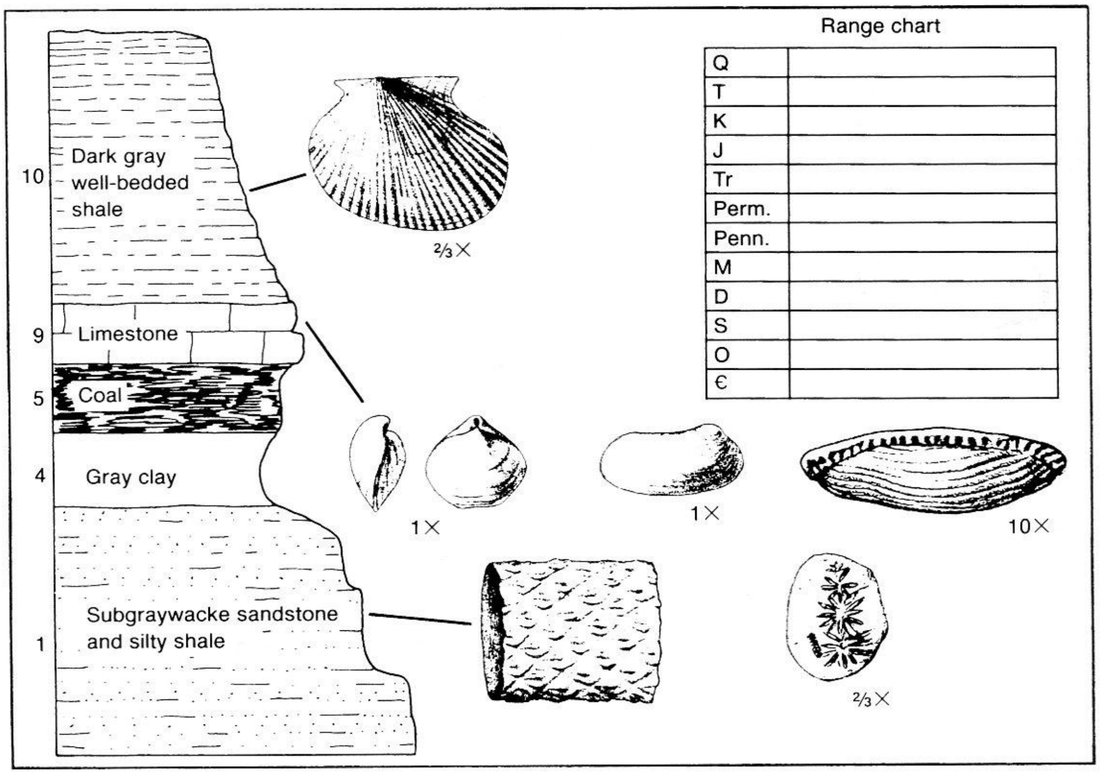


A



B

Figure 12.7 Columnar section of an outcrop in central Illinois.



3. Which of the numbered units are transgressive marine?

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4. Which of the numered units are terrestrial?

Fossils and Paleoenvironments

In addition to correlating and determining the age of strata, fossils are also useful in reconstructing the environment in which ancient organisms lived. In younger strata, the fossil animals and plants can be compared directly with their living relatives (Fig. 12.8), and the assumption is made that both require(d) the same environmental conditions for life. If there are no similar living counterparts for the comparison, then deductions about the environment must be based on the nature of the entire fossil assemblage, evidence from general comparative anatomy, and clues obtained from the enclosing sedimentary rock. In general, fossils of plants, insects, some fish, terrestrial vertebrate bones, and pollen grains and spores indicate a nonmarine environment. Brachiopods, crinoids, bryozoans, corals, and trilobites are certainly marine, and most species of these probably lived in relatively shallow water. Marine species can give further insight into the environments in which they lived based on their tolerance of salinity, their feeding techniques (suspension versus detritus feeders), and, as in the case of corals, light, water depth, and temperature requirements.

Study Questions

1. What group of living and fossil protists are being compared in Figure 12.8?

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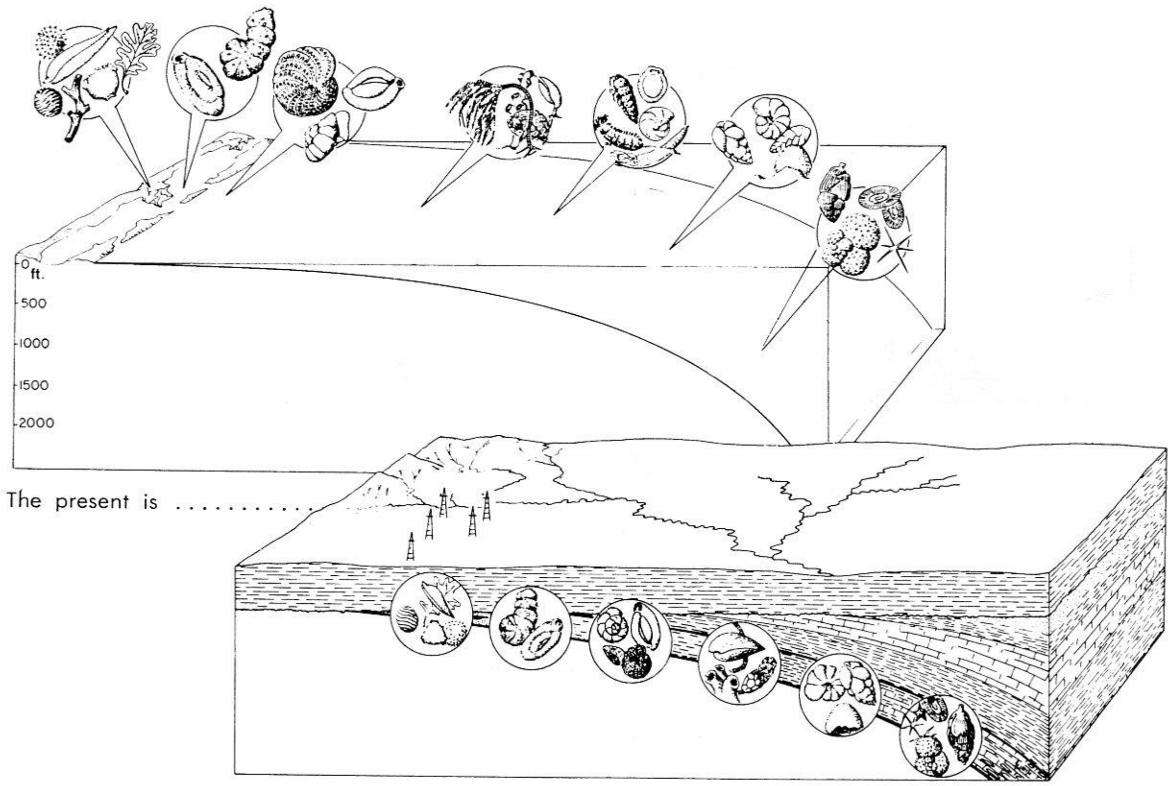
2. What kinds of organisms living on the present sea floor are not likely to be preserved as part of the fossil record?

Figure 12.8 Illustration of how the distribution and environment of an existing organism may be related to those of organisms that lived in the geologic past.



3. Considerable geologic work has been devoted to determining the depth of water in which particular foraminifers live. Why are petroleum geologists interested in mapping the occurrences of fossil benthic foraminifers to identify trends or directions toward ancient shallow-water areas and shorelines?

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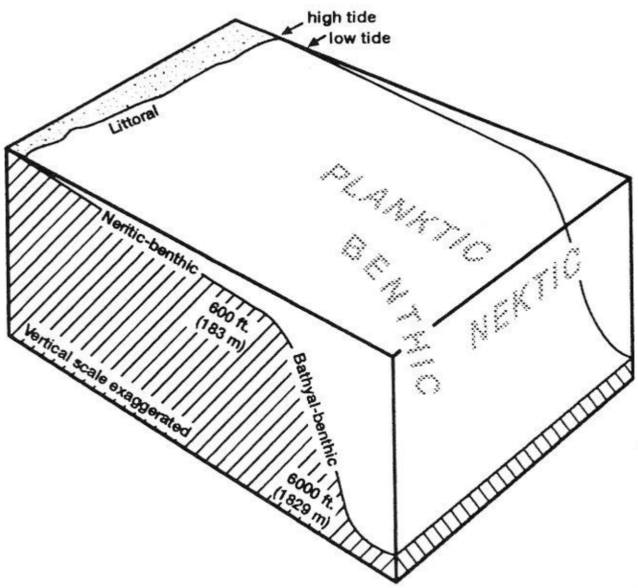
The Habitat of Marine Life

To recognize the significance of marine fossils in the history of the earth, it is necessary to study present-day organisms in relation to their natural abode or habitat. The study of those relations is called ecology. Paleoecology deals with the relations between ancient organisms and their environment. Many environmental conditions existing today had their parallels in the geologic past. Thus, if the fossil assemblage in a given rock layer is the counterpart of a community of organisms living today in tropical lagoons, then it can be inferred that the rock layer was deposited in an ancient lagoon. However, caution is required in making such inferences. In fossiliferous beds, the paleoecologist is really studying the environment in which the fossils were buried, which may or may not represent the environment in which they lived.

A simplified classification of marine environments is shown in Figure 12.9. The **littoral zone** (between high and low tide) contains animals and plants that have adapted to withstand periodic exposure, wave action, and sediment movement. The forms of life found in the **neritic-benthic** zone (low tide to about 200 m) require at least some light. That biologic requirement is readily met over most of this shallow zone where sunlight penetrates all the way to the sea floor. Here marine plant life proliferates as do the multitude of organisms that are directly or indirectly dependent on plants. Animals living in the **bathyal-benthic** zone (600 to 6000 ft, or 183 to 1830 m) are adapted to a habitat characterized by high pressure and extreme cold.

Within the environmental zones, organisms can be classified, according to their mode of life, as **planktonic** or **planktic, nektic,** or **benthic.** The **planktonic** (floaters) are predominantly animals and plants too small to be seen without magnification. The unicellular green plants, which make up part of the plankton, are the ultimate food source in the sea. Like their relatives the land plants, they use the energy of sunlight to produce carbohydrates from carbon dioxide by

Figure 12.9 Classification of marine environments.

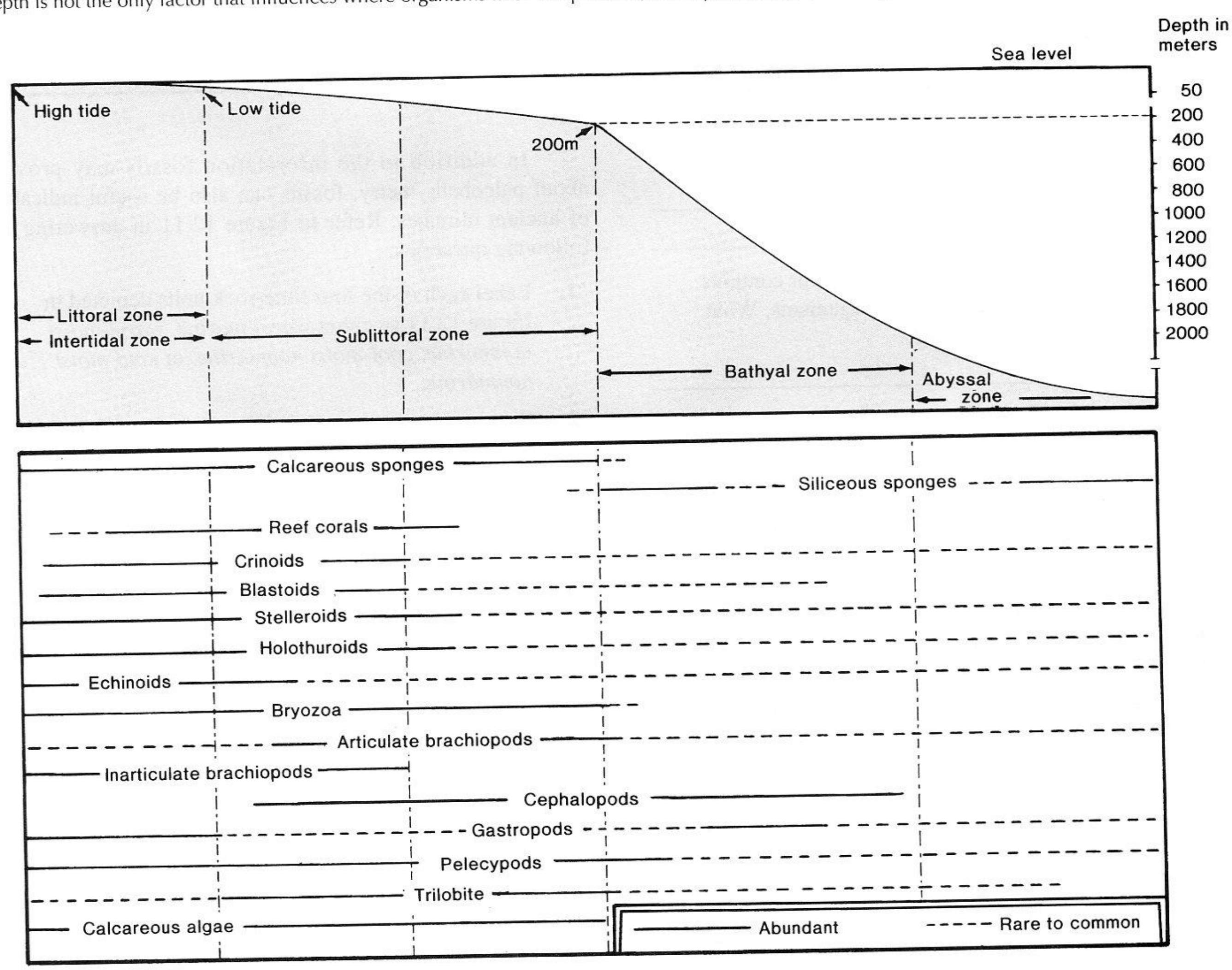


the process known as photosynthesis. **Nektic,** or swimming animals, include fishes, turtles, whales, porpoises, seals, cephalopods, and some arthropods. Most nektic forms are active predators. The bottom dwellers are termed **benthic** and include a great diversity of invertebrate animals as well as microscopic algae, the larger algae (seaweeds), some fungi, and bacteria.

Neritic-benthic invertebrates are among the most common fossils in sedimentary rocks. Based on their feeding habits, they can be divided into plant-eating **herbivores; carnivore**[-scavenger] organisms, which eat other animals both living and dead; the **filter feeders,** which strain tiny organisms and organic detritus from the bottom water; and the *deposit feeders,* which extract nutrition from the organic content of bottom sediment.

The range of water depths preferred by several major groups of fossil and living marine invertebrates is illustrated in Figure 12.10. Similar charts using smaller taxonomic groups such as species or families often provide smaller and more precise depth ranges. Nevertheless, even the larger ranges indicated for major groups can be useful.

Figure 12.10 General depth distribution of some of the groups of marine fossil and living invertebrates discussed in these studies. Similar charts depicting smaller taxa (species, genera, or families) often provide very precise bathymetric information. It should be remembered, however, that depth is not the only factor that influences where organisms live. Temperature, salinity, turbidity, and many other factors are also important.



Study Questions

1. At a given locality, a time-rock unit containing abundant fossil calcareous sponges and calcareous algae is conformably overlain by a time-rock unit containing siliceous sponges and cephalopods. What statement can be made about bathymetric change at the locality?

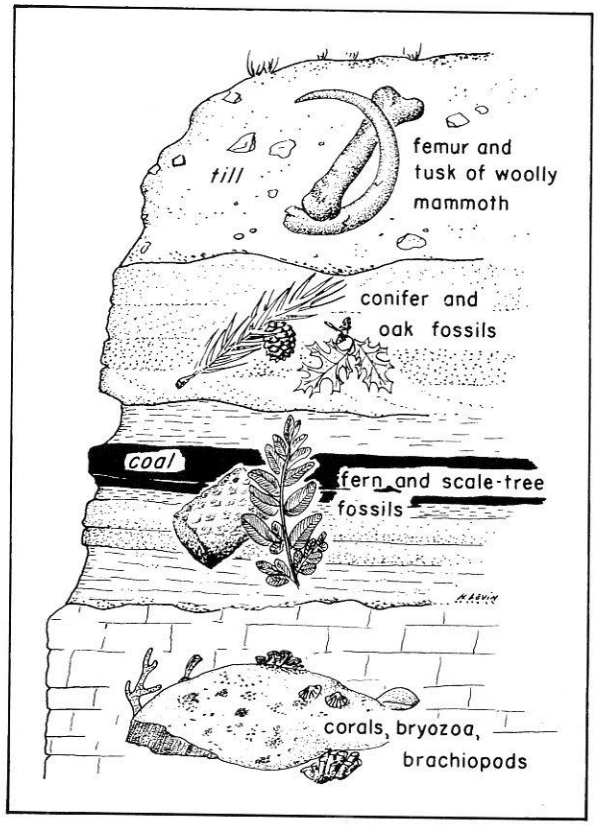
2. In general, why are cephalopods and planktonic foraminifera likely to be less useful than bryozoa in bathymetric analyses?

3. What general statement can be made about the paleobathymetry of a stratum containing abundant crinoids (see Fig. 12.10)?

4. Note that the neritic-benthic environment contains greater numbers and diversity of organisms. What factors may account for this?

5. Many benthic animals burrow into the sea floor and live in the tubes they have excavated. Why are the burrows produced by littoral-benthic animals generally deeper than those produced by animals living in the neritic-benthic zone?

Figure 12.11 The use of fossils as indicators of ancient climates.



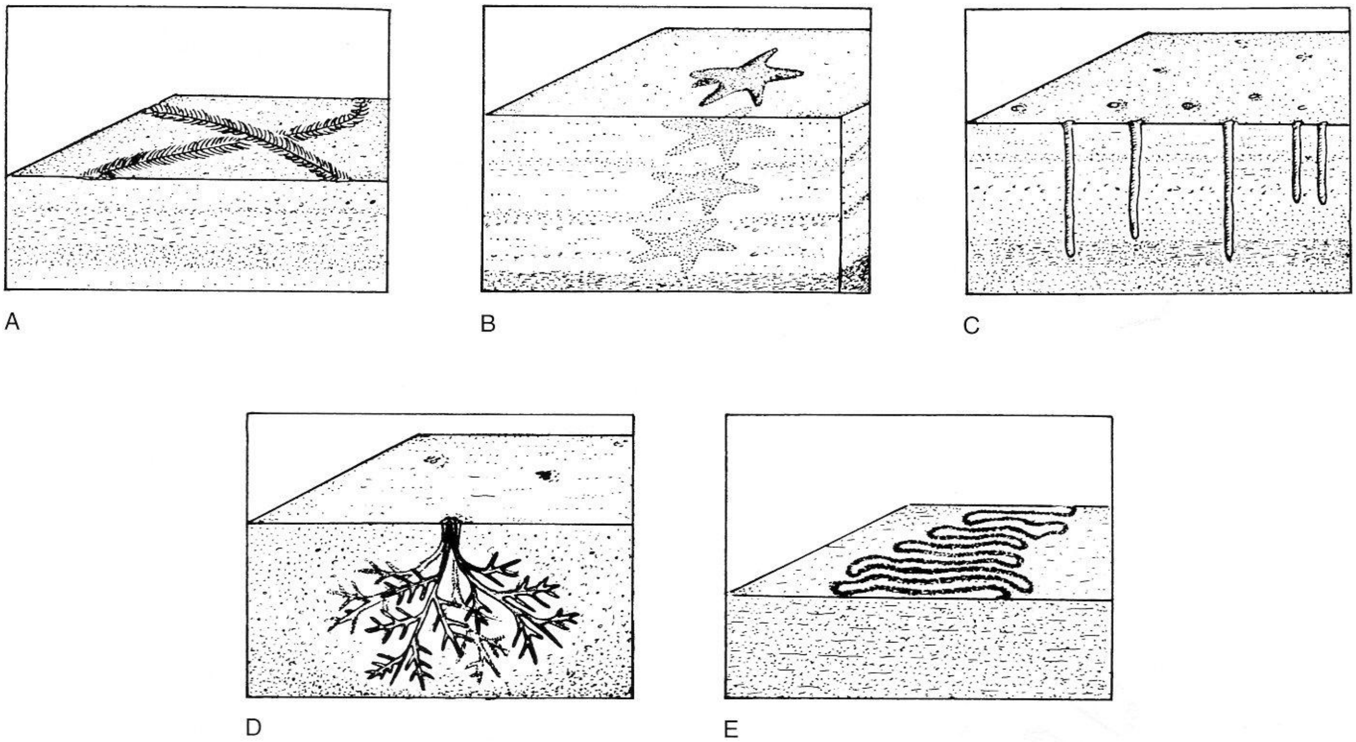
In addition to the information fossils may provide about paleobathymetry, fossils can also be useful indicators of ancient climates. Refer to Figure 12.11 in answering the following questions:

1. Label each of the four time-rock units depicted in Figure 12.11 as either *warm-marine, warm-moist nonmarine, cool-moist nonmarine,* or *cold-moist nonmarine.*
2. Draw an arrow to and label the surfaces of disconformity present at the outcrop. What is the evidence for these disconformities?

3. During which geologic era were the two lower units deposited?

   During which geologic era was the uppermost unit deposited?

Figure 12.12 Traces that reflect animal behavior.



What statement can be made about the age of the unit containing fossil remains of hardwood trees?

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Invertebrate Trace Fossils

As described in Chapter 10, fossils include not only the petrified remains of ancient organisms but also their **traces.** **Trace fossils** consist of **tracks, trails, burrows** (dwellings in soft sediment), **borings** (dwellings in hard substrates such as **hardgrounds**), fossilized excrement (**coprolites** or **fecal pellets**), and other markings made by former animals and plants. The study of such traces is called **ichnology.** Although trace fossils are often not as attractive as many petrifactions of animals, they are nevertheless very useful to geologists seeking clues about water depth, currents, food supply, and the rates of deposition in ancient seas and lakes. From some invertebrate traces one can sometimes infer body form where no remains of the external skeleton (shell or carapace) exist. One may be able to tell if the animal was resting, crawling, grazing, feeding, or simply living within a relatively permanent dwelling. For example, shallow depressions that more or less reflect the outline of the animal may be **resting traces. Crawling traces** are usually linear and show directed movement. **Grazing traces** occur along definite bedding planes and are characterized by systematic meandering or concentric and parallel patterns that represent the animal's effort to cover the area containing food in an efficient manner. The three-dimensional counterpart of grazing traces are called **feeding traces.** Feeding traces consist of systems of branched or unbranched burrows. Simple or U-shaped structures inclined or perpendicular to bedding are often the **dwelling traces** of various benthic invertebrates.

Study Questions

1. What type of extinct marine arthropod may have produced the crawling trace in Figure 12.12A?

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2. What kind of marine invertebrate may have produced the trace fossil called *Asteriacites* (Fig. 12.12B)?

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Is it likely the trace represents crawling, resting, or feeding?

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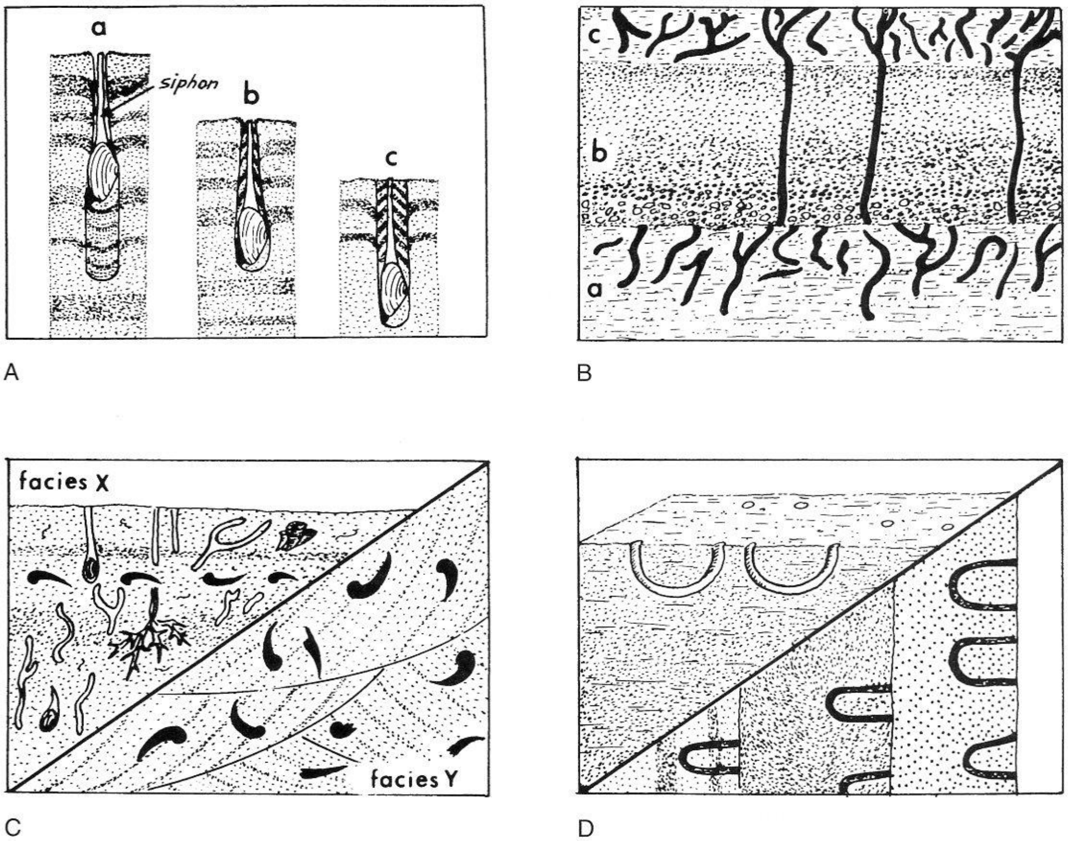
Figure 12.13 Trace fossil clues to sedimentation and structure.



Was sediment deposition at this site meager or relatively rapid? Why?

3. What type of behavior is indicated by the trace fossil depicted in Figure 12.12C?

What type of brachiopod might produce a vertical tube such as this?

4. What was the behavior of the animal that formed the trace fossil *(Chondrites)* shown in Figure 12.12D?

5. What type of behavior is indicated by the trace fossil in Figure 12.12E?

In addition to serving as clues to the behavior of animals, trace fossils also provide information about events that have occurred in the environment of deposition. They can be used, for example, to determine if deposition or erosion had taken place at the surface of sedimentation and may even suggest the approximate rate of deposition. In areas where strata have been deformed and overturned, trace fossils may help the geologist distinguish the tops from the bottoms of beds.

1. Figure 12.13A depicts dwelling traces of the pelecypod *Mya.*
   a. Which of the three traces shown was probably made at a time in which the surface of sedimentation was stationary and the animal was growing?

b. Which trace was probably made while the surface of sedimentation was rising as a result of active deposition?

c. Which trace suggests that currents may have been sweeping away sand at the surface of sedimentation?

2. What sequences of events occurred on the ocean floor at the locality depicted in Figure 12.13B? (The burrow traces are made by the marine worm *Nereis*.)

3. Figure 12.13C shows two different facies of a time-rock unit. What biological evidence suggests that the sediment of facies X does not represent a reworked sediment?

4. What conditions other than the reworking of sediment might account for a scarcity of trace fossils within a stratum?

5. The upper part of Figure 12.13D shows the U-shaped dwelling tubes of a species of marine worm. The lower part of the figure depicts dwelling traces of extinct worms presumed to have behaved similarly. The fossil traces occur in vertically dipping strata. Is the original top surface of the strata toward the right or left?

TERMS

acme biozone Body of strata that contains the maximum abundance of individuals of a species or other taxa.

assemblage biozone A biozone having three or more taxa of a group that is distinguishable from assemblages in overlying and underlying strata.

bathyal-benthic zone The ocean-floor environment extending from a depth of 600 to 6000 ft (183 to 1830 m).

benthic (or **benthonic**) Pertaining to aquatic bottom-dwelling organisms.

biostratigraphy The study of strata based on the fossils they contain.

biozone A body of rock defined by the presence, absence, or relative abundance of certain species or other taxa.

boring Biogenic sedimentary structure excavated into a hard substrate (e.g., rock, shell, or wood), usually to serve as a dwelling.

burrow Biogenic sedimentary structure emplaced in soft sediment below the sediment surface, usually for the purpose of feeding or dwelling, or as a result of locomotion.

carnivore-scavenger Pertaining to organisms that can feed on either living or dead animals.

carnivorous Pertaining to organisms that feed on animals.

concurrent range biozone A biozone defined by the interval of overlap between the first appearance of one species or other taxon, and the last appearance of a different species or taxon.

coprolite Large lump of fossilized excrement, generally much greater than 1 cm in length or diameter.

crawling trace Tracks in sediment or sedimentary rock that are produced by locomotion with the aid of appendages and/or muscular movement of the body.

deposit feeder An organism that feeds on organic debris on and within sediment covering the floor of a lake or sea.

dwelling trace Certain burrows and borings in sediment or sedimentary rock that were once more or less permanently inhabited by animals. Most such structures are cylindrical.

fecal pellet Small spherical, ovoid, or cylindrical lump of excrement; maximum dimensions generally less than 1 cm.

feeding trace Tracks or burrows in sediment or sedimentary rock that represent the traces of deposit feeders in search of food. Radial patterns in which previously mined sediment is avoided characterize such traces.

filter feeders (invertebrates) Animals that live by filtering small pieces of organic matter and smaller organisms out of the water. Filter feeders include bryozoa, brachiopods, sponges, and clams.

geologic range (of an organism) The geologic time span between the first and last appearance of an organism.

grazing trace Tracks or burrows in sediment in which a feeding organism moves in a symmetrical pattern to efficiently exploit nutritious sediment.

hardground Substrate composed of indurated rocks at a minor depositional hiatus or erosion surface, in which borings may be produced.

herbivorous Pertaining to organisms that feed on plants.

ichnology The study of fossil and recent traces such as tracks, burrows, and borings.

index fossil A fossil that identifies and dates the strata or succession of strata in which it is found. Also called a **guide fossil.**

intrazone Unfossiliferous intervals having defined biozones both above and below.

littoral zone In a simple classification of marine environments, the zone between high and low tide.

nektic (or **nektonic**) Term pertaining to aquatic organisms that swim, as opposed to those such as plankton, which float.

neritic-benthic zone The ocean-floor environment that extends from low tide to a depth of 600 ft (about 183 m).

planktonic (or **planktic**) Organisms that float or drift passively with the movements of a water mass.

resting trace Impressions formed in sediment or sedimentary rock by an animal temporarily at rest or in refuge; often reflect the morphology of the animal.

taxon range biozone A body of rock representing the maximum stratigraphic range of a species or other taxon, from its first appearance to its last.

trace Structure produced in sediment by the activity of an animal or plant; also called a **biogenic sedimentary structure.**

trace fossil Ancient trace preserved in lithified sediment; also called an **ichnofossil.**

track Individual footprint.

trackway Set of multiple, separate footprints that indicate movement.

trail Continuous locomotion trace without separate footprints.