TOPIC

13

Interpreting Geologic History

Vocabulary

absolute age	half-life	radioactive dating
bedrock	inclusion	radioactive decay
carbon-14 dating	index fossil	species
correlation	intrusion	unconformity
cross-cutting relationships	isotope	uranium-238
extrusion	organic evolution (theory of)	volcanic ash
fossil	outgassing	
geologic time scale	principle of superposition	

Topic Overview

The composition, structure, position, and fossil content of Earth's rocks provide information about Earth's geologic history. Evidence in Earth's Ⓡ rocks dates back approximately 4.2 billion years. In the *Earth Science Reference Tables*, carefully study the Geologic History of New York State and the Generalized Bedrock Geology of New York State. A bedrock, or geologic, map shows the rock types that underlie an area and their age.

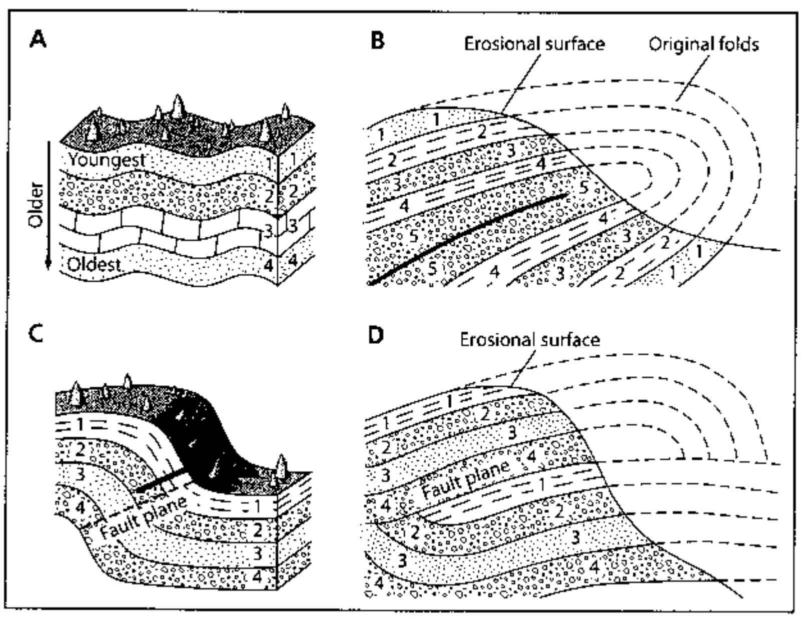


Figure 13-1. The principle of superposition and possible exceptions: (A) Normally, a rock layer is younger than the layers below it. (B) Overturned folds can result in an exception to the principle. Layer 1 at the lower right is actually a continuation of layer 1 at the upper left. (C) and (D) Movement of layers along an overthrust fault can result in an exception to the principle. Layers numbered alike are the same age. The arrow in diagram C shows the direction of overthrusting.

Relative Dating of Rocks and Events

Relative dating is the determination of the age of a rock or event in relation to the age of other rocks or events. The following descriptions explain how methods of relative dating make it possible to determine relative age. Note that relative age differs from **absolute age,** which refers to the actual age of a rock or an event in years.

Principle of Superposition

When observing layers of sedimentary rock, or some extrusive igneous rocks, geologists usually infer that the bottom layer is the oldest. Each overlying layer is then progressively younger, so that the top layer is the youngest, or most recently formed. This inference is called the **principle of superposition,** and it is the basis for methods of relative dating. (See Figure 13-1.) Superposition relates to the original horizontality of deposited sediments or of volcanic rock layers.

Exceptions to the principle of superposition sometimes occur when changes in Earth's crust cause the deformation of rock layers. Some exceptions are illustrated in Figure 13-1. For example, when there are overturns in folded rock layers, or when movement along faults thrusts older rock layers over younger layers, the principle of superposition no longer holds true.

Dating Intrusions, Extrusions, and Inclusions

When magma squeezes into preexisting rocks and crystallizes, it forms an igneous rock body called an **intrusion,** as shown in Figure 13-2. Intrusions can vary in thickness from centimeters to hundreds of kilometers. An intrusion is younger, in relative age, than any rock it cuts through.

When lava flows on Earth's surface and solidifies, it forms a mass of igneous rock called an **extrusion** as shown in Figure 13-2. Extrusions include lava flows and volcanoes. The extrusion is younger than any rocks beneath it, but will be older than any rocks that may later form on top of it.

An **inclusion** is a body of older rock within igneous rock. Often when magma rises towards Earth's surface, pieces of the rock that the magma is intruding—pushing through—will fall into the magma. Usually these pieces of older rock will melt to become part of the magma. However, if the temperature of the magma is lower, as occurs when the magma is about to solidify, the older body will not melt. The result is the formation of an inclusion as shown in Figure 13-3. Some of Earth's oldest dated rocks have inclusions in them; thus, scientists know that even older rocks exist. However, they may not know how much older these rocks are.

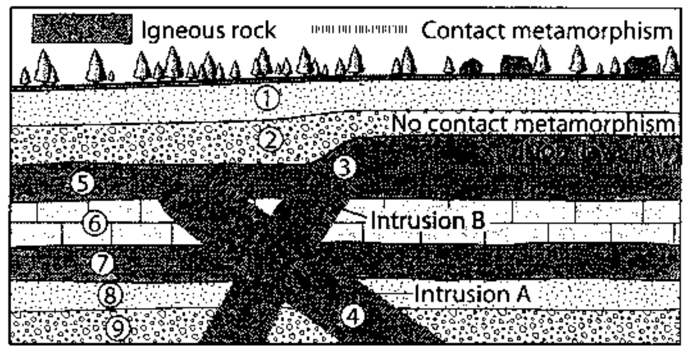


Figure 13-2. Relative ages of intrusions and extrusions: Intrusion A is younger than the layers it intrudes. Intrusion B is younger than intrusion A because it cuts intrusion A. The layers above the extrusion must be younger than the extrusion because of the absence of contact metamorphism along their common boundary. The rocks are numbered in order of increasing age.

Dating Rock Features and Cross-Cutting Relationships

Many of the structural features within rocks provide evidence to use in relative dating. For example, a rock is older than any fault, joint, tilting, or fold that appears in it. The reason is that rocks form without these features, and are folded, tilted, or cracked afterward.

Rock characteristics, as shown in Figure 13-3, can also be used in relative dating. In sedimentary rocks, the sediments are older than the rock itself, while the cement is younger. In igneous rocks, individual mineral crystals vary in age because they form at different temperatures reached by the magma as it cools and hardens over thousands or millions of years. Older mineral crystals are generally larger and show a well-developed crystal shape.

Rocks may also contain mineral deposits called veins. A vein forms when a watery mineral solution fills a crack or permeable zone in the rock. Like an intrusion, a vein is younger than the rock around it. Veins often contain valuable natural resources such as gold, silver, and lead ores.

Intrusions, faults, joints, and veins are types of **cross-cutting relationships.** Because cross-cutting relationships cut across older rock, they are younger.

Memory Jogger

Recall that contact metamorphism occurs when magma or lava comes in contact with older bedrock and alters the minerals and/or sediments by recrystallization. This process results in a younger metamorphic rock with a new texture and/or mineral composition.

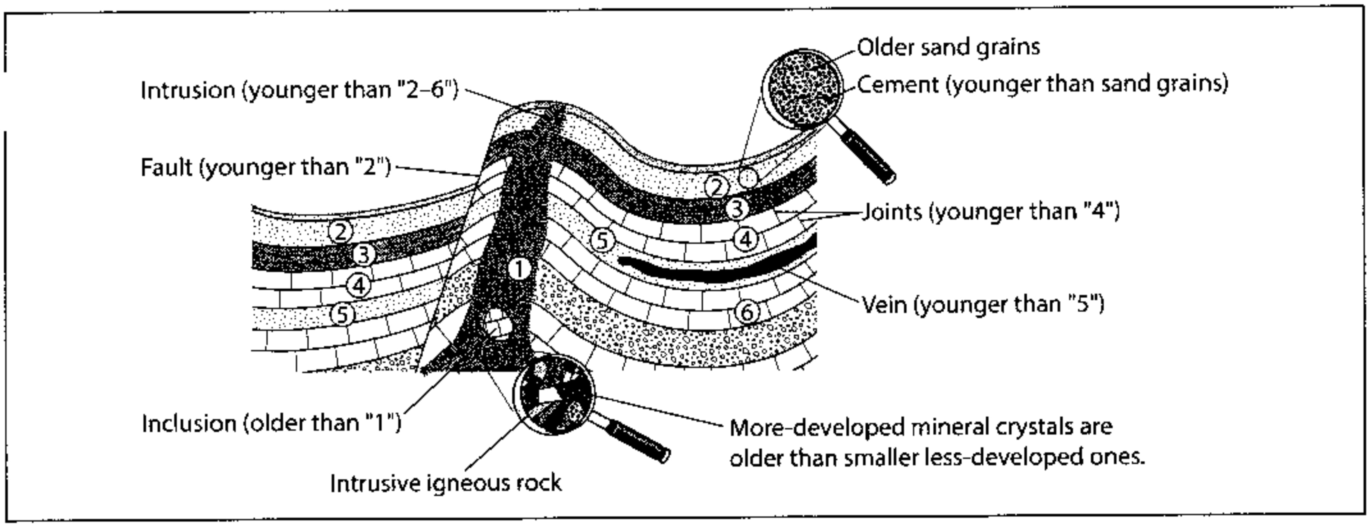


Figure 13-3. Relative ages of structural and internal features of rocks: Folds, faults, joints, and veins are younger than the rocks in which they occur. Sediments such as sand grains and inclusions in igneous rocks are older than the rocks in which they occur.

Review Questions

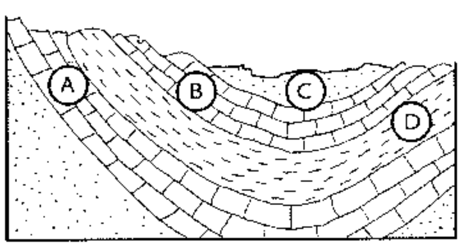
1. According to the Generalized Bedrock Geology of New York State in the *Earth Science Reference Tables,* what is the geologic age of the bedrock found at the surface at 43° 30′N latitude by 75° 00′ W longitude?

(1) Devonian (3) Early Ordovician
(3) Cambrian (4) Middle Proterozoic

2. Which area in New York State is located on rock formations that contain large amounts of salt deposits?

(1) Syracuse (3) New York City
(2) Long Island (4) Old Forge

3. The following diagram represents a cross-sectional view of a portion of Earth's crust showing sedimentary rock layers that have not been overturned. The letters identify the specific layers.

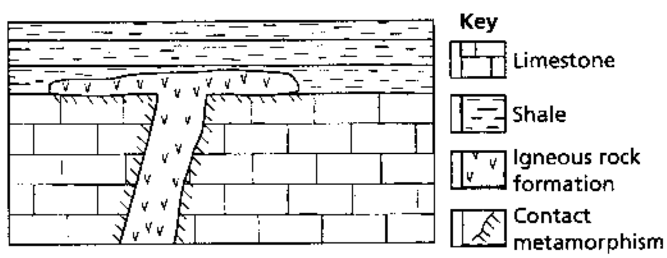


Which rock layer is probably the oldest?

(1) A (2) B (3) C (4) D

4. The following diagram shows a portion of Earth's crust. What is the relative age of the igneous rock?

(1) It is older than the limestone but younger than the shale.
(2) It is younger than the limestone but older than the shale.
(3) It is older than both the limestone and the shale.
(4) It is younger than both the limestone and the shale.

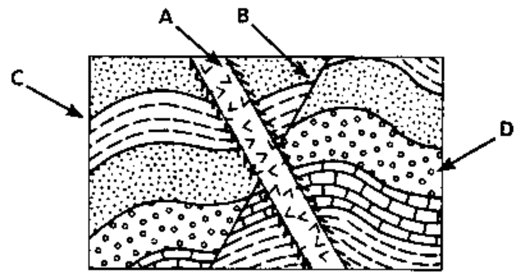


5. Suppose you are examining a section of sedimentary rock. What evidence could you observe that would support the principle of superposition?

6. What is the age of the surface bedrock at Niagara Falls, New York?

(1) Devonian (3) Ordovician
(2) Silurian (4) Cambrian

7. The following diagram represents exposed bedrock. Which geologic event occurred last?
(1) the intrusion of A
(2) the fault along line B
(3) the fold at C
(4) the deposition of gravel at D



Correlation

The process of **correlation** makes it possible to show that rocks or geologic events from different places are the same or similar in age. Correlation is an important tool in unraveling the sequence of geologic events in an area. Correlation is also useful in finding certain mineral resources, such as fossil fuels, which are found in rocks of a specific age. Some of the methods of correlation are described below.

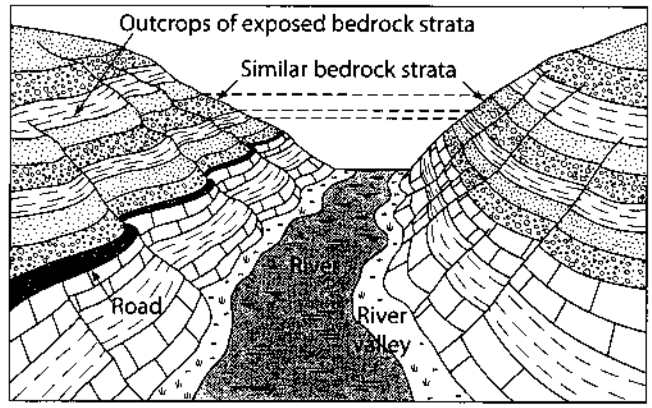


Figure 13-4. Correlation by observations of exposed bedrock and rock similarities: A geologist could follow and correlate bedrock layers in this exposed hillside by walking along the road on the left side of the river valley. The geologist might also be able to correlate layers on opposite sides of the valley by observing similarities in color, texture, and sequence of rock layers.

Correlation by Exposed Bedrock

An area's local rock, or **bedrock,** is usually covered by soil, other loose materials, or human-built structures. Sometimes, however, bedrock is exposed at Earth's surface through natural processes or by human activities such as road-building. Figure 13-4 shows exposed layers of bedrock—outcrops—along both sides of a river valley. Where bedrock is exposed, correlation can be accomplished by directly following the continuity of the rock layers. Direct observation of rock layers is especially easy in arid regions where little soil or vegetation covers the outcrops.

Correlation by Similarities in Rocks

Where rocks are separated from one another, they may be tentatively correlated by their similarities. These similarities may include overall appearance, color, mineral composition, and rock sequence, as indicated in Figure 13-4. Correlation of rocks by similarity is usually only valid over small areas, and even then may be incorrect. One reason is that similar rocks can form in like environments millions of years apart.

Memory Jogger

You may recall that most sedimentary rocks form from compacted and cemented sediments. In contrast, igneous rocks form directly from molten magma or lava, while metamorphic rocks form when rocks are subjected to heat and pressure.

Correlation by Use of Index Fossils

One of the best methods of correlation involves the use of particular fossils or groups of fossils. **Fossils** are the remains or evidence of former living things—such as bones, shells, footprints, or organic compounds (such as DNA). With minor exceptions, fossils are found exclusively in sedimentary rocks. They are rarely found in igneous and metamorphic rocks because fossils are usually destroyed by the melting

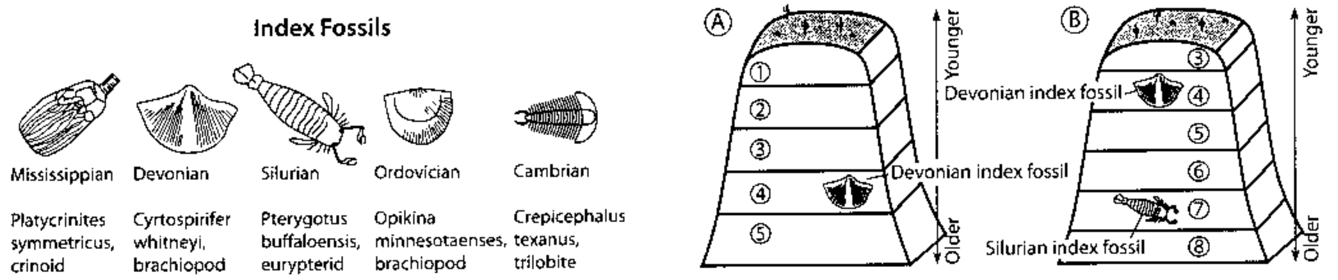


Figure 13-5. Correlation of rock layers by means of index fossils: The layers are in order from younger to older. In diagram A, a fossil of an organism known to have lived only during the Devonian Period is found in rock layer 4. This layer was therefore deposited during Devonian times. The layers above it are younger, and those below it are older. In diagram B, a similar fossil is found in one of the layers. This is therefore also a Devonian layer. A second index fossil, of the Silurian Period, is found in layer 7. This indicates that layers 5 and 6 are not younger than the Devonian and not older than the Silurian layers.

Memory Jogger

You may recall from the *Earth Science Reference Tables* that sand particles measure between 0.006 cm and 0.2 cm in diameter and that clay particles measure between 0.0001 cm and 0.0004 cm.

of igneous rocks and by the heat and pressure associated with the formation of metamorphic rocks.

The fossils used in correlation are called **index fossils.** As shown in Figure 13-5, the fossil remains of a particular type of life form may become useful as an index fossil if two conditions are met. First, the life form must have lived over a wide geographical area—so that its fossil remains will have a large horizontal distribution throughout rocks formed around the same time. Second, the life form must have existed for a relatively short time, so that its fossil remains have a small vertical distribution in the rock layers in which the fossils occur. (R)

Correlation by Volcanic Ash and Meteorite Deposits

During volcanic eruptions, **volcanic ash** consisting of sand-sized to clay-sized particles of extrusive igneous rock is shot into the air. In large eruptions, volcanic ash scatters over wide areas of Earth's surface. See Figure 13-6. The scattered ash then settles among other sediments in many different environments. Since ash from each volcanic eruption has a unique mineralogical, or chemical, composition, specific ash deposits can be detected in rock layers. Such ash deposits are useful in correlation because they are widely distributed and represent a small interval of time. Deposits of volcanic ash serve as specific age markers in rocks and glacial ice that may be thousands of kilometers apart.

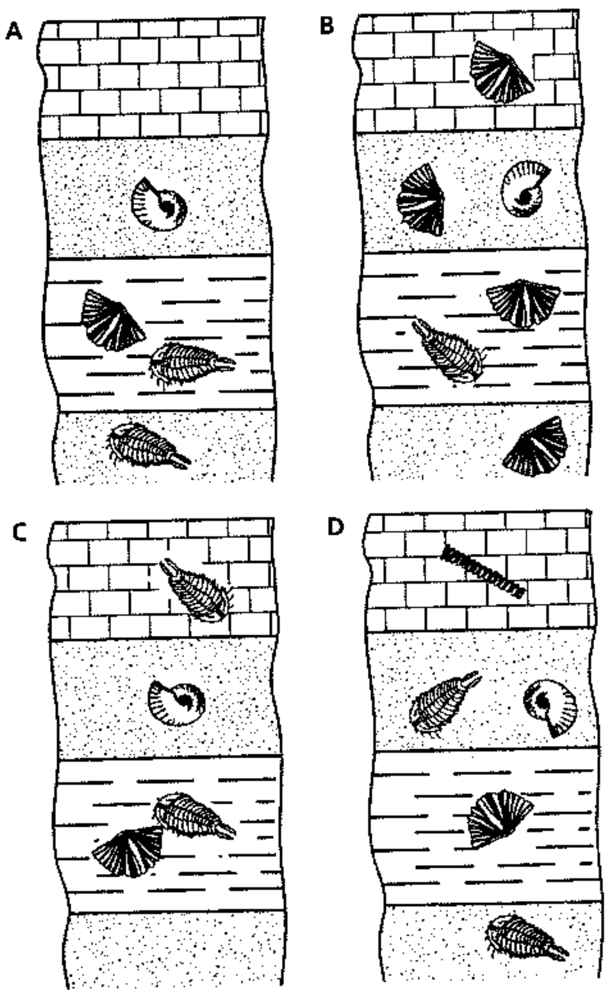
Figure 13-6. Volcano eruptions can serve as age markers: An explosive volcano eruption can deposit ash over vast areas and many different rock-forming environments. The deposited ash then serves as a specific age marker in many different rock types.

In a similar fashion, rock particles and debris produced by the impact of an asteroid, comet, or meteorite can cover large parts of Earth's surface. For example, at the end of the Mesozoic Era approximately 65 million years ago, a large comet or asteroid hit Mexico's Yucatan peninsula. Debris from the impact scattered over much of Earth's surface and can be found on all continents and in the sediments of most ocean areas. The debris, which included particles of the comet or asteroid, formed identifiable deposits, which can be used in correlation.

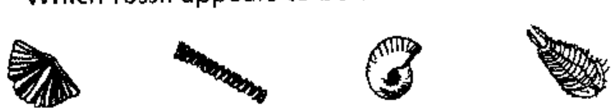
Review Questions

8. The simplest way to correlate exposed rock layers in the same general vicinity when they contain no fossils is by
   (1) examining intrusions
   (2) radioactive dating
   (3) following the continuity of the layers
   (4) tracing a fault

9. The following diagrams represent the rock layers and fossils found at four widely separated areas of exposed bedrock.



Which fossil appears to be the best index fossil?

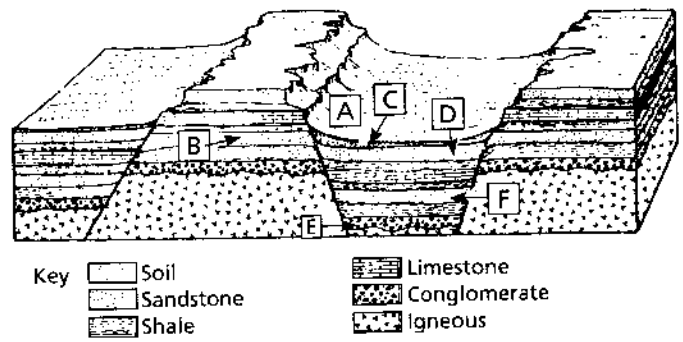


(1) (2) (3) (4)

10. Describe two essential characteristics of an index fossil.

11. In a conglomerate rock sample that is composed of limestone particles cemented together by calcite, what is the oldest part of the rock sample?

Base your answers to questions 12 through 14 on the following diagram.



12. The disturbed rock structure shown is probably the result of
   (1) warping
   (2) folding
   (3) volcanism
   (4) faulting

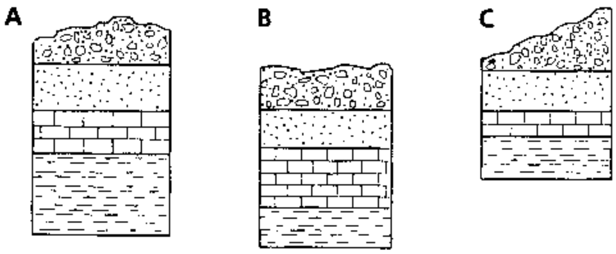
13. Which is the oldest sedimentary rock in this diagram?
   (1) conglomerate
   (2) sandstone
   (3) shale
   (4) limestone

14. Rock layer B is the same age as layer
   (1) C
   (2) D
   (3) E
   (4) F

15. The following diagram of three profile sections show fossil deposits W, X, Y, and Z found at widely separated locations. Which would be the best index fossil?
   (1) W
   (2) X
   (3) Y
   (4) Z

Rock layer 1	W		W		W Z	
Rock layer 2	W Z		Y		Z	
Rock layer 3	W X		X		X Z	
	Locality A		Locality B		Locality C	

16. The following diagrams represent cross sections of three areas of exposed bedrock approximately 100 kilometers apart. What would be the best method of correlating the rock layers of each area?
(1) comparing rock types
(2) comparing mineral composition
(3) comparing index fossils
(4) comparing thickness of rock layers



17. Why can layers of volcanic ash found between other rock layers often serve as good geologic time markers?
(1) Volcanic ash usually occurs in narrow bands around volcanoes.
(2) Volcanic ash usually contains index fossils.
(3) Volcanic ash usually contains the radioactive isotope carbon-14.
(4) Volcanic ash usually is rapidly deposited over a large area.

18. According to the *Earth Science Reference Tables*, which rock is most likely the oldest?
(1) conglomerate containing the tusk of a mastodont
(2) shale containing trilobite fossils
(3) sandstone containing fossils of flowering plants
(4) siltstone containing dinosaur footprints

19. The best basis for concluding that a certain layer of shale rock in New York State was deposited at the same time as one in California is that both
(1) are the same distance below the surface
(2) contain similar fossil remains
(3) are sedimentary rocks
(4) have the same chemical composition

20. Why might it be more likely for a fossil to be found in a sedimentary rock than in either an igneous or a metamorphic rock?

Geologic History From the Rock Record

In general, fossils in rock layers serve to establish the relative age of the rock layers. As life forms on Earth constantly evolve, or change over time, some life forms exist or are dominant only during specific intervals of geologic time. Thus, fossils in rocks can be used to order an area's geologic events according to relative age. For example, the rock record shows that dinosaurs and ammonoids existed in a long interval called the Mesozoic Era. However, the rock record also shows that certain types of dinosaurs existed only for shorter time intervals.

Geologic Time Scale

Mainly on the basis of changing fossil evidence, geologists have been able to divide geologic time into divisions. From longest to shortest, these divisions of time are called eons, eras, periods, and epochs. A model of these divisions of geologic time is called the **geologic time scale.** The Ⓡ Geologic History of New York State in the *Earth Science Reference Tables* represents the geologic time scale as a chart, while Figure 13-7 represents it as a timeline. Note that eons, eras, and other divisions of geologic time are not exact units of time such as hours or minutes. For example, in Figure 13-7, which shows the relative lengths of eons and eras, no two eras represent the same amount of time.

The Precambrian is a "super" eon composed of the earliest Archean and Proterozoic eons and represents approximately 88 percent of all geologic time. Precambrian fossils are rare and difficult to identify because the earliest known life forms were small and had no hard parts. Also, most Precambrian rocks have been either buried by more recent rocks, eroded away, or converted to metamorphic rocks or magma. To become familiar with the major divisions of geologic time, review the Geologic History (R) of New York in the *Earth Science Reference Tables*. Also, learn to recognize the names of life forms associated with particular eons, eras, periods, and epochs.

Unconformities

In attempting to read the rock record, geologists often find evidence of buried eroded surfaces called **unconformities.** One example is shown in Figure 13-8. An unconformity in the rock record of an area indicates that at some time in its geologic history, uplift occurred. This uplift exposed the rocks to weathering and erosion, which removed part of the rock record. A later sinking of land or rise in sea level caused the area to be covered by water. New sediments were then deposited on the eroded land surface, producing the unconformity. Most unconformities show a lack of parallelism between the older rock layers beneath the erosion surface and the younger rock layers above. The lack of parallelism occurs because the older rock layers were folded or tilted during uplift.

The presence of an unconformity means that parts of the rock record are missing—like missing pages or chapters in a history book. Although there is a gap in the record of geologic time, an unconformity is still useful in relative dating. The rocks above an unconformity are younger than the unconformity, and the rocks below it considerably older. An unconformity also usually correlates with a time of mountain building, called an orogeny, and the associated plate convergence. In the *Earth Science* (R) *Reference Tables*, the times of orogenies are listed as Important Geologic Events in New York in the Geologic History of New York State.

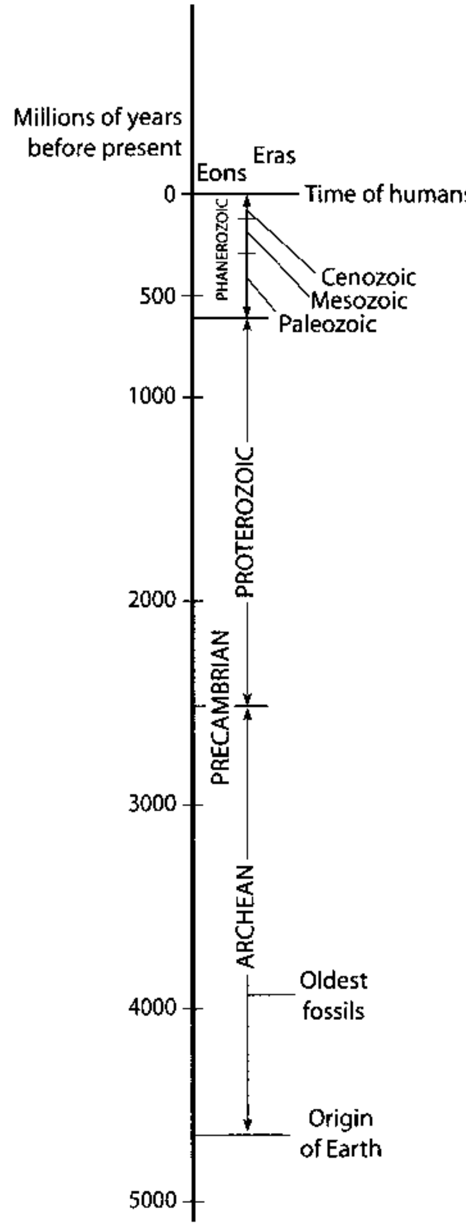
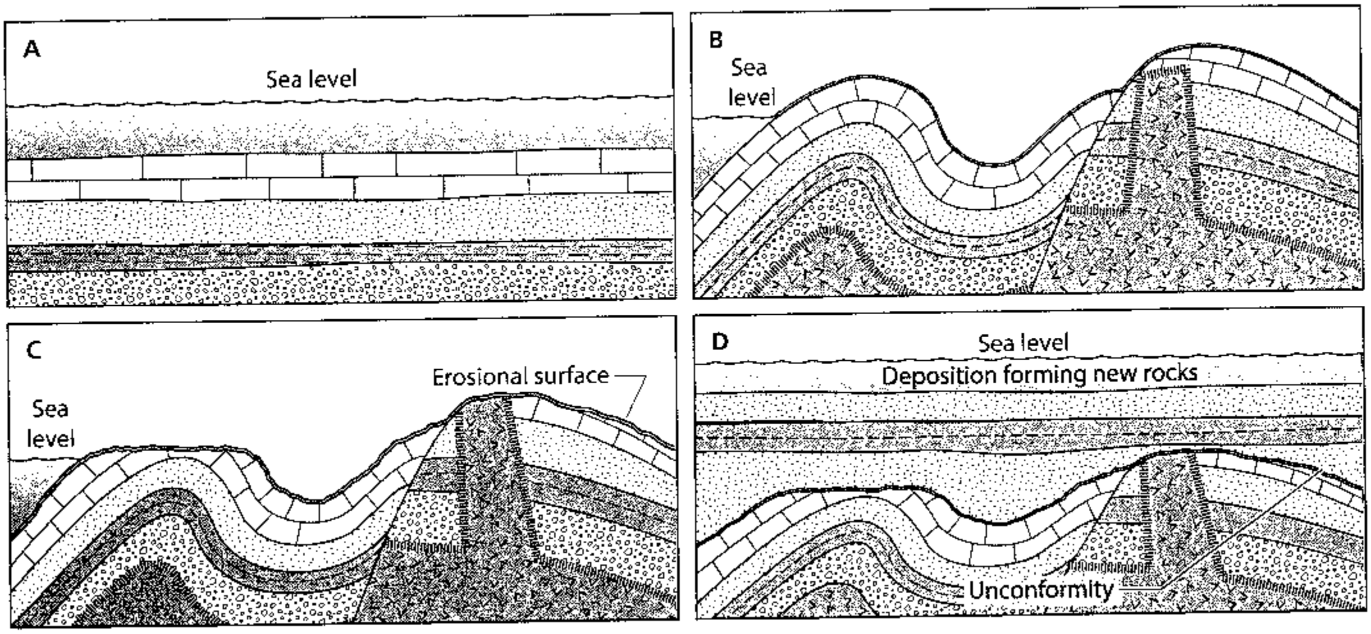


Figure 13-7. Timeline of Earth's geologic time: Life has existed for a large percentage of Earth's history. However, humans have existed for a comparatively short time (only 0.04 percent of Earth's history).

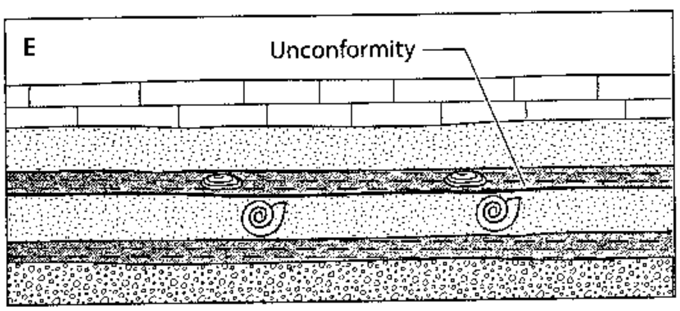
Uniformity of Process

One of the basic principles geologists use to interpret geologic history is the uniformity of process, which implies that "the present is the key to the past." This principle assumes that geologic processes happening today also occurred in the past and that much of the rock record can be interpreted by observing present geologic processes. Uniformity of process does not mean that different processes could not have happened or that past geologic processes always occurred at the same rate as they do today.

As an example of uniformity of process, suppose that a geologist in tropical Africa finds a conglomerate sedimentary rock layer. The sediments in the rock are unsorted, have a wide range of sizes, and have some partly rounded shapes with various scratches. Based on glacial processes known today, the geologist can infer that this conglomerate layer was the result of a past glaciation.



Events producing an unconformity with lack of parallelism: (A) Deposition forms sedimentary rock layers. **(B)** Crustal deformation and uplift occur. **(C)** Weathering and erosion remove part of the rock record. **(D)** Submergence (moved below sea level) and new deposition result in an unconformity along the now buried erosional surface.



An unconformity in parallel layers: (E) Uplift, erosion, and submergence have also occurred here, but without deformation. Evidence of a gap in the rock record may be given by widely different ages of the fossils in the layers above and below the unconformity.

Figure 13-8. Development of an unconformity

Uniformity of process implies that the chemical, physical, geological, and biological characteristics of nature remain the same throughout time. Thus, present observations can not only help geologists interpret Earth's past, but also make certain predictions about its future. By gathering sufficient data, it becomes possible to accurately predict certain natural disasters, such as volcanic eruptions, earthquakes, landslides, storms, and floods. Coupled with appropriate emergency procedures when needed, such predictions can help minimize death, injury, and property loss.

Review Questions

21. You are searching for fossils in the surface bedrock in Elmira, New York. Why are you unlikely to find dinosaur fossils at this location?

22. During which time was the majority of the exposed bedrock in New York State deposited?

(1) Precambrian
(2) Mesozoic
(3) Cenozoic
(4) Paleozoic

23. Rocks containing fossils of the earliest land plants could most likely be found in New York State bedrock near

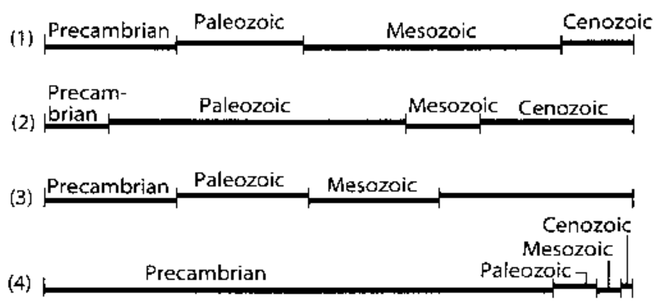
(1) Syracuse
(2) Oswego
(3) Ithaca
(4) Old Forge

24. Approximately how long ago were the Taconic Mountains uplifted?
(1) 540 million years ago
(2) 470 million years ago
(3) 310 million years ago
(4) 120 million years ago

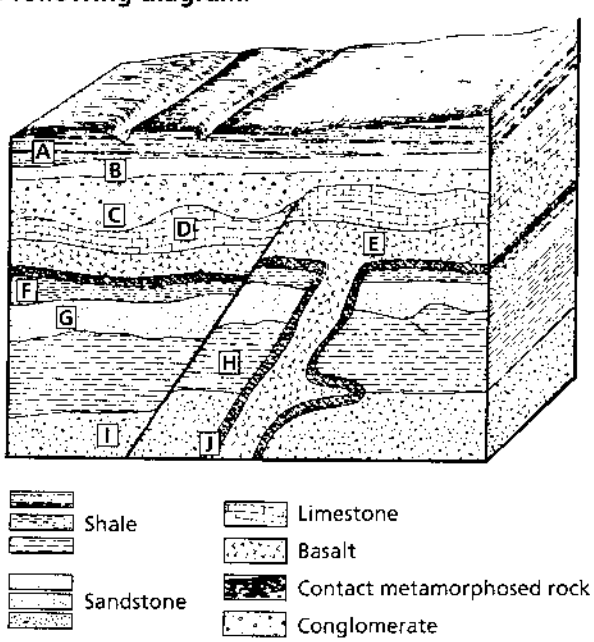
25. According to the Geologic History of New York State in the *Earth Science Reference Tables,* what is the estimated age of Earth as a planet in millions of years?
(1) 540 (3) 4600
(2) 4000 (4) 5000

26. The geologic time scale has been subdivided into a number of time units largely on the basis of
(1) fossil evidence (3) rock types
(2) rock thickness (4) radioactive dating

27. Which line is the best representation of the relative duration of each of the geologic time intervals?



Base your answers to questions 28 through 32 on the following diagram.



28. Which is the most recently formed rock?
(1) A (2) B (3) C (4) D

29. An unconformity is located between
(1) A and B (3) C and D
(2) B and C (4) F and G

30. The conclusion that the limestone layer D is younger than the basalt layer E is supported by evidence of
(1) faulting
(2) contact metamorphism
(3) igneous intrusion
(4) fossils

31. The last event before faulting occurred was the formation of
(1) C (2) D (3) E (4) J

32. Which must have most recently preceded the formation of layer D?
(1) faulting (3) intrusion
(2) orogeny (4) uplift

33. An unconformity between two sedimentary layers is most likely produced by
(1) the deposition of gravel followed by the deposition of sand and silt
(2) continuous sedimentation in a deep basin over a long period
(3) uplift followed by extensive erosion, submergence, and deposition
(4) a period of extrusive vulcanism followed by another period of extrusive vulcanism

34. Because the chemical, physical, geological, and biological characteristics of nature remain the same throughout time, we can interpret the past and
(1) prevent natural disasters
(2) identify unconformities
(3) predict natural hazard events
(4) determine the age of bedrock

35. Fossils are rarely found in Precambrian rocks because, at that time
(1) no life existed
(2) few life forms had hard parts
(3) few sedimentary rocks formed
(4) a meteorite impact destroyed most fossils

36. "The present is the key to the past." Explain what this statement means in the context of geologic history.

Absolute Dating of Rocks Using Radioactive Decay

The principle of superposition and methods of correlation help to determine the relative age of rock layers, but do not give their absolute age. Absolute age is expressed in specific units, such as years before the present. One method of absolute dating is the counting of annual layers of glacial lake sediments, which is similar to tree-ring dating. However, the primary method of absolute dating is described in the text that follows.

Isotopes and Radioactive Decay

An element is a substance consisting of atoms that are chemically alike. Most elements exist in several varieties called **isotopes.** The difference between one isotope of an element and another is in the mass of its atoms. For example, the mass of an atom of the most common isotope of carbon is 12 units. This isotope, carbon-12, is usually just called, "carbon," while another isotope in which the atoms have a mass of 14 units is called carbon-14.

Almost all the mass of an atom is concentrated in a central region called the nucleus (plural, nuclei). The nuclei of the atoms of many isotopes are unstable or radioactive. They emit particles and electromagnetic energy in a process called **radioactive decay,** nuclear decay or nuclear fission thus changing into atoms of other isotopes and elements. The nucleus remaining after radioactive decay may also be unstable and decay further over time. Eventually, a stable isotope—one that is not radioactive or does not undergo radioactive decay—forms.

Uranium-238 One of the most important radioactive isotopes used in dating rocks is **uranium-238,** the isotope of uranium whose atoms have a mass of 238 units. The nuclei of its atoms pass though a series of radioactive decays, eventually producing atoms of lead-206, a stable isotope of the element lead.

Half-life The decay of any individual atomic nucleus is a random event; that is, it may occur at any time. However, among the billions of atoms in any sample of an isotope, a certain definite fraction will decay in a given time. In the next time interval of the same length, the same fraction of the remaining atoms will decay as did in the previous time interval.

The time required for half of the atoms in a given mass of an isotope to decay is called the **half-life** of the isotope. In a given sample of a radioactive isotope, half of the original atoms will have decayed to other isotopes at the end of one half-life period, and half will remain unchanged. At the end of the next half-life period, half of these remaining atoms will have decayed, leaving one-fourth of the original atoms unchanged. This halving of the number of unchanged atoms during successive half-life periods continues indefinitely.

Each radioactive isotope has its own characteristic half-life. The half-life of an isotope is not affected by any environmental factors, such as temperature, pressure, or involvement in chemical reactions. The half-life is also not affected by the amount, mass, or volume of the sample. By the principle of uniformity of process, it can be assumed that the half-life of a given isotope has remained the same throughout Earth's history. Half-lives

Table 13-1. Radioactive Decay Data		
Radioactive Isotope	**Disintegration**	**Half-life** (exponential/ordinal)
Carbon-14	$^{14}C \rightarrow {}^{14}N$	5.7×10^3 = 5700 years
Potassium-40	$^{40}K \rightarrow {}^{40}Ar$, $^{40}K \rightarrow {}^{40}Ca$	1.3×10^9 = 1,300,000,000 years
Uranium-238	$^{238}U \rightarrow {}^{206}Pb$	4.5×10^9 = 4,500,000,000 years
Rubidium-87	$^{87}Rb \rightarrow {}^{87}Sr$	4.9×10^{10} = 49,000,000,000 years
Polonium-214	$^{214}Po \rightarrow {}^{210}Pb$	1.6×10^{-4} = 0.00016 seconds

for different isotopes vary widely—from fractions of seconds to billions of years. Table 13-1 shows some examples. For more information, see Physical Constants—Radioactive Decay Data in the *Earth Science Reference Tables.*

Radioactive Dating

The half-life of a radioactive isotope can be used, along with the ratio between the amount of the original isotope and the amount of its decay-product, to estimate the absolute age of a rock sample. This method is called **radioactive dating.** For example, consider a rock formed with uranite mineral grains containing uranium-238 and no lead-206. As time passed, the uranium-238 would slowly change to lead-206—its stable decay product—at its fixed half-life rate. At the end of one half-life period (4.5 billion years for uranium-238), half the uranium-238 atoms would have changed to atoms of lead-206. If a rock is found today with this 1:1 ratio of uranium-238 atoms to lead-206 atoms, it can be concluded that the rock formed 4.5 billion years ago. If the ratio between uranium-238 and lead-206 is higher than 1:1, the rock must have formed less than 4.5 billion years ago.

The age corresponding to any particular ratio of uranium-238 to lead-206 can be calculated mathematically. The curves in Figure 13-9 show how the percentage of uranium-238 decreases and the percentage of lead-206 increases with time in a given rock. The shape of the curves for any other radioactive isotope and its stable decay product would be similar. However, the time intervals would differ due to the different length of the half-life period.

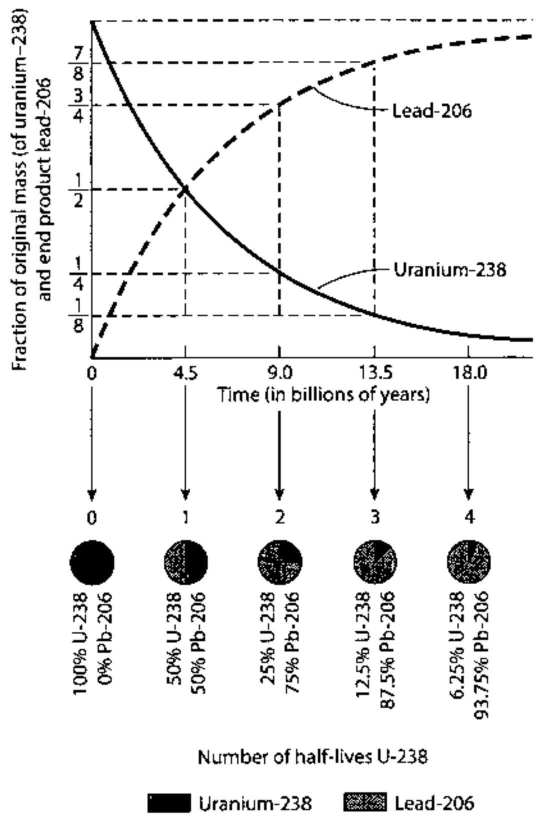


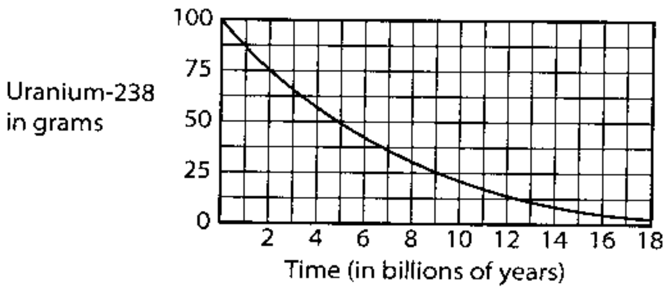
Figure 13-9. Curves showing radioactive decay of uranium-238 and formation of the stable decay product lead-206: After one half-life (4.5 billion years), half, or 50 percent, of the original uranium atoms have become lead atoms. By five half-lives, only 3.125 percent of the uranium atoms are left, and there are 96.875 percent lead atoms.

Carbon-14 Dating Radioactive elements with long half-lives, such as uranium-238, are used to date rocks that are hundreds of millions, or even billions, of years old. Over such long periods, any isotope with a short half-life would have decayed to such an extent that the remaining amounts would be immeasurable.

Some radioactive isotopes with short half-lives are useful for dating rocks and organic remains of relatively recent origin. One such useful isotope is carbon-14, with a half-life of 5700 years. **Carbon-14 dating**—also called radiocarbon dating—can be used to date rocks and organic remains, such as the bones of a mastodont, up to approximately 70,000 years in age. See the Geologic History of New York State in the *Earth* Ⓡ *Science Reference Tables.*

Review Questions

Base your answers to questions 37 through 39 on the following graph, which shows the radioactive decay of uranium-238.

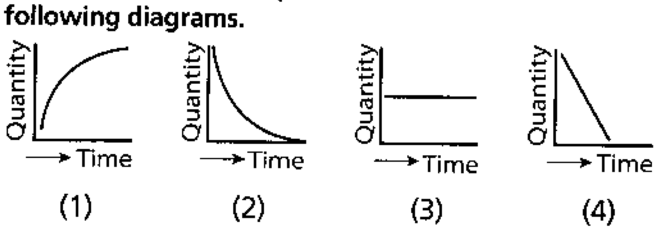


37. The half-life of uranium-238 as shown on this graph is closest to
(1) 2.5 billion years
(2) 3.5 billion years
(3) 4.5 billion years
(4) 5.5 billion years

38. Because of the half-life nature of the decay process, uranium-238 will theoretically
(1) decay completely before 4.5 billion years
(2) decay completely in 18 billion years
(3) decay completely in 200 billion years
(4) continue to decay indefinitely

39. Some uranium is obtained from an intrusive granite formation. It is then analyzed and found to contain approximately 1 gram of lead-206 to every 3 grams of uranium-238. Approximately how many billions of years old is the granite?
(1) nine (3) eighteen
(2) two (4) four

Base your answers to questions 40 and 41 on the following diagrams.



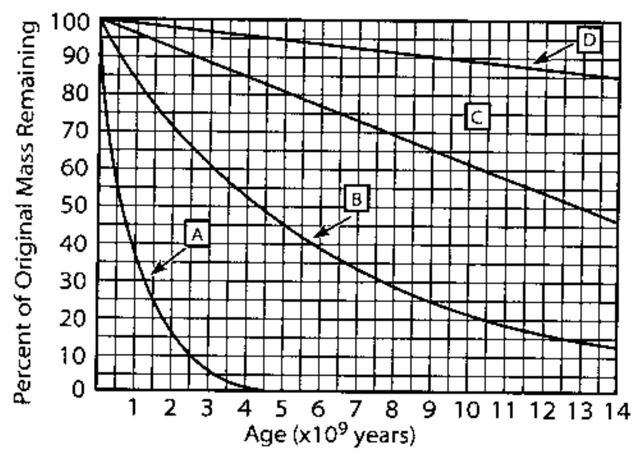
40. Which curve represents the expected decay rate of uranium-238 if its temperature were raised almost to the melting point?

41. If the decay curve for the element carbon-14 were plotted, which diagram shows the general shape that the curve would be?

42. The half-life of a particular radioactive substance
(1) decreases as pressure on it increases
(2) decreases as its mass decreases
(3) increases as the temperature increases
(4) is independent of mass, temperature, and pressure

43. If a specimen of a given radioactive substance is reduced in size, its half-life
(1) decreases
(2) increases
(3) remains the same

44. Which radioactive substance shown on the following graph has the longest half-life?
(1) A (2) B (3) C (4) D



45. Why is carbon-14 usually NOT used to accurately date objects more than 50,000 years old?
(1) Carbon-14 has a relatively short half-life, and too little carbon-14 is left after 50,000 years.
(2) Carbon-14 has a relatively long half-life and not enough carbon-14 has decayed after 50,000 years.
(3) Carbon-14 has been introduced as an impurity in most materials older than 50,000 years.
(4) Carbon-14 has only existed on Earth during the last 50,000 years.

46. Carbon-14 is often used to date fossils from the Holocene Epoch. Why would carbon-14 be less useful in dating an Ordovician fossil?

Evolution of Earth and Life

For a long time, people have wondered about Earth's history and how life on Earth came to be. From the study of fossils and rock layers, scientists have been able to gain much knowledge of Earth's past.

Variations in Fossils and Environments

The fossil record, preserved in sedimentary rocks, shows that a wide variety of life forms have lived in Earth's changing environments over time. Most of these life forms are now extinct. Since the chances of fossilization are low, and the percent of all sedimentary rocks studied for fossils is minuscule, most forms of past life probably have not been identified.

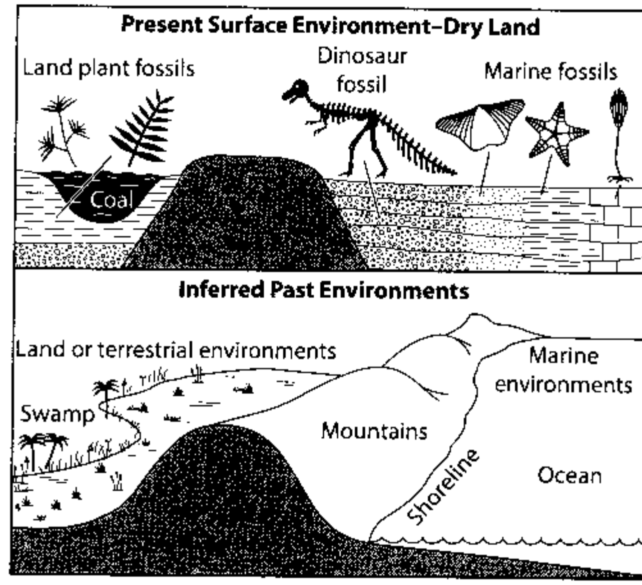


Figure 13-10. Reconstruction of past environments from fossil evidence and rock properties: From the existence of dinosaur fossils, marine fossils, and changes in sedimentary rock type, the location of the former shoreline and ocean can be inferred. From the existence of plant fossils and coal, the location of the former swamp can be inferred.

Comparisons of fossils with similar life forms alive today make it possible to infer facts about Earth's past environments, as shown in Figure 13-10. For example, fossils of ancient corals have been found in Devonian period rocks of the Allegheny Plateau in western New York State. As most present-day corals live in shallow, warm ocean waters, it can be inferred that these rocks were formed in a shallow, warm-water ocean environment. The Devonian/Mississippian map, at the far right of the table Geologic History of New York State in the *Earth Science Reference Tables*, shows that New York State was much nearer to the equator at that time and thus had a warmer climate. Ⓡ

Environment Evolution and Plate Tectonics A major reason for changes in Earth's environments over geologic time has been the movements of plates and their associated landmasses. In the *Earth Science Reference Tables* these movements are shown in a series of maps in the column Inferred Positions of Earth's Landmasses in the Geologic History of New York State. As the plates and their landmasses move, their latitude changes. The result is a change in climate. For example, the climate of a landmass which has moved closer to one of Earth's poles will become colder. Similarly, the climate of a landmass which has moved closer to the equator will become warmer. Ⓡ

Plate movements also result in other environmental changes. For example, plate convergence can result in continent-to-continent collisions that form long, high mountain ranges such as the Himalayas. Such mountain ranges can produce local climate changes. Also, rising magma at rapidly diverging plate boundaries can lead to a rise in the ocean floor, pushing ocean water onto the landmasses.

Environmental Evolution and Rock Types As Earth's environments changed over time, specific rocks and minerals formed, as well as deposits of fossil fuels. For example, hot and humid conditions during the Carboniferous Period of the Paleozoic Era and an abundance of land above sea level resulted in widespread swamps. The worldwide coal deposits of today were formed from these swamps. During parts of the Silurian Period of the Paleozoic Era, plate movements in hot and dry environments led to the

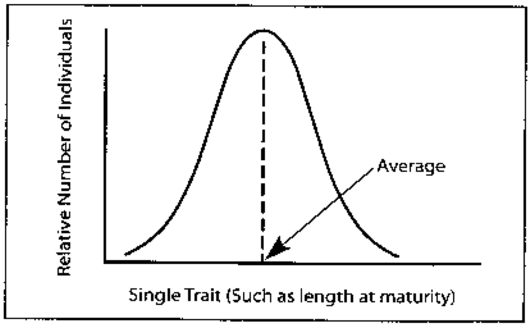


Figure 13-11. Variations in a single trait within a species: In any population of a species, each trait usually has an average value. In most individuals, the trait will be close to the average. In a few, it will be much below average; in a similar number, it will be much above average. If the departure from average in either direction has an advantage for survival and can be inherited, the average will shift in this favorable direction in later generations.

isolation of many ocean areas. Thus isolated, the waters of these ocean areas evaporated— precipitating evaporite rocks and mineral deposits, such as salt and gypsum. Deposits of salt and gypsum are found in western New York State.

Fossils and the Evolution of Life

A **species** of living things is a group of organisms which are similar enough to be able to interbreed and produce fertile young. However, not all members of a species are exactly alike. For example, in humans and in different breeds of dogs one sees that many variations in each species exist. When variations in a species are graphed, a bell-shaped curves often forms, as shown in Figure 13-11.

The theory of **organic evolution** states that life forms change through time. As environmental conditions change, variations within a species give certain individuals a greater chance of surviving and reproducing. Genetic material coding for these variations will be passed on to the offspring, and the favorable variations will be preserved. At the same time, individuals with unfavorable variations will gradually die out or become extinct. After a long period of time, individuals with many accumulated variations can lose the ability to interbreed with earlier varieties of the species. These individuals then become a new species.

The fossil record provides evidence for the theory of organic evolution. Fossils from adjacent intervals of geologic time sometimes show a gradual transition from an older species to a newer one.

Evidence in the fossil record also shows that evolution does not always occur at the same rate. Instead, there are times of rapid extinctions and subsequently rapid evolution of new species (punctuated evolution). Some of these times of rapid extinctions and evolution correspond to major divisions in the geologic time scale.

Rapid Evolution of Life After an Impact Event

An impact event, such as the collision of a comet or asteroid with Earth, may cause catastrophic environmental changes leading to rapid extinctions and evolution. Such an event probably occurred approximately 65 million years ago, at the interface of the Mesozoic and Cenozoic eras. At this time, a mass extinction occurred— about 70 percent of all existing species became extinct, including many species of dinosaurs. This mass extinction ended the Mesozoic Era and the dominance of reptiles on land and in the oceans. The Cenozoic Era began, and mammals became the dominant life forms on land.

Evidence exists that about 65 million years ago, Earth collided with one or more comets or asteroids many kilometers in diameter. This impact event created huge tsunamis, burned much of Earth's vegetation, and hurled millions of tons of dust-sized aerosols into the stratosphere. The aerosols remained in the stratosphere for many years, blocking out much of the insolation from the sun. With the amount of solar energy reaching Earth's surface drastically reduced, surface temperatures cooled. Photosynthesis also declined, reducing the growth of plants and algae which form the basis of the food supply for most living things. These environmental changes led to a mass extinction, and a chance for previously less successful life forms, such as mammals, to thrive and evolve. There is evidence that similar impact events occurred at the ends of the Triassic, Permian, and Devonian Periods of the geologic time scale.

Early Evolution on Earth

You may recall some of the events in the formation of Earth and the solar system. The following paragraphs discuss further inferences about some of the earliest events in Earth's history, based on available evidence. Most events discussed here occurred during the Archean and Proterozoic Eons of the Precambrian. Some of these, along with more recent events in Earth's history, are shown in Figure 13-12.

Find the following events, and other important events in Earth's evolution, on the diagram in Figure 13-12. For further details of Earth's history, see the Geologic History of New York State in the *Earth Science Reference Tables.* (R)

- Evidence from the radioactive decay dates of moon rocks and meteorites shows that the planet Earth probably formed approximately 4.6 billion years ago.
- During its early formation, Earth heated up and largely melted due to heat from impact events, radioactive decay of isotopes within Earth's interior, and gravity-induced movement of materials towards Earth's center.
- During early Earth's melting, Earth materials separated into zones according to their density. The densest materials, such as iron and nickel, settled to form Earth's core. The less dense silicates, and other rock and mineral components, became the mantle and perhaps the earliest crust. Gaseous elements and compounds rose above Earth's surface. Most of Earth's earliest atmosphere probably escaped into space.
- After hundreds of million of years, a largely solid crust formed, and plate tectonic activity began. The earliest evidence of a solid crust is approximately 4.2 billion years old. Gases from Earth's interior seeped out of the crust through cracks and volcanic eruptions in a process called **outgassing**. A second atmosphere formed—probably composed of water vapor, carbon dioxide, nitrogen, and other gases.
- When Earth's atmosphere and surface had cooled enough, water precipitated to form the oceans. Sedimentary rocks more than 4 billion years old provide evidence of this early ocean. Approximately 3.8 billion years ago, or earlier, single-celled life forms were present. Ocean salts—dissolved minerals—began to accumulate from chemical weathering of Earth's crust.
- Approximately 3.5 billion years ago, life forms similar to living stromatolites (colonies of bacteria and algae) evolved. These life forms used carbon dioxide and released free oxygen, some of which rose into the atmosphere. Over time, Earth's atmosphere of mostly carbon dioxide changed into one largely of nitrogen and oxygen.
- Most oxygen in the early atmosphere reacted with iron compounds forming iron oxide, or rust. Earth's early landmasses may have looked like the rust-colored surface of Mars. Millions of tons of iron oxide minerals were deposited in the oceans between 3.5 billion and 2.8 billion years ago.

- By approximately 2.8 billion years ago, most of the iron compounds that could react with oxygen had already done so. Thus, the amount of oxygen in the atmosphere began to increase. Some of the oxygen probably formed an early ozone layer in the stratosphere that protected life forms from the sun's deadly ultraviolet radiation.

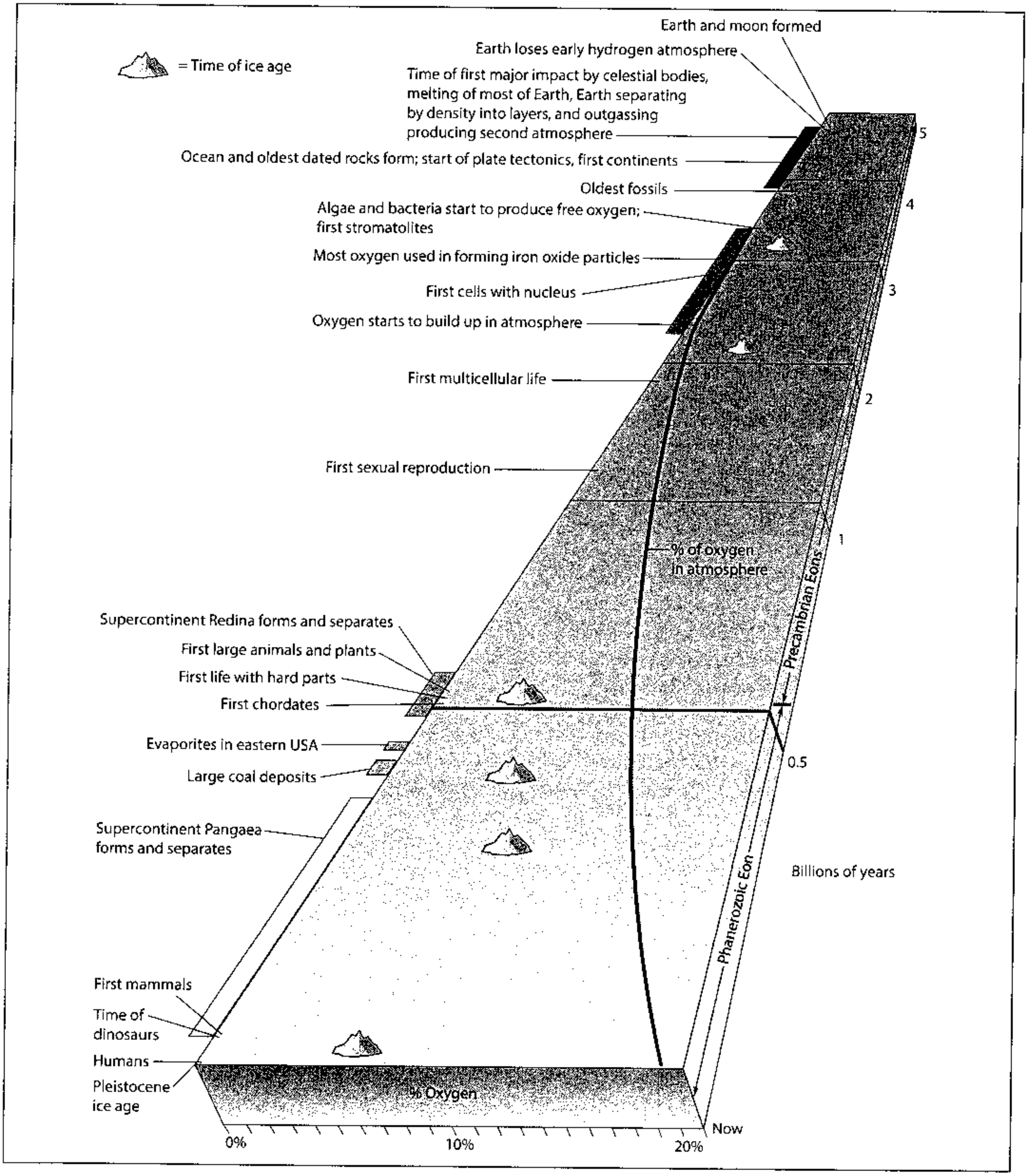


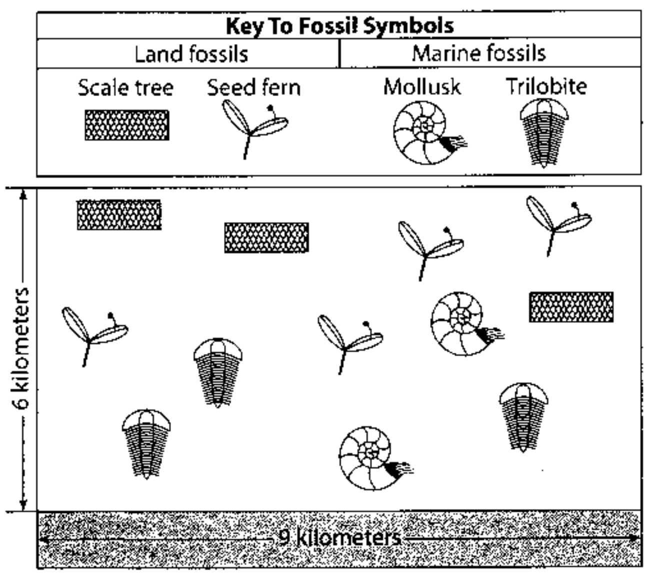
Figure 13-12. History of Earth: The diagram shows some highlights of the evolution of Earth and life.

• During the Precambrian, life forms slowly evolved from single-celled bacteria to multicelled life forms that could reproduce sexually. Most were soft-bodied. In the first part of the Paleozoic Era—the Cambrian Period—life forms evolved hard parts, and extensive evidence of life forms begins to appear in the rock record. Ancestors of most present-day life forms can be found in fossils from the Cambrian Period.

Review Questions

47. The following diagram represents a cross section of Earth's crust. The symbols in the diagram indicate the location on a horizontal surface of certain fossils that formed during the Carboniferous Period. For what purpose would the fossil information on the map be most useful?

(1) to find the location of the shoreline during the Carboniferous Period
(2) to measure the age of the bedrock by carbon-14 radioactive dating
(3) to provide evidence of the evolution of humans
(4) to indicate the extent of folding that occurred during the Devonian Period



48. Shark and coral fossils are found in the rock record of certain land areas. What does the presence of these fossils indicate about those areas?

(1) They have undergone glacial deposition.
(2) They were once covered by thick vegetation.
(3) They have undergone intense metamorphism.
(4) They were once covered by shallow seas.

49. Approximately 3.5 billion years ago photosynthetic organisms evolved. What dramatic change in Earth's atmosphere resulted primarily from this event?

50. The changes observed in the fossil record from the Precambrian to the Cenozoic Era best provide evidence of

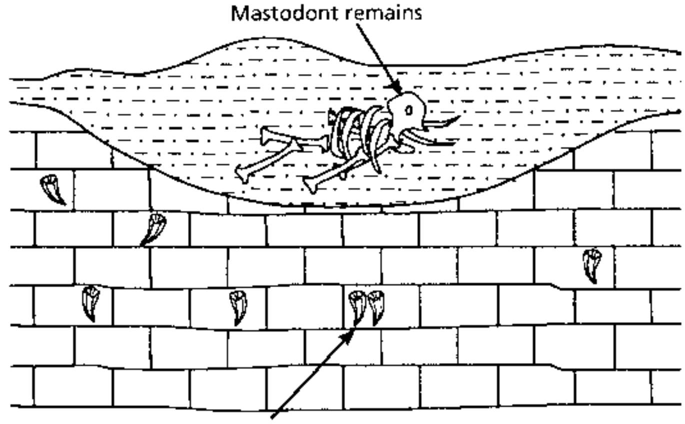
(1) sublimation
(2) radioactive decay
(3) organic evolution
(4) planetary motion

51. Which statement is false?

(1) Two members of one species must be exactly alike.
(2) The members of a species can vary in physical features.
(3) The members of a species can interbreed and produce fertile young.
(4) A species may exist on Earth for millions of years.

52. The following diagram represents a site in western New York State. The remains of a mastodont were found in sediments from a swamp located above limestone bedrock. Fossils of Paleozoic coral were discovered in the limestone beneath the swamp. Observations made at this site provide evidence that

(1) the local climate and environment have changed dramatically
(2) fossil coral provided food for mastodonts
(3) North America has drifted to the east from Europe and Africa
(4) mastodonts and coral were alive at the same time



(Not drawn to scale.)

Practice Questions

Directions

Review the Test-Taking Strategies section of this book. Then answer the following questions. Read each question carefully and answer with a correct choice or response.

Part A

1 Which of the following landscape features of New York State were most recently formed?
(1) the Finger Lakes
(2) the Catskills
(3) the Palisades sill
(4) the rocks of the Adirondack Mountains

2 Trilobite fossils from different time periods show small changes in appearance. These observations suggest that the changes may be the result of
(1) evolutionary development
(2) a variety of geologic processes
(3) periods of destruction of the geologic record
(4) the gradual disintegration of radioactive substances

3 From the study of fossils, what can be inferred about most species of plants and animals that have lived on Earth?
(1) They are still living today.
(2) They are unrelated to modern life forms.
(3) They existed during the Cambrian Period.
(4) They have become extinct.

4 An igneous rock contains one-half of its original amount of potassium-40. According to the *Earth Science Reference Tables*, the age of the igneous rock is closest to
(1) 0.7×10^9 years
(2) 1.3×10^9 years
(3) 2.1×10^9 years
(4) 2.6×10^9 years

5 Mesozoic rocks and fossils found in Australia would most likely match Mesozoic rocks and fossils found in
(1) Europe
(2) Antarctica
(3) the Atlantic Ocean
(4) North America

6 Which two gases were commonly outgassed from Earth's interior into the atmosphere around 4 billion years ago?
(1) carbon dioxide and nitrogen
(2) oxygen and hydrogen
(3) nitrogen and oxygen
(4) hydrogen and carbon dioxide

7 Geologists can use meteorite fragments to correlate different types of sedimentary rock thousands of kilometers apart because meteorite fragments
(1) are not changed by erosion
(2) would be spread over much of Earth's surface
(3) are all formed from the same minerals
(4) are often found in layers of sedimentary rock

8 What event in the evolution of life, around 540 million years ago, began an extensive fossil record on Earth?
(1) flowering plants evolved
(2) the extinction of armored fish
(3) animals evolved hard parts
(4) modern coral groups evolved

9 Trilobite fossils were recently discovered in Himalayan Mountain bedrock. During which geologic period could these organisms have lived?
(1) Neogene
(2) Cretaceous
(3) Triassic
(4) Cambrian

10 What is the geologic age of the surface bedrock of most of the Allegheny Plateau landscape region in New York State?
(1) Cambrian
(2) Devonian
(3) Silurian
(4) Ordovician

11 When did the Jurassic Period end?
(1) 65.5 million years ago
(2) 146 million years ago
(3) 163 million years ago
(4) 200 million years ago

12 According to the *Earth Science Reference Tables,* which geologic event is associated with the Grenville Orogeny?
(1) the metamorphism of the rocks of the Adirondack Mountains
(2) the advance and retreat of the last continental ice sheet
(3) the separation of South America from Africa
(4) the initial opening of the Atlantic Ocean

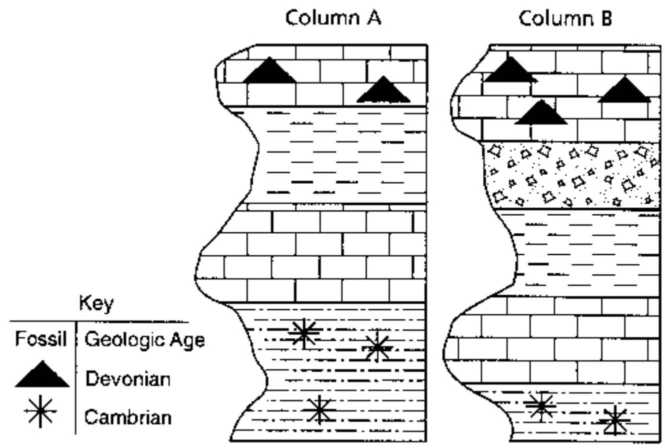
13 Present-day corals live in warm, shallow ocean water. Which inference is best supported by the discovery of Ordovician-age corals in the surface bedrock of western New York State?
(1) Western New York State was covered by a warm, shallow sea during Ordovician time.
(2) Ordovician-age corals lived in the forest of western New York State.
(3) Ordovician-age corals were transported to western New York State by cold, freshwater streams.
(4) Western New York was covered by a continental ice sheet that created coral fossils during the Ordovician period.

14 Unconformities (buried erosional surfaces) provide evidence that
(1) many life forms have become extinct
(2) faults are older than the rock in which they are found
(3) part of the geologic record has been destroyed
(4) metamorphic rocks have formed from sedimentary rocks

15 Based on studies of fossils found in subsurface rocks near Buffalo, New York, scientists have inferred that the climate of this area during the Ordovician Period was much warmer than the present climate. Which statement best explains this change in climate?
(1) The sun emitted less sunlight during the Ordovician Period.
(2) Earth was farther from the sun during the Ordovician Period.
(3) The North American continent was nearer to the equator during the Ordovician Period.
(4) Many huge volcanic eruptions occurred during the Ordovician Period.

Part B

Base your answers to questions 16 through 19 on the following diagrams. Columns A and B represent two widely separated areas of exposed bedrock. The symbols show the rock types and the locations of fossils found in the rock layers. The rock layers have not been overturned.



16 State one method of correlating rock layers found in the exposed bedrock represented by Column A with rock layers found in the exposed bedrock represented by Column B. [1]

17 An unconformity (buried erosion surface) exists between two layers in the exposed bedrock represented by Column A. Identify the location of the unconformity by drawing a thick wavy line at the correct position on column A.

18 State the evidence that limestone is the most resistant layer in these areas of exposed bedrock. [1]

19 State the oldest possible age, in millions of years, for the fossils in the siltstone layer. [1]

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20 In what era and period of geologic time were much of the present-day coal deposits formed? [1]

21 What produced most of the oxygen presently found in Earth's atmosphere? [1]

22 How can divergence of lithospheric plates affect the evolution of life on a continent? [1]

23 Why do large masses of the evaporite sedimentary rocks—rock salt and rock gypsum—exist in Silurian rocks of western New York State but are not forming there today? [1]

24 What are two events associated with the impact of a comet or an asteroid with Earth that would cause a major extinction of life? [2]

25 Why did most of the iron that existed near Earth's surface around 4.5 billion years ago end up in Earth's core? [1]

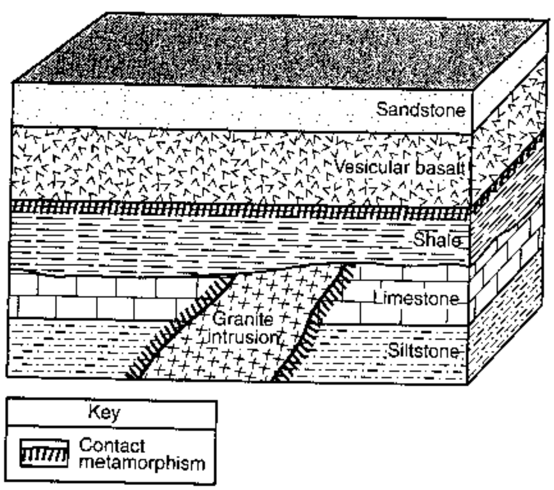
26 Compare the age of Earth and our solar system to the age of the most distant galaxies. [1]

27 While exploring a stream a student found a rock containing a trilobite fossil. Name the most likely type of rock this student found. [1]

28 If a rock contains a trilobite fossil in what geologic era did the rock most likely form? [1]

Part C

Base your answers to questions 29 through 32 on the geologic cross section below. Radioactive dating indicates that the granite intrusion is 279 million years old and the vesicular basalt is 260 million years old. The rock layers have not been overturned.



29 List the six rock units in the order from the oldest to the youngest. [1]

30 During which geologic time period did the shale layer form? [1]

31 The granite intrusion caused part of the limestone layer to undergo metamorphism. What metamorphic rock would most likely be found in this zone of contact metamorphism? [1]

32 Between which two rock layers in the diagram is there most likely an unconformity? [1]

---

33 Why can life, as we presently know it, exist on Earth and not on other planets in our solar system? [1]

34 In natural exposed bedrock, how is it possible that a meter-wide piece of sandstone can be found within an igneous rock such as granite? [1]

Read the following article about radon. Use your knowledge of earth science and the information in the following article to answer questions 35–38.

Radon (gas) gained public attention in 1984 when a worker in a Pennsylvania nuclear power plant set off radiation alarms—not when he left work, but as he entered. His clothing and hair were contaminated with radon decay products. Investigation revealed that his basement at home had a radon level 2800 times the average level in indoor air. The home was located along a geological formation known as the Reading Prong—a mass of uranium-bearing rock that runs from near Reading, Pennsylvania, to near Trenton, New Jersey.

Radon is continually generated by the gradual decay of uranium. Because uranium has a half-life of about 4.5 billion years, radon will be with us forever. Radon itself decays, having a half-life of only about four days. Its decay products (except lead 206) are all radioactive solids that adhere to dust particles, many of which we inhale. Steadily accumulating evidence indicates radon may be a significant cause of lung cancer, second only to smoking.

35 If the half-life of radon is only about four days, why does the Reading Prong, which is many million years old, still produce radon gas? [1]

36 Radon is often most concentrated in basements. What does this suggest about the density of radon gas compared to that of air? [1]

37 Would radon be a suitable radioactive element to use in radioactive dating? Explain. [2]

38 If you were a homeowner on the Reading Prong, what might you do to ensure the lowest possible concentration of radon gas in your home? [1]

Base your answers to questions 39 through 41 on the passage below.

Fossils and the History of Earth's Rotation

Data from coral fossils support the hypothesis that Earth's rotation rate has been slowing down by about 2.5 seconds per 100,000 years. Scientists believe this is due to the frictional effects of ocean tides. This slowing rotation rate decreases the number of days in the year.

Scientists have discovered that corals produce a thin layer of shell every day, resulting in growth rings. These daily layers are separated by yearly ridges.

The Devonian coral fossil, *Pleurodictyum*, has approximately 400 growth rings between each yearly ridge, which suggests that there were about 400 days in a year during the Devonian Period.

Supporting this hypothesis, scientists have found coral from the Pennsylvanian Period that have about 390 growth rings per year, while present-day corals have about 365 growth rings per year.

39 Approximately how many fewer Earth days per year are there today than there were during the Devonian Period?

(1) 10 (3) 35
(2) 25 (4) 40

40 What inference can be made about the number of growth rings per year for a coral from the Permian Period and Ordovician Period compared to the number of growth rings per year for the Devonian coral, *Pleurodictyum*?

(1) Ordovician coral would have fewer, but Permian coral would have more.
(2) Ordovician coral would have more, but Permian coral would have fewer.
(3) Both Ordovician and Permian coral would have fewer.
(4) Both Ordovician and Permian coral would have more.

41 The evidence of the fossil *Pleurodictyum* found in surface bedrock in the Finger Lakes region of New York State suggests that this region was once

(1) covered by a glacial ice sheet
(2) covered by a warm, shallow sea
(3) located in a desert area
(4) located in a tropical rain forest

Base your answers to questions 42 through 44 on the paragraph below, which provides background information regarding recent fossil discoveries in Canada.

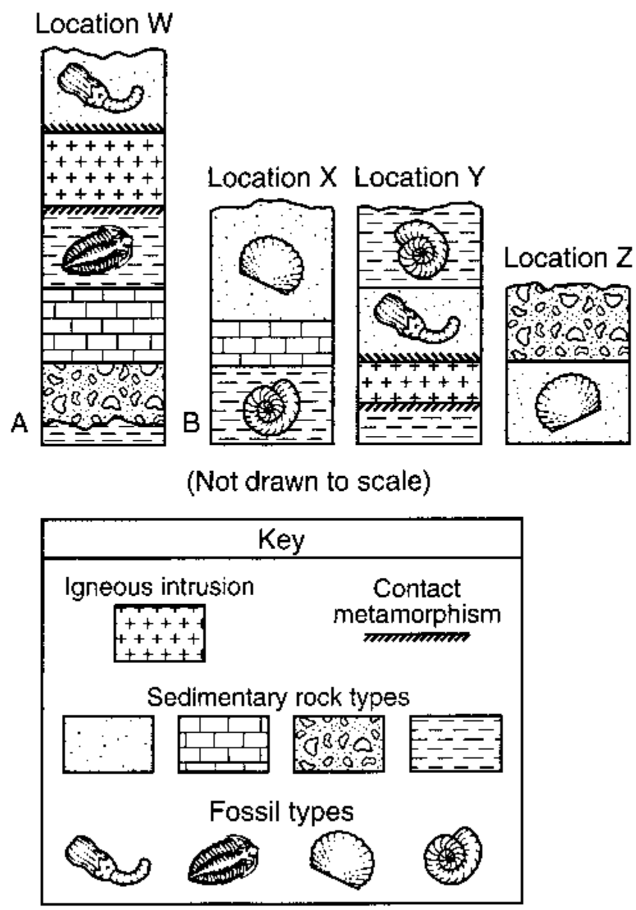
Scientific evidence indicates that the earliest mammals may have evolved approximately 225 million years ago from an ancient reptile group called the therapsids. For millions of years afterward, early mammals and therapsids coexisted until the therapsids apparently became extinct 165 million years ago. However, geologists have recently found a fossil they believe to be a therapsid that is only 60 million years old. They found the fossil, which they have named *Chronoperates paradoxus* (paradoxical time-wanderer), near Calgary in Canada. This find suggests that for 105 million years after the apparent extinction of the therapsids, a few of the reptiles continued to live in a narrow geographic range in Canada.

42 According to fossil evidence, during which geologic period did the earliest mammals appear on Earth? [1]

43 Explain briefly why *Chronoperates paradoxus* would not be a good index fossil. [1]

44 State one method geologists could have used to determine that *Chronoperates paradoxus* lived 60 million years ago. [1]

Base your answers to questions 45 through 47 on the cross sections below, which show widely separated outcrops at locations *W*, *X*, *Y*, and *Z*. The rock layers have not been overturned. Line *AB* in the cross section at location *W* represents an unconformity. Fossils are shown in some of the layers.

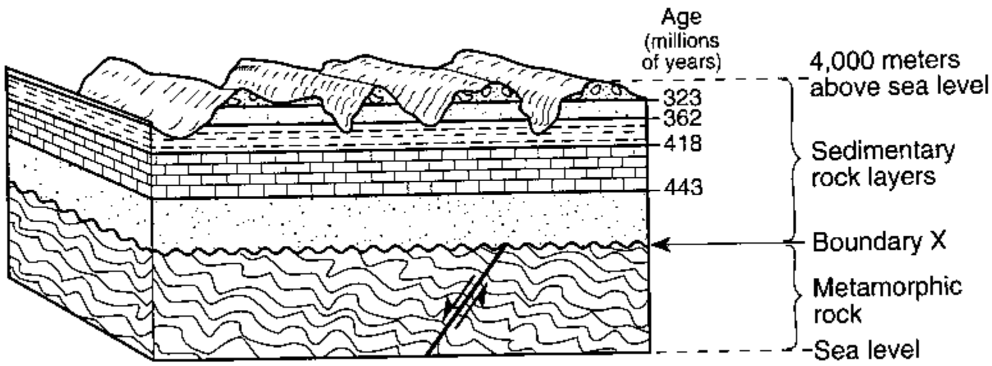


(Not drawn to scale)

45 Determine the relative geologic age of the four fossils by correlating the rock layers between these outcrops. Number the fossils from 1 to 4 in order of relative age, with 1 as the oldest and 4 as the youngest. [1]

46 Identify *two* of the processes involved in the formation of the unconformity represented by line *AB* in the cross section at location *W*. [1]

Base your answers to questions 47 through 49 on the cross section below and on your knowledge of Earth science. The cross section shows a portion of Earth's crust. The age, in millions of years, of each boundary between the different sedimentary rock layers is shown. The age of boundary X between the sedimentary rock and the metamorphic rock is not shown. Assume no overturning has occurred.

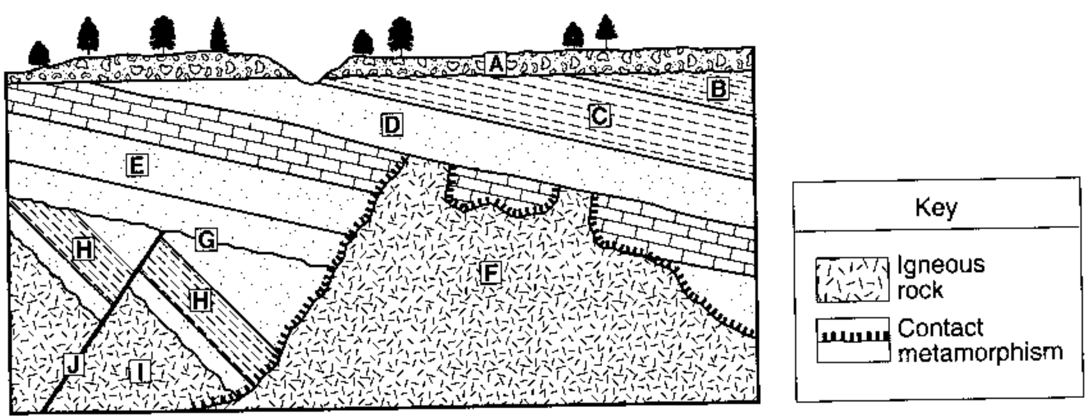


47 Identify the geologic feature represented by boundary X. [1]

48 Describe how the rock type below boundary *X* was formed. [1]

49 Identify by name one index fossil that existed when the limestone rock shown in the cross section was being formed. [1]

Base your answers to questions 50 through 53 on the cross section below which shows a portion of Earth's crust. Letters A through J represent rock units or geologic structures. The rock units have not been overturned.



50 On the cross section, draw a circle around the letter of the oldest rock unit shown. [1]

51 On the same cross section, place an **X** to indicate a location where the rock, marble, was formed. [1]

52 Describe *one* piece of evidence shown in the cross section that suggests rock unit *D* is younger than rock unit *F*. [1]

53 Explain why rock unit *H* is *not* one continuous layer. [1]