12 Geologic Time

Big idea

Earth History

Q: How do geologists reconstruct Earth's past?

Ammonites were mollusks related to squid. These ammonites at Kimmeridge Bay in England, are from the Jurassic period, which lasted from 200–140 million years ago.

VIRGINIA SCIENCE STANDARDS OF LEARNING

ES.1.c, ES.2.b, ES.9.a, ES.9.b, ES.9.c.
See lessons for details.

INQUIRY

TRY IT!

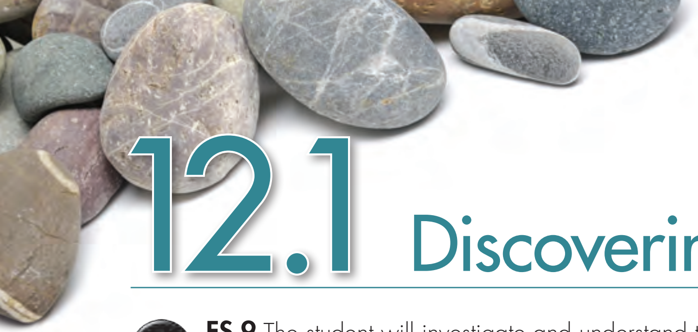
WHAT CAN BECOME A FOSSIL?

Procedure

1. Your teacher will give you some samples of different organic materials. Organic material comes from a living thing.
2. Using a hand lens and microscope, examine each sample carefully.
3. Separate those items that you think have a good chance of becoming a fossil.

Think About It

1. **Observe** What characteristics do the samples have that led you to select them as possible candidates for fossilization?
2. **Form a Hypothesis** What do you think needs to happen to these samples in order for them to become fossilized?
3. **Design an Experiment** Outline an experiment to test your answers to Questions 1 and 2.



12.1 Discovering Earth's History

ES.9 The student will investigate and understand that many aspects of the history and evolution of Earth and life can be inferred by studying rocks and fossils. Key concepts include **b.** superposition, cross-cutting relationships, index fossils, and radioactive decay are methods of dating bodies of rock. Also covered **ES.9.c.**

Key Questions

What is the principle of uniformitarianism?

What are the key principles of relative dating?

How do geologists interpret the rock record?

Vocabulary

- uniformitarianism
- relative dating
- law of superposition
- principle of original horizontality
- principle of cross-cutting relationships
- unconformity
- correlation

Reading Strategy

Identify Main Ideas Copy the table below, leaving room for notes. As you read, fill in the first column with a main idea and add details that support it in the second column.

Main Idea	Details
1. a. ?	b. ?
2. c. ?	d. ?
3. e. ?	f. ?

LIKE PAGES in a long and complicated history book, rocks record the geological events and changing life forms of the past. The book, however, is not complete. Many pages, especially in the early chapters, are missing. Others are tattered, torn, or smudged. Yet enough of the book remains to allow much of the story to be deciphered. Interpreting Earth history is a prime goal of the science of geology. The Grand Canyon, seen in **Figure 1,** is an example of just how beautiful the book of Earth's history can be.

Uniformitarianism

Scientists in Europe and the British Isles began developing the basic principles of modern geology during the 1700s by observing the landscapes around them. James Hutton, a Scottish physician and farmer, published *Theory of the Earth* in 1795. In this work, Hutton argued that Earth's varied landscape, from towering mountains to deep valleys, is the result of weak, slow-acting processes acting over long spans of time. Hutton's work was expanded upon by other geologists and was the foundation for the principle of uniformitarianism. **Uniformitarianism is the idea that the physical, chemical, and biological laws that operate today also operated in the past.** Thus, to understand ancient rocks, we must fi st understand present-day processes and their results. The principle of uniformitarianism is commonly expressed by saying "The present is the key to the past."

Acceptance of uniformitarianism requires acceptance of a very long history for Earth. If Earth were just a few thousand years old, there would not be enough time for slow-acting processes to form the geologic features we see today. To address this need, Hutton introduced a concept called *deep time,* which proposed that Earth had an indefi itely long history. As we will see, scientists were eventually able to determine that the absolute age of Earth is approximately 4.5 billion years.

Today, scientists understand that geological processes may not always have had the same relative importance. Nor have they always operated at precisely the same rate. Moreover, some important geologic processes are not currently observable, but evidence that they occur is well established. For example, we know that large meteorites have hit Earth, changed its climate, and caused extinctions even though we have no human witnesses.

FIGURE 1 Layers of History Trained geologists read and interpret layers of rock in the Grand Canyon as a historian might read and interpret pages in a book.

Despite these complications, the principle of uniformitarianism is an extremely important idea in modern geology. Hutton and other early geologists gave us the knowledge and framework for understanding the rock record. Their work established that Earth is very old and has changed over geologic time, and that processes observed on Earth in the present also acted in the past.

Reading Checkpoint *What is deep time?*

Relative Dating

By studying layers of rock exposed at the surface, such as those visible in the Grand Canyon, scientists can infer the order in which the layers formed. The method that geologists use to place rocks in chronological order is called **relative dating.** Relative dating identifies which rock units formed fi st, second, third, and so on. **The law of superposition, the principle of original horizontality, the principle of cross-cutting relationships, unconformities, and inclusions all help determine the relative ages of rock layers.** As important as relative dating is, it can only provide information about the sequence in which events occurred. It does not tell us how long ago the events occurred.

Law of Superposition Nicolaus Steno, a Danish anatomist, geologist, and priest (1636–1686), made observations that are the basis of relative dating. Based on his observations, Steno developed the law of superposition. The **law of superposition** states that in an undeformed sequence of sedimentary rocks, each layer is older than the one above it and younger than the one below it. Although it may seem obvious that a rock layer could not be deposited unless it had something older beneath it for support, it was not until 1669 that Steno stated the principle. This rule also applies to other surface-deposited materials, such as lava flows and layers of ash from volcanic eruptions.

FIGURE 2 Disturbed Rock Layers Rock layers that are folded or tilted must have been moved into that position by crustal disturbances after their deposition. These folded layers are exposed in the Namib Desert (southwestern Africa).

Principle of Original Horizontality Steno also developed the important **principle of original horizontality,** which states that sediment is generally deposited in flat, horizontal layers. Many layers of the Grand Canyon are horizontal. We can therefore infer that they are in their original undisturbed position. However, the rock layers shown in **Figure 2** have been tilted and bent. According to the principle of original horizontality, these rocks formed in flat layers. So whatever bent and tilted the layers must have done so after the rock layers had formed.

Principle of Cross-Cutting Relationships Later geologists developed another principle used in relative dating. This principle, called the **principle of cross-cutting relationships,** states that a fault or intrusion must be younger than any geologic formation through which it cuts. For example, in **Figure 3** you can see that Fault A occurred after the sandstone was deposited because Fault A "broke" the sandstone layer. However, Fault A occurred before the conglomerate was laid down, because that layer is unbroken by the fault. Using the same principle, Intrusion A must be younger than Fault A and the conglomerate layer because it crosses both of them.

☑ **Reading Checkpoint** *To what type of rock can the law of superposition and the principle of original horizontality be best applied?*

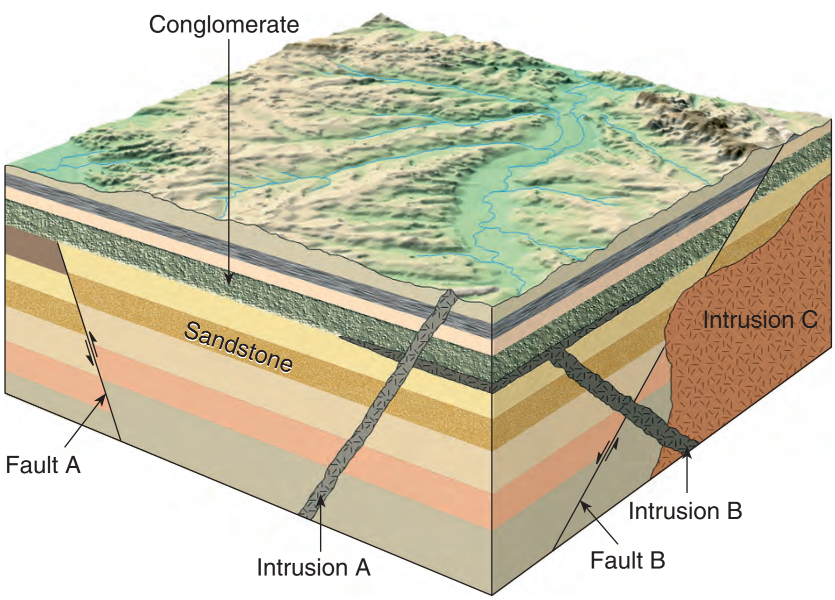


FIGURE 3 Principle of Cross-cutting Relationships An intrusive rock body is younger than the rocks it intrudes. A fault is younger than the rock layers it cuts.
Interpret Diagrams ***What are the relative ages of Fault B, Intrusion B, and Intrusion C?***

Unconformities Throughout Earth's history, the deposition of sediment has been interrupted again and again. Nowhere is Earth's rock record complete. A surface that represents a break in the rock record is termed an **unconformity.** An unconformity indicates a long period during which deposition stopped, erosion removed previously formed rocks, and then deposition resumed. Unconformities help geologists identify what intervals of time are not represented in the rock record. There are three basic types of unconformities: angular unconformities, disconformities, and nonconformities. **Figure 5** shows examples of each type of unconformity in the Grand Canyon.

- ***Angular Unconformity*** In an angular unconformity, layers of sedimentary rock form over older sedimentary rock layers that are tilted or folded. **Figure 4** shows this process.
- ***Disconformity*** In a disconformity, two sedimentary rock layers are separated by an erosional surface. Because the rocks on both sides of the unconformity are of the same type, disconformities can be difficult to recognize.
- ***Nonconformity*** In a nonconformity, an erosional surface separates older metamorphic or igneous rocks from younger sedimentary rocks.

FIGURE 4 Formation of an Angular Unconformity An angular unconformity represents an extended period during which deformation and erosion occurred.

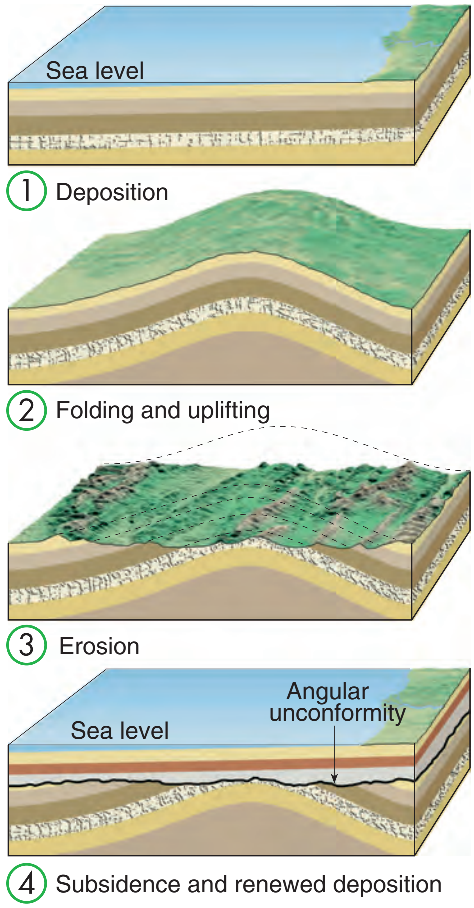
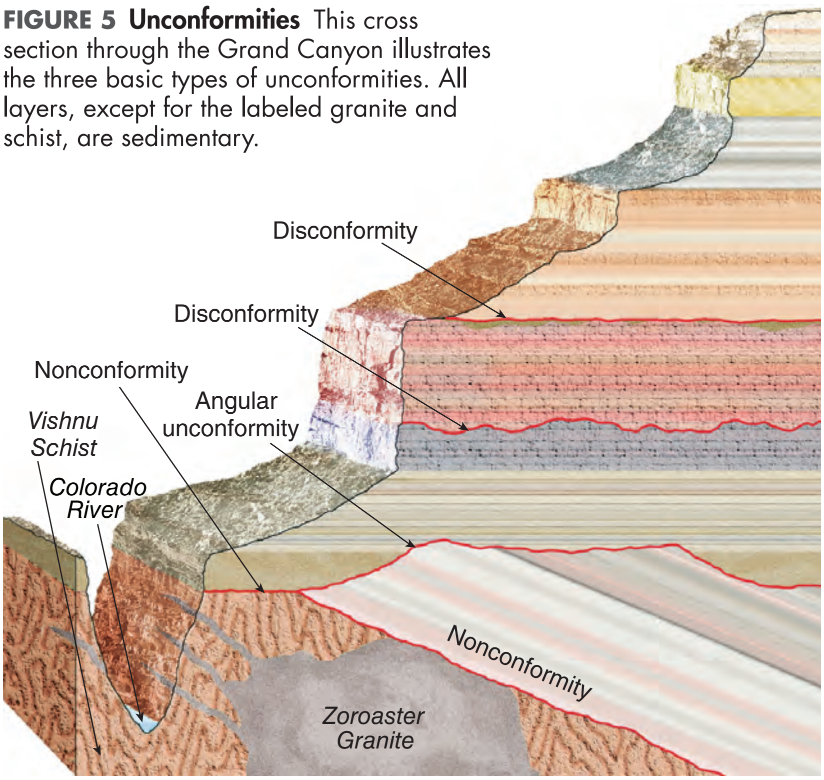


FIGURE 5 Unconformities This cross section through the Grand Canyon illustrates the three basic types of unconformities. All layers, except for the labeled granite and schist, are sedimentary.



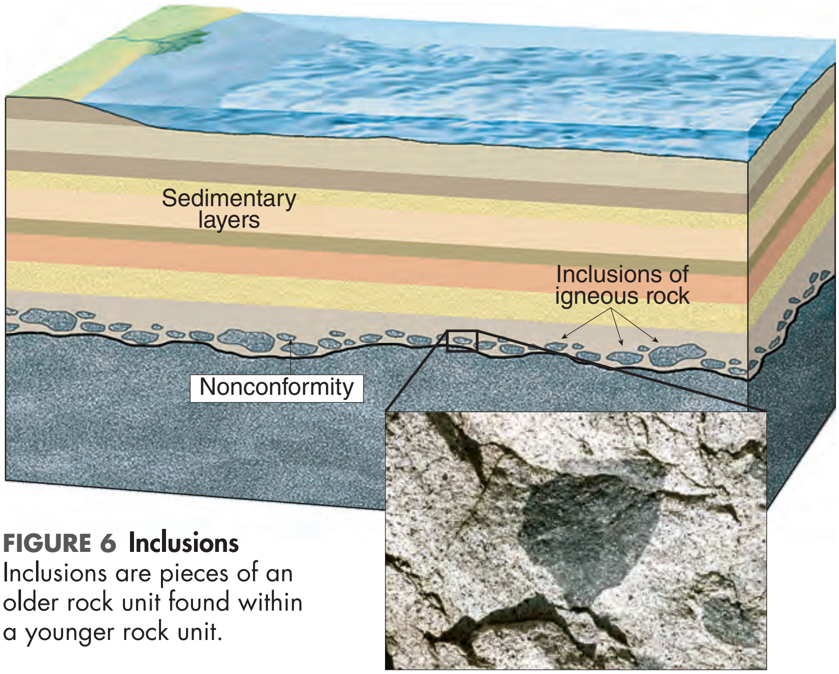


FIGURE 6 Inclusions
Inclusions are pieces of an older rock unit found within a younger rock unit.

Inclusions Sometimes the study of inclusions can help the relative dating process. *Inclusions* are pieces of one rock unit that are contained within another rock unit. We know that the rock unit containing the inclusions must have formed after the layer that provided the fragments. Therefore, the rock unit containing inclusions is the younger of the two. **Figure 6** shows inclusions of igneous rock within a layer of sedimentary rock. The inclusions indicate that the sedimentary layer was deposited on top of a layer of igneous rock. The sedimentary layer must be younger than the igneous rock because the sedimentary layer contains pieces of the igneous rock. We know the layer was not intruded upon by magma from below that later hardened, because there is a nonconformity between the layers.

Correlation

By applying the principles of relative dating, geologists can interpret the history of an area. But what if the goal is to interpret the history of an entire region? **Scientists correlate rock layers at different locations to piece together a more complete interpretation of the rock record.** In geology, **correlation** is the process of matching rock layers at different locations that formed at the same time and by the same processes. For example, the correlation of rock layers at three sites on the Colorado Plateau in southern Utah and northern Arizona is shown in **Figure 7.** Because of erosion, neither location contains a complete rock sequence. However, by correlating layers at multiple locations, a more complete picture of the sedimentary rock record in the area is revealed. When correlation between widely separated areas or between continents is the goal, however, geologists must rely on something else to help them—fossils.

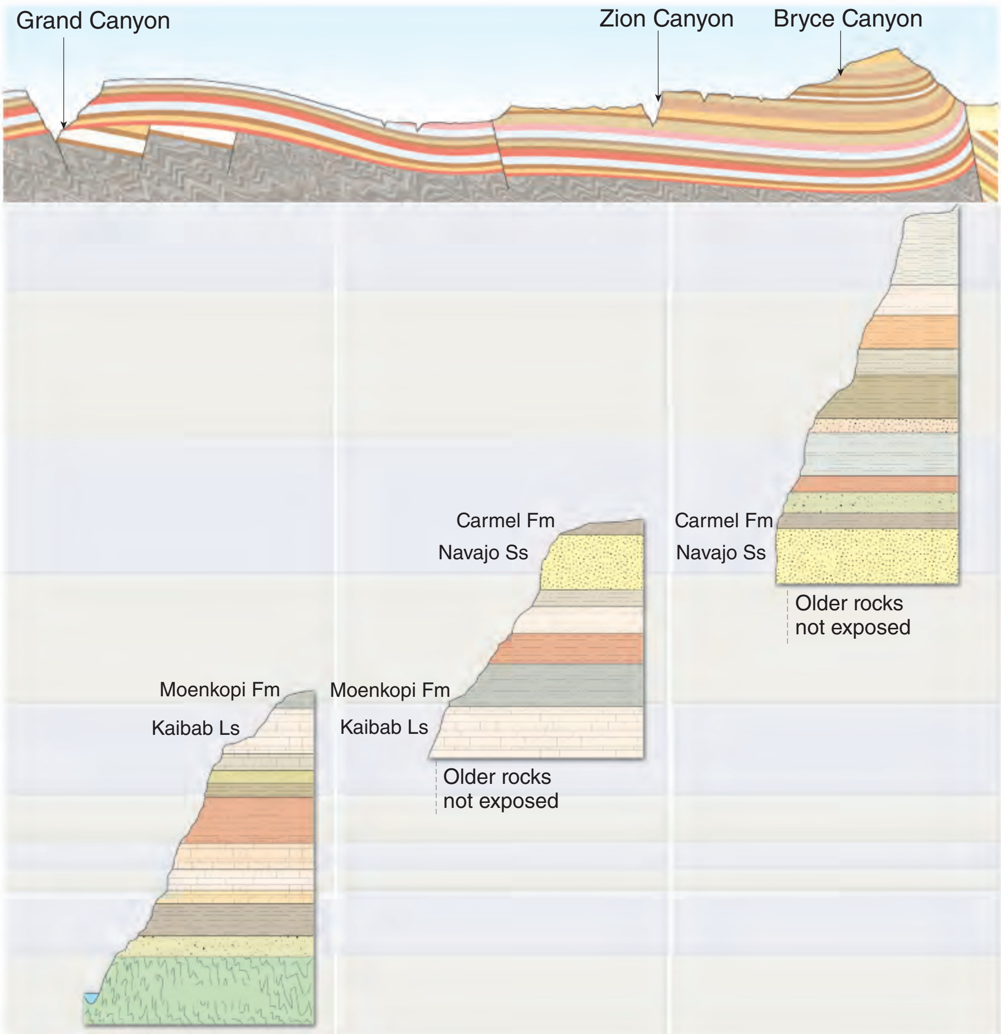


FIGURE 7 A More Complete Record Correlation of rock layers at three locations on the Colorado Plateau—the Grand Canyon, Zion Canyon, and Bryce Canyon—provides a more complete geologic history for the area than any one site could provide.
Interpret Diagrams ***Which rock layers are found in both the Grand Canyon and Zion Canyon?***

12.1 Assessment

Review Key Concepts

1. Explain the following statement: "The present is the key to the past."
2. List and briefly describe Steno's principles.
3. In your own words, write definitions for the terms *inclusion*, *unconformity*, and *correlation*.
4. Why do geologists correlate rock layers?

Think Critically

5. **Apply Concepts** How did the acceptance of uniformitarianism change the way scientists viewed Earth?
6. **Infer** What can you infer about the age of sedimentary rock layers relative to the age of a sill intruded into those layers?
7. **Classify** A geologist finds layers of sedimentary rocks immediately above an eroded anticline. What type of unconformity is this? Explain.
8. **Relate Cause and Effect** Why is Earth's rock record for any given location incomplete?

WRITING IN SCIENCE

9. **Describe** Imagine that you are hiking in the Grand Canyon. Using Steno's principles, write a paragraph describing what you see, how old the layers are, and how they were deposited.

12.2 Fossils: Evidence of Past Life

ES.9 The student will investigate and understand that many aspects of the history and evolution of Earth and life can be inferred by studying rocks and fossils. Key concepts include **b.** superposition, cross-cutting relationships, index fossils, and radioactive decay are methods of dating bodies of rock.

Key Questions

What are the different types of fossils?

What conditions help a fossil to form?

Why are fossils important?

What is natural selection?

Vocabulary

- extinct • fossil
- principle of fossil succession
- index fossil
- evolution
- natural selection
- adaptation

Reading Strategy

Monitor Your Understanding
Draw and complete a chart like the one below. After you finish this section, correct or add details as needed.

Fossils	How Fossils Form	How Fossils are Used
a. ?	b. ?	c. ?

WOOLY MAMMOTHS once roamed the cold plains of northern Asia, North America, and Europe. Thousands of years ago, they became **extinct,** meaning they died out. In the Arctic, scientists often fi d mammoth fossils, such as the huge tusks in **Figure 8.** A **fossil** is the preserved remains or traces of an organism.

Types of Fossils

When you think of the word *fossil,* you likely picture something like a dinosaur bone. But the bones you see on display in a natural history museum are more like rocks than bones. Moreover, they represent just one type of fossil. **The different types of fossils include petrified fossils, molds and casts, compressions, impressions, unaltered remains, and trace fossils.**

Petrified Fossils If you were allowed to pick up a dinosaur bone, you'd be surprised at how heavy it felt. That is because the bone has been petrified, or literally "turned into stone." In this process, mineral-rich water soaks into the small cavities and pores of organic tissue such as shell, bone, or even wood, as shown in **Figure 9A.** As minerals precipitate, they fill the spaces and replace dissolving tissue. In this way, petrification preserves the detailed structure of the original organism.

Molds and Casts A fossil mold is created when a shell or other organic structure is buried in sediment and then dissolved by underground water. The mold reflects only the shape and surface markings of the organism. It doesn't reveal any information about its internal anatomy. Cast fossils **(Figure 9B)** are created if the hollow spaces of a mold are later filled with minerals.

FIGURE 8 Frozen in Time
The permafrost in Siberia preserved the frozen remains of this mammoth for thousands of years. Permafrost is a layer of ice that forms under land in the Arctic.

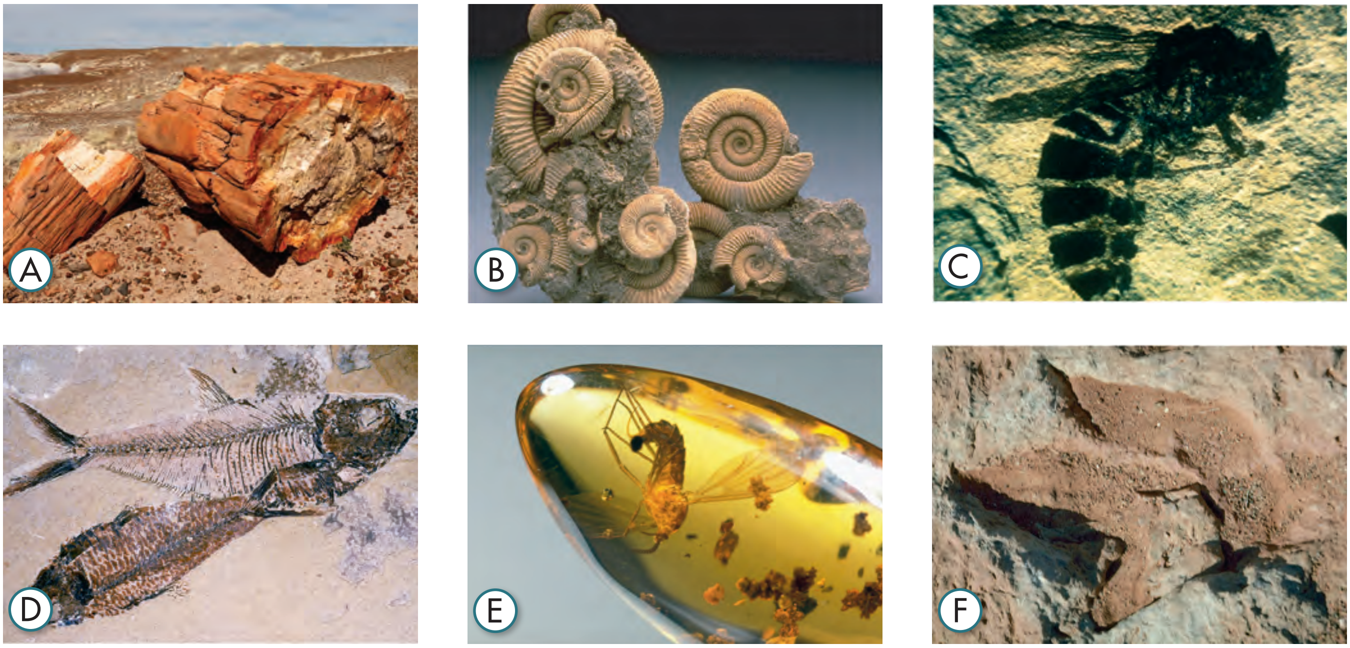


FIGURE 9 Types of Fossils **A** Petrified fossil of wood in Petrified Forest National Park, Arizona **B** Natural casts of shelled organisms called ammonites **C** Compression fossil of bee, preserved as a thin film of carbon **D** Impression fossil of two ancient fish **E** Unaltered remains of an insect in amber **F** Trace fossil of dinosaur footprints found in fine-grained limestone near Tuba City, Arizona

Compression Fossils Compression fossils are two-dimensional organic remains. Compression fossils form when pressure squeezes out liquids and gases from a buried organism, leaving behind only a delicate, thin film of carbon. Most impression fossils are of plants, though there are some of animals, as shown in **Figure 9C.**

Impression Fossils Impression fossils, like compression fossils, are two dimensional. Unlike compression fossils, impression fossils do not contain any organic matter. However, impression fossils, like those of the fish in **Figure 9D,** may still show fi e details of an organism's external structure.

Unaltered Remains Sometimes, fossilization preserves all or part of an organism with relatively little change. The mammoth frozen in permafrost is one example. **Figure 9E** shows another example. The fly seen in the fi ure has been preserved in amber—the hardened resin, or sap, of ancient trees.

Trace Fossils Trace fossils are indirect evidence of prehistoric life. Tracks, like those in **Figure 9F,** form when footprints are covered with sediment before they can be washed away. Other types of trace fossils include burrows, coprolites, and gastroliths. Burrows are holes made by an animal that were later filled with minerals and preserved. Coprolites and gastroliths provide useful information about the eating habits of organisms. Coprolites are fossils of dung and stomach contents and gastroliths are highly polished stomach stones used by some extinct reptiles to grind food.

☑ **Reading Checkpoint** *What is a trace fossil?*

PLANET DIARY

For links about **Fossils,** visit PlanetDiary.com/HSES.

The Fossil Record

All the fossils that geologists have found, arranged by their relative ages, make up the fossil record. But the fossil record includes only a fraction of the different kinds of organisms that have lived on Earth. Why? Some organisms are more likely than others to be preserved as fossils. **Two conditions that favor preservation of an organism as a fossil are rapid burial and the possession of hard parts.** Rapid burial protects an organism from being eaten by scavengers or decomposed by bacteria. Once buried, organisms also have a better chance of being preserved if they have hard parts such as shells, bones, and teeth. Hard parts are tougher than soft arts and more likely to remain intact long enough to become fossilized.

Even if an organism becomes fossilized, it is no guarantee that it will one day be found. If the rock layer that surrounds it is melted or metamorphosed, the fossil will be lost. And if the rock layer remains buried, the fossils it contains will likely never be discovered. Despite their incomplete record, however, scientists have learned a tremendous amount from fossils. **Fossils enable scientists to correlate rock layers and infer past environments, and they provide evidence for evolution.**

Fossil Succession The **principle of fossil succession** states that fossil organisms tend to be found in the same general order at different locations. This principle was developed by William Smith, an English engineer. While digging and planning canal routes, Smith noted that the fossils he encountered weren't randomly distributed through rock layers. Instead, each layer contained a distinct assortment of fossils that did not occur in the layers above or below it. In **Figure 10,** for example, Rock unit A has a different collection of fossils from Rock Unit B. Many geologists who followed Smith confi med his observations.

ACTIVE ART

For: Index fossil activity
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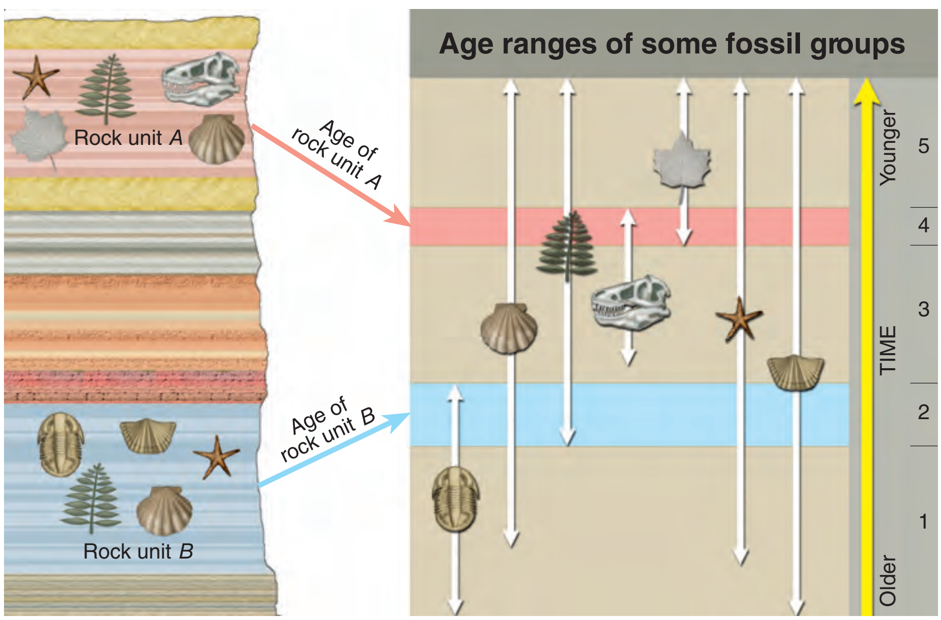


FIGURE 10 Correlating With Fossils Overlapping ranges of fossils help date rocks more exactly than using a single fossil. The fossils contained in Rock Unit A all have overlapping age ranges in time 4. The fossils in Rock Unit B have overlapping age ranges in time 2. Therefore, Rock Unit A was deposited in time 4, and Rock Unit B was deposited in time 2.

Fossils and Correlation The principle of fossil succession enables geologists to correlate rock layers based on the fossils they contain. The best type of fossils to use for correlation are called index fossils. An **index fossil** is a fossil that is both geographically widespread and abundant in the fossil record, but that existed for only a limited span of time. The presence of an index fossil in rock layers at different locations means that the layers are of roughly the same age. Rock layers, however, do not always contain a specific index fossil. In this case, geologists can use groups of fossils to establish the relative age of the rock, as shown in Figure 10.

Fossils and Past Environments Fossils can help build detailed pictures of past environments. Suppose, for example, that geologists working far from shore fi d fossil clam shells in limestone. From this, they can infer that the region was once covered with seawater. The geologists might also be able to conclude the approximate position of the ancient shoreline by observing the types and locations of fossils and comparing them to modern forms. For example, living organisms that live near shore tend to have thick shells that can withstand powerful waves. So, if the fossil clams had thick shells, a scientist could infer that the ancient shoreline was once located nearby.

FIGURE 11 Evidence of a Past Environment Fossil corals found in Texas limestone indicate the area was covered by a warm, tropical sea about 300 million years ago.

Fossils can also provide information about the temperature of water in the past. Certain present-day corals, for example, require warm and shallow tropical seas—similar to those around Florida and the Bahamas today. When similar corals are found in ancient limestone, such as those in **Figure 11,** they indicate that a Florida-like marine environment must have existed when the corals were alive.

Fossils and Evolution Geologists had noticed that fossils from older rock layers were very different from the fossils in younger layers. This had, by the mid-nineteenth century, convinced most scientists that life on Earth had undergone **evolution,** or changed over time. However, there was not a scientifically accepted explanation for *how* life evolved until English naturalist Charles Darwin came along. In 1859, Darwin proposed the theory of natural selection. **According to the theory of natural selection, traits that improve an individual's chance for survival and reproduction will be passed on more frequently to future generations than traits that do not.** These beneficial traits are called **adaptations.** Natural selection is among the most well-tested and accepted theories in science. It provides a framework by which scientists study and interpret the history of life.

Reading Checkpoint *What is an adaptation?*

FIGURE 12 Walking Whale This extinct water-dwelling mammal, *Ambulocetus natans,* evolved about 45 million years ago in south Asia. *Ambulocetus,* which means "walking whale," represents one stage in the evolution of modern whales from land animals.

In general, organisms that are well-adapted to their environment survive more often than organisms that are not as well-adapted. As a result, these well-adapted individuals are more likely to pass on their traits to later generations. Over time, natural selection can bring about tremendous changes. For example, the fossil record shows that the ancestors of modern whales were land-dwelling mammals with four legs **(Figure 12).** Natural selection, acting over millions of years, has resulted in the legless, streamlined organisms we know today.

12.2 Assessment

Review Key Concepts

1. List the different types of fossils.
2. Describe the conditions that favor the formation of fossils.
3. In your own words, explain the theory of natural selection.
4. Describe two ways that geologists can use fossils to interpret Earth's history.

Think Critically

5. **Compare and Contrast** How are compression fossils and impression fossils similar? How are they different?
6. **Sequence** Describe how a clam might become a fossil.
7. **Apply Concepts** What is the role of natural selection in evolution?
8. **Infer** Look at Figure 10. Can any of the fossils in the diagram be used as an index fossil? Explain why or why not.

BIGIDEA EARTH HISTORY

9. **Connect Concepts** How are the law of superposition and the principle of fossil succession related? How do they help us understand the history of life?

12.3 Dating with Radioactivity

ES.9 The student will investigate and understand that many aspects of the history and evolution of Earth and life can be inferred by studying rocks and fossils. Key concepts include **b.** superposition, cross-cutting relationships, index fossils, and radioactive decay are methods of dating bodies of rock; and **c.** absolute and relative dating have different applications but can be used together to determine the age of rocks and structures. Also covered **ES.9.a.**

EARLY GEOLOGISTS like William Smith could only determine the relative ages of rock layers. They could not fi d exact dates for events in Earth's past. Today, however, we know that Earth is about 4.5 billion years old and that the dinosaurs became extinct about 65 million years ago. To understand the method geologists used to arrive at these dates, you need fi st to understand radioactivity.

What Is Radioactivity?

Recall that each atom has a nucleus made up of protons and neutrons and that the number of neutrons in the atoms of a given element can vary. Different forms of an element are called *isotopes.*

Radioactive Isotopes In most atoms, the forces that bind protons and neutrons together in the nucleus are strong and balanced. In some isotopes, however, there is an excess of energy within the nucleus. These atoms have unstable nuclei. **Unstable atomic nuclei spontaneously break apart, or decay, releasing energy.** The term for the process by which atoms decay is **radioactivity,** or radioactive decay. **Figure 13** shows the three different types of radioactive decay.

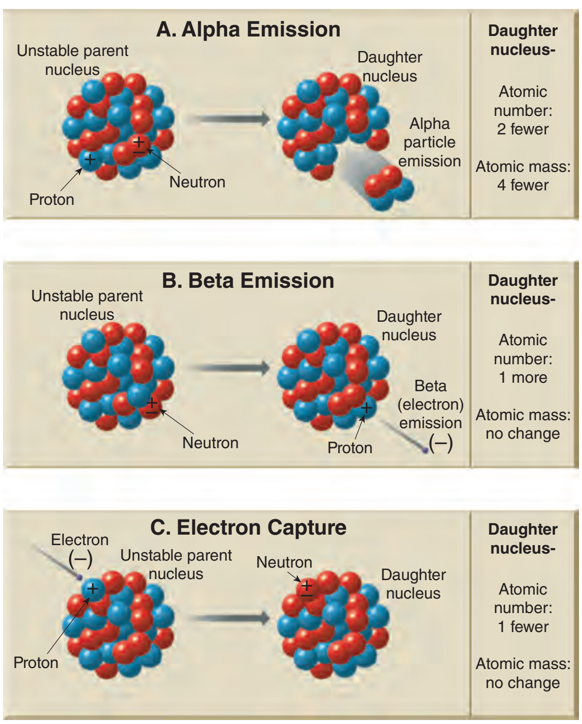


FIGURE 13 Radioactive Decay In each type of radioactive decay, the number of protons (atomic number) in the nucleus changes, thus producing a different element.

Key Questions

What happens during radioactive decay?

How are isotopes used in radiometric dating?

How can radiometric dating be used to date organic material?

How can radiometric dating be used to infer the age of sedimentary rocks?

Vocabulary

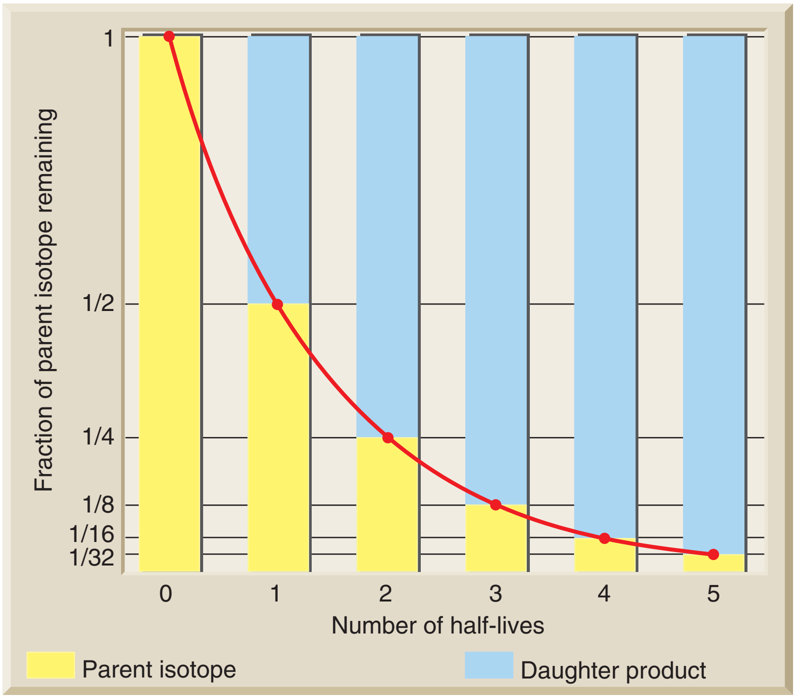
- radioactivity
- half-life
- radiometric dating
- radiocarbon dating

Reading Strategy

Monitor Your Understanding Preview the key concepts, topics, headings, vocabulary, and figures in this section. Copy the chart below. List two things you expect to learn about each. After reading, state what you learned about each item you listed.

What I expect to learn	What I learned
1. a. ?	b. ?
2. c. ?	d. ?

FIGURE 14 The Half-Life Decay Curve The radioactive decay curve shows change that is exponential. Half of the radioactive parent isotope remains after one half-life. After a second half-life, one quarter of the parent isotope remains, and so forth. **Interpret Graphs** ***If 1/32 of the parent isotope remains, how many half-lives have passed?***



Radioactive Isotopes Radioactive decay continues, sometimes through many intermediate steps, until a stable, or nonradioactive isotope is formed. For example, uranium-238 decays over time to form the stable isotope lead-206. An unstable, or radioactive, isotope of an element is called the *parent isotope.* The isotopes that result from the decay of the parent are called the *daughter products.*

Half-Life A half-life is a common way of expressing the rate of radioactive decay. A **half-life** is the amount of time necessary for one half of the nuclei in a sample of radioactive isotope to decay to its stable isotope, as shown in **Figure 14.** If the half-life of the parent isotope is known, and the parent/daughter ratio can be measured, then the age of the sample can be calculated. For example, if the half-life of an unstable isotope is 1 million years, and 1/16 of the parent isotope remains, the sample must be about 4 million years old, since four half-lives have passed.

Radiometric Dating

Radiometric dating is a method of calculating the absolute ages of rocks and minerals that contain certain radioactive isotopes. A rock or mineral's *absolute age* is the approximate number of years before present that it formed. **In radiometric dating, scientists measure the ratio between the radioactive parent isotope and the daughter products in a sample to be dated. The older the sample, the more daughter product it contains.** For igneous rock, radiometric dating establishes when rock minerals crystallized. For metamorphic rock, radiometric dating determines when new minerals formed due to heat, pressure, or fluids. As we will see, radiometric dating is not used to directly date sedimentary rocks.

Table 1 Radioactive Isotopes Frequently Used in Radiometric Dating		
Radioactive Parent	Stable Daughter Product	Currently Accepted Half-Life Values
Uranium-238	Lead-206	4.5 billion years
Uranium-235	Lead-207	713 million years
Thorium-232	Lead-208	14.1 billion years
Rubidium-87	Strontium-87	47.0 billion years
Potassium-40	Argon-40	1.3 billion years

How can a radioactive isotope serve as a reliable "clock"? The rates of decay for many isotopes have been precisely measured and do not vary under the physical conditions that exist in Earth's outer layers. Each radioactive isotope has been decaying at a constant rate since the formation of the rocks in which it occurs. The products of decay have also been accumulating at a constant rate. Of the many radioactive isotopes that exist in nature, five have proved particularly useful in providing radiometric ages for ancient rocks. These five radioactive isotopes are listed in **Table 1.**

Limitations of Radiometric Dating An accurate radiometric date can be obtained for a mineral only if there has been no loss of parent or daughter isotope since the mineral's formation. For example, the stable daughter product of potassium is argon gas. To calculate absolute age using potassium and argon, geologists measure the ratio of radioactive potassium-40 atoms to stable argon atoms in a sample. They then use the known half-life of potassium-40 to estimate the sample's age based on the ratio. Given the long half-life of potassium-40, this method can be used to date rocks that are hundreds of millions of years old. However, because it is a gas, argon may leak from minerals and throw off easurements. Cross-checking of samples, using two different radiometric methods, is done whenever possible to ensure accuracy.

Age of Earth Radiometric dating methods have enabled scientists to assign dates to thousands of events in Earth history. Earth's oldest rocks (so far) are metamorphic gneisses in northern Canada. These rocks have been dated at 4.03 billion years. Even older mineral grains have been dated. Tiny crystals of the mineral zircon with radiometric ages as old as 4.3 billion years have been found in younger sedimentary rocks in western Australia. So, Earth is at least that old, but is it even older? To determine the age of Earth, scientists have compared isotope ratios in a variety of meteorites. Assuming that the solar system formed together from the solar nebula, Earth and all meteorites should be the same age, about 4.5 billion years old.

INQUIRY APPLY IT!

Q: *In radioactive decay, is there ever a time when all of the parent material is converted into the daughter product?*

A: Theoretically, no. During a half-life, half of the parent material is converted into the daughter product. Then half of the remaining parent material is converted to the daughter product in another half life, and so on. By converting only half of the parent material with each half-life, there is never a time when all the parent material would be converted. However, after many half-lives, the parent material will be present in such small amounts that it is essentially undetectable.

FIGURE 15 Radiocarbon Dating Carbon-14 is used to date organic materials that formed up to about 75,000 years ago. Here, an archaeologist is uncovering the remains of a sea turtle near an ancient stone formation. Radiocarbon dating of the remains will help determine their approximate age.

Dating with Carbon-14

To date organic materials, carbon-14 is used in a method called **radiocarbon dating.** Organic material is a substance that contains carbon and comes from a living thing. Carbon-14 is the radioactive isotope of carbon. Carbon-14 is continuously produced in the upper atmosphere. It quickly becomes incorporated into carbon dioxide, which circulates in the atmosphere and is absorbed by living matter. As a result, all organisms—including you—contain a small amount of carbon-14.

While an organism is alive, the decaying radiocarbon is continually replaced. Thus, the ratio of carbon-14 to carbon-12—the stable isotope of carbon—remains constant. **When an organism dies, the amount of carbon-14 gradually decreases as the carbon-14 decays. By comparing the ratio of carbon-14 to carbon-12 in a sample, radiocarbon dates can be determined.**

Because the half-life of carbon-14 is only 5730 years, it can be used to date events up to about 75,000 years ago. The age of the ancient sea turtle shown in **Figure 15** can be determined using radiocarbon dating. Carbon-14 has become a valuable tool for anthropologists, archaeologists, and historians, as well as for geologists who study recent Earth history.

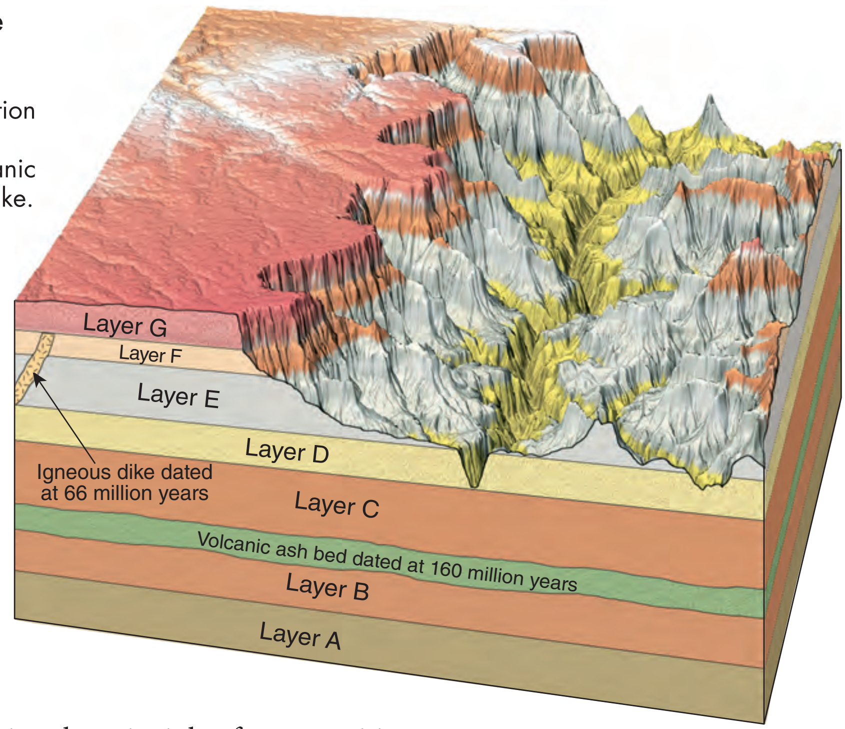
Reading Checkpoint *What is compared when dating samples with carbon-14?*

Radiometric Dating of Sedimentary Rock

Radiometric dating can rarely be used to date sedimentary rocks directly. Sedimentary rocks may contain particles that can be dated. But these particles are not the same age as the rocks in which they occur. The sediment from which the rock formed probably weathered from older rocks. Radiometric dating would not be accurate since the sedimentary rock is made up of so many older rock particles.

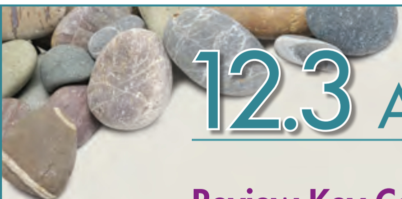
Geologists have developed an indirect method of dating sedimentary rocks. **To determine the age of sedimentary rock, geologists must relate the sedimentary rock to datable masses of igneous rock.** Applying Steno's principles, geologists identify two igneous rock masses. One rock mass must be relatively older than the sedimentary rock. The other rock mass must be younger. Radiometric methods can then be used to date the two igneous rock masses. The age of the sedimentary rock must lie between the ages of the igneous rocks. If present, fossils may help refi e the estimate.

FIGURE 16 Estimating the Age of Sedimentary Rock Layers Sedimentary rock layers can be dated in relation to igneous rocks of known age—in this case, the volcanic ash bed and the igneous dike. **Infer** *What can you infer about Layers A and B?*



Look at **Figure 16.** Using the principle of superposition, you can tell that layers C–G are younger than 160 million years old, since they lie above the dated volcanic ash bed. Using the principle of cross-cutting relationships, you can see that the dike is younger than layers E and F. Therefore layers C–F must be between 160 and 66 million years old.

☑ **Reading Checkpoint** *Why can't radiometric dating be used to determine the absolute age of sedimentary rock?*



12.3 Assessment

Review Key Concepts

1. What happens to atoms that are radioactive?
2. What is the role of isotopes in radiometric dating?
3. Describe radiocarbon dating.
4. How do geologists use radiometric dating to date sedimentary rock layers indirectly?

Think Critically

5. **Apply Concepts** A geologist wants to use potassium-argon dating to date a granite rock found on the surface. What is a possible source of inaccuracy in dating the rock?
6. **Apply Concepts** Using radiometric dating, a scientist determines that a sample of quartz minerals is 1.2 billion years old. From this, she concludes that the sandstone containing the quartz is also 1.2 billion years old. Explain her mistake.
7. **Interpret Diagrams** In a sample of igneous rock, one-quarter of the isotope thorium-232 remains. How old is the rock? Use Figure 15 and Table 1 to help you.

WRITING IN SCIENCE

8. **Describe** How might radiocarbon dating be used to study an ancient civilization?

EARTH & HISTORY

Dating With Tree Rings

If you look at the top of a tree stump or at the end of a log, you will see that it is made of a series of concentric rings, like those shown in **Figure 17.** Every year in temperate regions, trees add a layer of new wood under the bark. Each of these tree rings becomes larger in diameter outward from the center. During favorable environmental conditions, a wide ring is produced. During unfavorable environmental conditions, a narrow ring is produced. Trees growing at the same time in the same region show similar tree-ring patterns.

Because a single growth ring is usually added each year, you can determine the age of a tree by counting its rings. Cutting down a tree to count the rings is not necessary anymore. Scientists can use small, nondestructive core samples from living trees.

The dating and study of annual rings in trees is called the science of *dendrochronology.* Dendrochronology provides useful information regarding the relative ages for events in the historic and recent prehistoric past. Because tree rings are a storehouse of data, they are a valuable tool in the reconstruction of past environments.

To make the most effective use of tree rings, extended patterns known as ring chronologies are established. They are produced by comparing the patterns of rings among trees in an area. If the same pattern can be identified in two trees, one of which has been given an absolute date based on an independent line of evidence, the second tree can then be dated by aligning its ring pattern to that of the first dated tree. This technique, called cross dating, is illustrated in **Figure 18.**

Cross dating allows the ages of dead tree remains to be dated. Tree-ring chronologies extending back for thousands of years have been established for some regions. To date a timber sample of unknown age, its ring pattern is matched against the reference chronology.

Tree-ring chronologies have important applications in such disciplines as climate, geology, ecology, and archaeology. For example, tree rings are used to reconstruct long-term climate variations within a certain region. Knowledge of such variations is of great value in studying and understanding the recent record of climate change.

FIGURE 17 Tree Rings Each year's growth for a tree is laid down as a ring. Because the amount of growth (thickness of a ring) depends upon precipitation and temperature, tree rings are useful records of past climates.

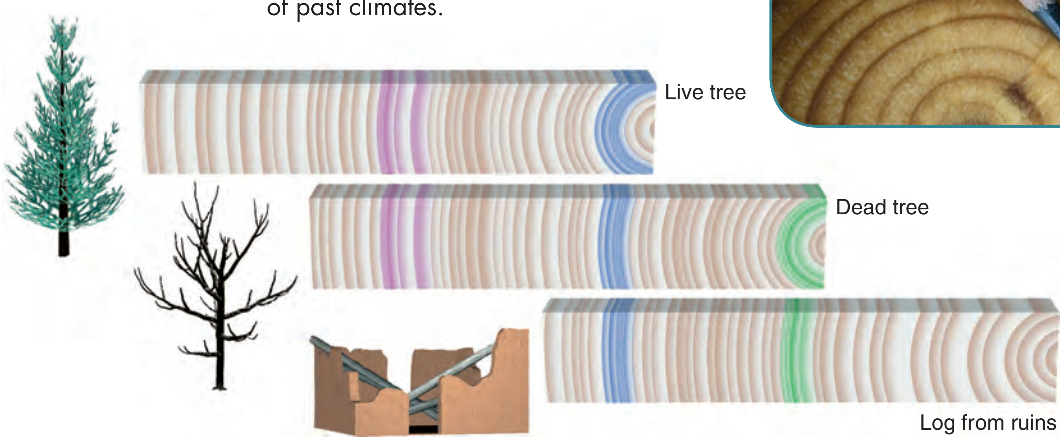


FIGURE 18 Cross Dating If a scientist knows the absolute date of a live tree, they can use cross dating to estimate the age of an ancient ruin. First, a tree-ring chronology for the area is established using cores extracted from living trees of known age. This chronology is extended further back in time by matching overlapping patterns from older, dead trees. Finally, cores taken from beams inside the ruin are dated using the chronology established from the other two sites.

12.4 The Geologic Time Scale

ES.9 The student will investigate and understand that many aspects of the history and evolution of Earth and life can be inferred by studying rocks and fossils. Key concepts include **a.** traces and remains of ancient, often extinct, life are preserved by various means in many sedimentary rocks; **b.** superposition, cross-cutting relationships, index fossils, and radioactive decay are methods of dating bodies of rock.

GEOLOGICAL EVENTS by themselves have little meaning until they are put into context. Studying an event in history, whether it be the Civil War or the evolution of mammals, requires a timeline. Among geology's major contributions to human knowledge is the timeline it has developed for Earth history.

What Is the Geologic Time Scale?

Geologists of the eighteenth and nineteenth centuries proposed a sequence of events in Earth's history using relative dating principles. The result is the **geologic time scale,** a timeline of Earth's history. **The geologic time scale is a record that includes both geologic events and major developments in the evolution of life.** Today's time scale includes many absolute dates, the result of radiometric dating techniques that became available in the twentieth century. Even with all of our technology, however, the time scale is not considered fi al or complete. It is constantly revised as new data become available.

FIGURE 19 Around Since the Dinosaurs These cliffs on the coast of England are made of rock that formed about 200 million years ago, which, according to the time scale, was during the time of the dinosaurs.

Key Questions

What is the geologic time scale?

How is the geologic time scale constructed?

Vocabulary

- geologic time scale
- eon
- Precambrian time
- era
- period
- epoch

Reading Strategy

Outline As you read, make an outline of the important ideas in this section. Use the orange headings as the main topics and fill in details from the remainder of the text.

The Geologic Time Scale
I. What Is the Geologic Time Scale?
A. ?
B. ?
II. Structure of the Time Scale
A. ?
B. ?

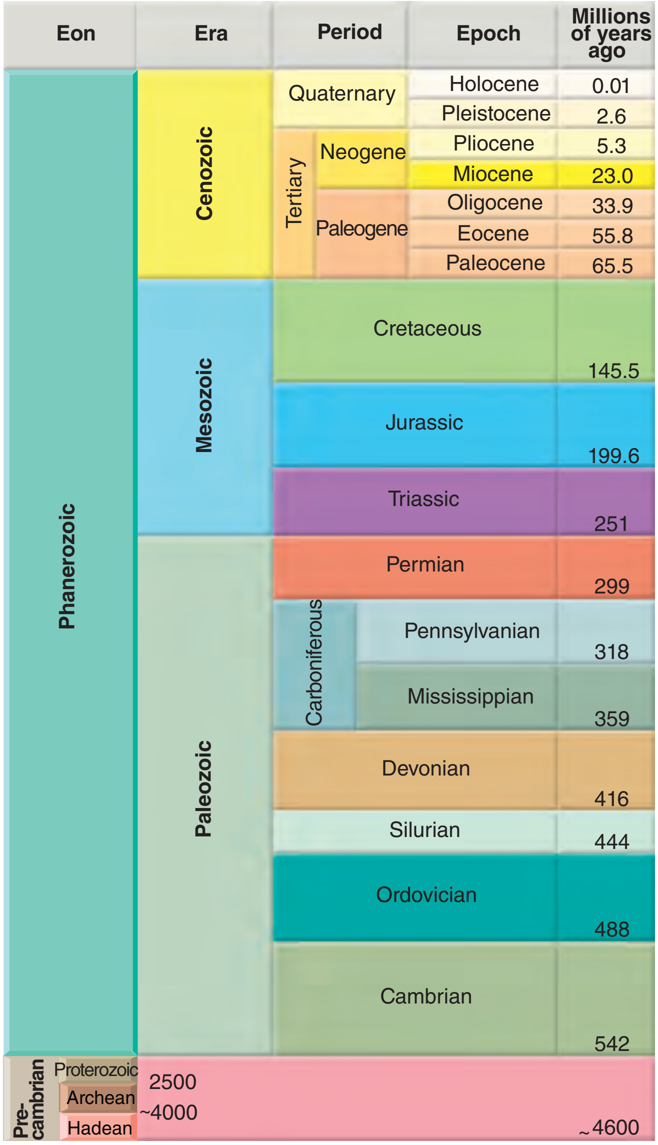


FIGURE 20 The Geologic Time Scale This figure is not drawn to scale. The Phanerozoic makes up only about 12 percent of Earth's history. The Phanerozoic eon is broken into more subdivisions than earlier eons because scientists have more data to work with.

Structure of the Time Scale

The geologic time scale is divided into eons, eras, periods, and epochs. **Eons represent the longest intervals of geologic time. Eons are divided into eras. Each era is subdivided into periods. Finally, periods are divided into still smaller units called epochs.** The primary divisions of the time scale are shown in **Figure 20.** In general, divisions between time scale units mark major geologic events, evolutionary changes, or both.

Each division of the time scale has a name. Usually, the name comes from either the area where rocks of the age were fi st found or from some unique characteristic of the rocks. For example, Jurassic refers to the Jura Mountains of France and Switzerland. The Carboniferous is named for the large coal deposits that formed during that period. *Carboniferous* means "carbon bearing."

Eons

Geologists divide Earth's history into four long units called **eons.** About 88 percent of geologic time is made up of the fi st three of these eons—the Hadean, Archaean, and Proterozoic. During these eons, Earth formed, the atmosphere and oceans developed, and early life evolved. Another term for this long time span is **Precambrian time.**

Precambrian fossils are scarce. One reason for this is that there is very little Precambrian rock at the surface. Over billions of years, most Precambrian rocks have not only been buried by layers and layers of younger rock, but much has also been eroded or metamorphosed, destroying or altering fossils. In addition, for most of Earth's history, life existed only as single-celled organisms, which do not leave easily identifiable fossils. Only very late in the Precambrian did multicelled organisms evolve in the oceans.

About 540 million years ago, the Phanerozoic eon began. The term *Phanerozoic* comes from the Greek words meaning "visible life." The term is appropriate because the rocks of this eon contain abundant fossils. These fossils document the evolution of more complex life forms.

Notice on the time scale the many subdivisions of the Phanerozoic. These subdivisions reflect the large amount of data that geologists have about the rocks and fossils of the Phanerozoic in comparison with data from earlier eons.

Eras There are three **eras** within the Phanerozoic eon: the Paleozoic, Mesozoic, and Cenozoic eras. *Paleozoic* comes from the Greek words for "ancient life." Most of the major groups of modern organisms, including insects, vertebrates (animals with backbones), and nonflowering plants, evolved during this era. *Mesozoic* means "middle life." During the Mesozoic era, flowering plants evolved and many types of reptiles, including dinosaurs and marine reptiles **(Figure 21),** became abundant. Mammals also evolved during the Mesozoic. The fossil record shows that the Paleozoic and Mesozoic eras both ended with dramatic, worldwide changes in life forms. Many types of organisms became extinct. *Cenozoic* means "recent life." During the Cenozoic era, many different types of mammals and birds evolved, and flowering plants became abundant.

FIGURE 21 Mesozoic Life Not all life forms in the Mesozoic were big like the dinosaurs. This marine reptile from the Triassic, *Keichousaurus hiu,* was less than a foot long.

Periods and Epochs Each era is subdivided into **periods.** Different geologic events, environmental conditions, and life forms characterize each period. Traditionally, geologists divided the Cenozoic era into two periods: the Tertiary and Quaternary. Today, most geologists divide the Cenozoic into the Paleogene, Neogene, and Quaternary, as shown in Figure 20.

Periods are divided into still smaller units called **epochs.** You will notice that there are many named epochs within the periods of the Cenozoic era. This again reflects how much data are available about the recent past. The periods of the Mesozoic and Paleozoic eras are also divided in epochs, though they are not usually referred to by specific names. Instead, the terms *early, middle,* and *late* are generally applied to the epochs of these earlier periods.

12.4 Assessment

Review Key Concepts

1. What is the geologic time scale?

2. What subdivisions make up the geologic time scale?

3. How is the geologic time scale today different from the geologic time scale developed by geologists in the 1800s?

4. Why are there more subdivisions of the time scale for the Phanerozoic eon than for earlier eons?

Think Critically

5. Interpret Diagrams To which era does each of the following periods belong: Ordovician, Tertiary, Permian, Triassic?

6. Calculate What percentage of geologic time is made up of the Cenozoic era?

WRITING IN SCIENCE

7. Define Research one of the periods of the geologic time scale. Write a definition of the period that includes the name of the era to which the period belongs, when the period began and ended, one major event from the period, and an explanation of its name.

INQUIRY

EXPLORATION LAB

Fossil Occurrence and the Age of Rocks

Problem How can the occurrence of fossils and their known age ranges be used to date rocks?

Materials geologic time scale, graph paper, pencil

Skills Interpret Diagrams, Graph, Form a Hypothesis, Infer

Connect to the Big idea Groups of fossil organisms occur in the rock record for specific intervals of time. This time interval is called the fossil's *range*. Knowing the range of the fossils of specific organisms, or groups of organisms, can be used to fi d the relative age of rock layers. In this laboratory exercise, you will use such information to assign a date to a hypothetical unit of rock.

Procedure

1. A section of rock made up of layers of limestone and shale has been studied and samples have been taken. A large variety of fossils were collected from the rock samples. Use a sheet of graph paper to make a bar graph using the information shown in the Fossil Data Table. Begin by listing the types of fossils on the horizontal axis. Use the fi ure on the next page to list the units of the geologic time scale on the vertical axis.
2. Transfer the range data of each fossil onto your graph. Draw an X in each box, beginning at the oldest occurrence of the organism up to the youngest occurrence. Shade in the marked boxes. You will end up with bars depicting the geologic ranges of each of the fossils listed.
3. Examine your graph. Are there any time units that contain all of the fossils listed? Write this time period at the bottom of the graph.

Fossil Data Table

	Type of Fossil	Oldest occurrence	Youngest occurrence
1	Foraminifera	Silurian	Quaternary
2	Bryozoan	Silurian	Permian
3	Gastropod	Devonian	Pennsylvanian
4	Brachiopod	Silurian	Mississippian
5	Bivalve	Silurian	Permian
6	Gastropod	Ordovician	Devonian
7	Trilobite	Silurian	Devonian
8	Ostracod	Devonian	Tertiary
9	Brachiopod	Cambrian	Devonian

Analyze and Conclude

1. **Interpret Graphs** What is the age of the hypothetical rock layer that these fossils were collected from?
2. **Infer** Based on the age determined, do you think that this group of fossils could be considered index fossils? Why or why not?
3. **Infer** Suppose that the particular trilobite listed in line 7 of the data table is limited to rocks of lower Devonian age and that these trilobite fossils are widespread throughout North America. Can this fossil be considered an index fossil? Why or why not?
4. **Explain** The fossils in this group were collected from limestone and shale rocks. Based on what you have learned about the formation of these rock types, what type of environment did these organisms live in?
5. **Infer** Shale often contains fossils of leaves. If the gastropods listed in line 3 and line 6 were collected from shale containing leaf fossils, could you use radiocarbon dating to assign a numerical date to this rock unit? Explain.

GO FURTHER Use the library or Internet to research these fossils. Find out how some of them are used in the oil industry or the cosmetics industry.

The Geologic Time Scale

Eon	Era	Period	Epoch	Millions of years ago
Phanerozoic	Cenozoic	Quaternary	Holocene	0.01
			Pleistocene	2.6
		Tertiary – Neogene	Pliocene	5.3
			Miocene	23.0
		Tertiary – Paleogene	Oligocene	33.9
			Eocene	55.8
			Paleocene	65.5
	Mesozoic	Cretaceous		145.5
		Jurassic		199.6
		Triassic		251
	Paleozoic	Permian		299
		Carboniferous – Pennsylvanian		318
		Carboniferous – Mississippian		359
		Devonian		416
		Silurian		444
		Ordovician		488
		Cambrian		542
Pre-cambrian	Proterozoic			2500
	Archean			~4000
	Hadean			~4600

ES.1 The student will plan and conduct investigations in which **c.** scales, diagrams, charts, graphs, tables, imagery, models, and profiles are constructed and interpreted. **ES.2** The student will demonstrate an understanding of the nature of science and scientific reasoning and logic. Key concepts include **b.** evidence is required to evaluate hypotheses and explanations. **ES.9** The student will investigate and understand that many aspects of the history and evolution of Earth and life can be inferred by studying rocks and fossils. Key concepts include **b.** superposition, cross-cutting relationships, index fossils, and radioactive decay are methods of dating bodies of rock.

12 Study Guide

Big idea Earth History

12.1 Discovering Earth's History

Uniformitarianism is the idea that the physical, chemical, and biological laws that operate today also operated in the past.

The law of superposition, the principle of original horizontality, the principle of cross-cutting relationships, unconformities, and inclusions all help determine the relative ages of rock layers.

Scientists correlate rock layers at different locations to piece together a more complete interpretation of the rock record.

uniformitarianism (336)
relative dating (337)
law of superposition (337)
principle of original horizontality (338)
principle of cross-cutting relationships (338)
unconformity (339)
correlation (340)

12.2 Fossils: Evidence of Past Life

The different types of fossils include petrified fossils, molds and casts, compressions, impressions, unaltered remains, and trace fossils.

Two conditions that favor preservation of an organism as a fossil are rapid burial and the possession of hard parts.

Fossils enable scientists to correlate rock layers and infer past environments, and they provide evidence for evolution.

According to natural selection, traits that improve an individual's chance for survival and reproduction will be passed on more frequently to future generations than traits that do not.

extinct (342)
fossil (342)
principle of fossil succession (344)
index fossil (345)
evolution (345)
natural selection (345)
adaptation (345)

12.3 Dating with Radioactivity

During radioactive decay, unstable atomic nuclei spontaneously break apart, or decay, releasing energy.

In radiometric dating, scientists measure the ratio between the radioactive parent isotope and the daughter products in a sample to be dated. The older the sample, the more daughter product it contains.

When an organism dies, the amount of carbon-14 gradually decreases as the carbon-14 decays. By comparing the ratio of carbon-14 to carbon-12 in a sample, radiocarbon dates can be determined.

To determine the age of sedimentary rock, geologists must relate the sedimentary rock to datable masses of igneous rock.

radioactivity (347)
half-life (348)
radiometric dating (348)
radiocarbon dating (350)

12.4 The Geologic Time Scale

The geologic time scale is a record that includes both geologic events and major developments in the evolution of life

Eons represent the longest intervals of geologic time. Eons are divided into eras. Each era is subdivided into periods. Finally, periods are divided into still smaller units called epochs.

geologic time scale (353)
eon (354)
Precambrian time (354)
era (355)
period (355)
epoch (355)

12 Assessment

Review Content

Choose the letter that best answers the question or completes the statement.

1. What principle states that the physical, chemical, and biological laws that operate today have also operated in the geologic past?
   a. uniformitarianism
   b. theory of evolution
   c. principle of original horizontality
   d. law of superposition

2. What is the name of the process that matches rocks of similar ages in different regions?
   a. indexing
   b. correlation
   c. succession
   d. superposition

3. What name is given to fossils that are both widespread geographically and abundant in number, but are limited to a short span of time in the fossil record?
   a. key
   b. succeeding
   c. relative
   d. index

4. What is the name of the process during which atomic nuclei decay?
   a. fusion
   b. correlation
   c. nucleation
   d. radioactivity

5. Which unit of geologic time is the greatest span of time?
   a. era
   b. eon
   c. period
   d. epoch

6. What are remains or traces of prehistoric life called?
   a. indicators
   b. replicas
   c. fossils
   d. fissures

7. What name is given to layers of tilted rocks that are overlain by younger, more flat-lying rock layers?
   a. disconformity
   b. angular unconformity
   c. nonconformity
   d. fault

8. What are atoms with the same atomic number but different mass numbers called?
   a. protons
   b. isotopes
   c. ions
   d. nucleotides

9. Which of Steno's principles states that most layers of sediments are deposited in flat-lying layers?
   a. original horizontality
   b. cross-cutting relationships
   c. fossil succession
   d. superposition

10. What name is given to pieces of rock that are contained within another, younger rock?
    a. intrusions
    b. interbeds
    c. hosts
    d. inclusions

11. About how old is Earth?
    a. 400,000 years
    b. 4.0 million years
    c. 5.8 million years
    d. 4.5 billion years

Understand Concepts

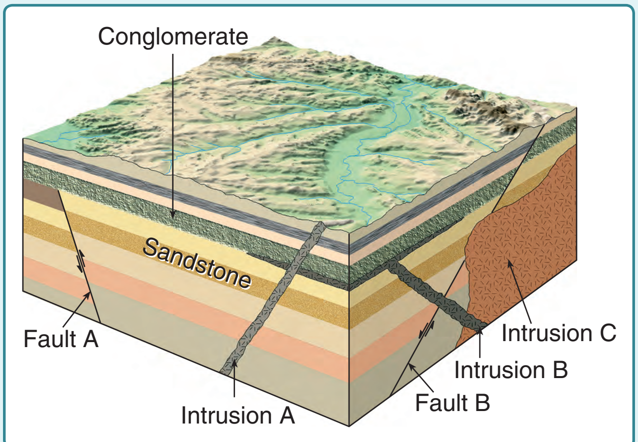
12. How have the processes that affect Earth's surface changed through time?
13. Why does the law of superposition apply primarily to sedimentary rocks?
14. How are cross-cutting relationships used in relative dating?
15. How do unconformities form?
16. List and briefly describe three different types of fossils.
17. What two conditions increase an organism's chance of becoming a fossil?
18. What did Darwin propose as the mechanism of evolution? Explain.
19. How can certain fossils, such as corals, be used to indicate water temperatures of the past?
20. What is a half-life?
21. Explain how radioactivity and radiometric dating are related.
22. Why can't radiometric dating be used with accuracy on metamorphic rocks?

Think Critically

23. **Compare and Contrast** Compare the techniques of relative dating to those of radioactive decay dating.
24. **Draw Conclusions** Why can't carbon-14 be used to date material that is older than 75,000 years?
25. **Explain** Why is it important to have a closed system when using radioactive decay dating?
26. **Predict** An analysis of some sedimentary rocks suggests the environment was close to the shoreline where high energy waves hit the shore. Corals and shelled organisms lived here. Describe what their fossils would be like.
27. **Apply Concepts** Why is radiometric dating the most reliable method of dating events and formations from the geologic past?

Analyze Data

Refer to the diagram to answer Questions 28 and 29.



28. **Apply Concepts** Which fault is older, A or B? Explain how you know.
29. **Apply Concepts** Which intrusion is older, A or B? Explain how you know.
30. **Calculate** A sample of potassium-40 has a mass of 12.5 grams. If the sample originally had 50 grams of potassium-40 at the start of radioactive decay, how many half-lives have passed? The half-life of potassium-40 is 1.3 billion years. How old is the sample?

Concepts in Action

31. **Apply Concepts** Fossilized human remains are sometimes found in bogs in northwestern Europe. These bogs are wet, low-oxygen areas that contain decaying plant material. How would you go about dating such a fossil?
32. **Compare and Contrast** Apply the concept of uniformitarianism to explain how a particular sequence of rock layers could be interpreted as a former ocean coastline. (*Hint:* compare what you might see at a modern shoreline to what you would see in the rocks).
33. **Predict** An organism evolves with certain adaptations for survival on a wet, tropical island. Over millions of years, plate movements shift he island into a cooler, drier climate. What might happen to this type of organism over time?
34. **Calculate** Nuclear power plants produce radioactive waste that must be stored properly until it is no longer harmful to life on Earth. Uranium-238 has a half-life of 4.5 billion years. If, in order to be safe, a uranium sample must decay to 1/64 of its original amount, for how many years must the waste be stored?

Performance-Based Assessment

Communicate Create a poster illustrating the different ways that fossils can form.
Be sure to include altered and unaltered remains with examples of both. If possible, include samples of fossils that are found in your area.

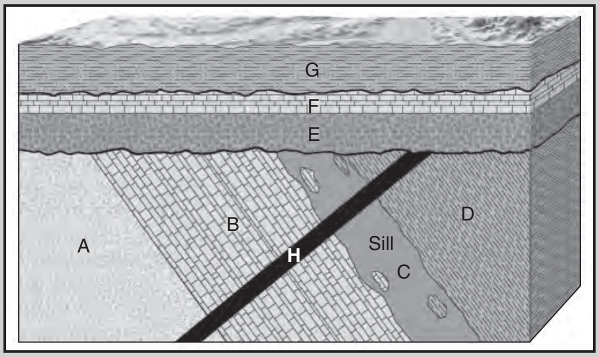
Virginia SOL Test Prep

Tips for Success

When examining a diagram, it is important not to be confused by unnecessary information. It helps to identify only the features that relate to the question being asked. Reread the question with these features in mind and then answer the question. In the diagram below, you do not need to know what rock types are present.

Which choice correctly lists the order in which rock layers A through D formed?

A A, B, C, D
B D, C, B, A
C B, C, D, A
D A, B, D, C



(Answer: D)

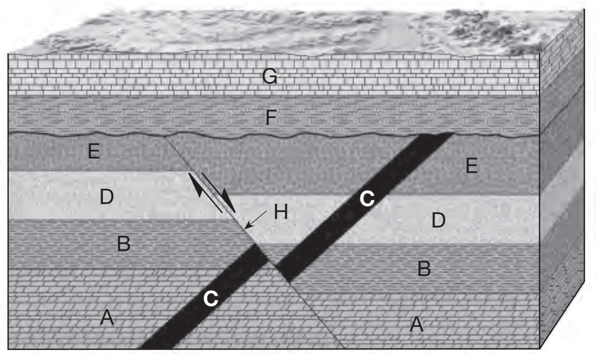
Use the diagram above to answer Question 1. Choose the letter that best answers the question.

1 When were rock layers A through D uplifted and tilted?
A after deposition of Layer G
B after deposition of Layer F and before deposition of Layer G
C after deposition of Layer D and before deposition of Layer E
D after deposition of Layer A and before deposition of Layer G
ES.9.b

2 Whose work became the foundation for the principle of uniformitarianism?
F Charles Darwin
G James Hutton
H William Smith
J Louis Agassiz
ES.9.b

3 Using relative dating methods, which of the following are scientists able to do?
A Identify the order in which rock units formed.
B Assign a numerical date to each rock layer studied.
C Determine the age of the fossils within each layer.
D Identify what rock types are present.
ES.9.c

Use the diagram below to answer Question 4.



4 How can you tell that intrusion C is older than fault H?
F The top of Intrusion C is eroded.
G Intrusion C is broken by Fault H.
H Fault H ends at the eroded Layer E.
J Both Intrusion C and Fault H end at Layer E.
ES.9.b

If You Have Trouble With . . .				
Question	1	2	3	4
See Lesson	12.1	12.1	12.1	12.1