CHAPTER

12 The History of Life

KEY CONCEPTS

12.1 The Fossil Record
Fossils are a record of life that existed in the past.

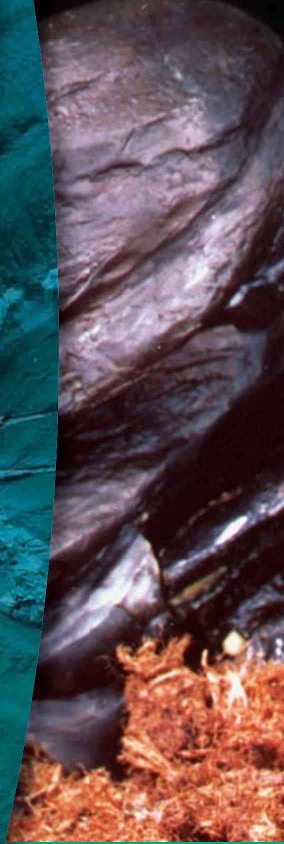
12.2 The Geologic Time Scale
The geologic time scale divides Earth's history based on major past events.

12.3 Origin of Life
The origin of life on Earth remains a puzzle.

12.4 Early Single-Celled Organisms
Single-celled organisms existed 3.8 billion years ago.

12.5 Radiation of Multicellular Life
Multicellular life evolved in distinct phases.

12.6 Primate Evolution
Humans appeared late in Earth's history.



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What can fossils teach us about the past?

This man, known only as Tollund Man, died about 2200 years ago in what is now Denmark. Details such as his skin and hair were preserved by the acid of the bog in which he was found. A bog is a type of wetland that accumulates peat, the deposits of dead plant material. Older remains from bogs can add information to the fossil record, which tends to consist of mostly hard shells, teeth, and bones.

Connecting CONCEPTS

Arthropods This fossil of an extinct lobsterlike arthropod was discovered at a site where some of the world's oldest fossils are found—the Burgess Shale, in British Columbia, Canada. Arthropods are a large group of invertebrates that have segmented body parts and jointed legs. Fossils found at the Burgess Shale site offer a glimpse of what life was like during the Cambrian period, more than 500 million years ago. These fossils are special due to their great age and their remarkable state of preservation. In this chapter, you will read more about how fossils are preserved and about the time period during which this ancient arthropod lived.

12.1 The Fossil Record

KEY CONCEPT Fossils are a record of life that existed in the past.

MAIN IDEAS

- Fossils can form in several ways.
- Radiometric dating provides an accurate estimate of a fossil's age.

VOCABULARY

relative dating, p. 362
radiometric dating, p. 362
isotope, p. 362
half-life, p. 362

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Connect Tollund Man and the arthropod found in the Burgess Shale site are both traces of Earth's history of life, although they lived about 500 million years apart. They were also preserved as fossils in different ways. In this section, you will learn about types of fossils, how fossils form, and how they can help us understand the history of life on Earth.

MAIN IDEA

Fossils can form in several ways.

Fossils are far more diverse than the giant dinosaur skeletons we see in museums. The following are some of the processes that make fossils. **FIGURE 12.1** shows examples of fossils produced in different ways.

- **Permineralization** occurs when minerals carried by water are deposited around a hard structure. They may also replace the hard structure itself.
- **Natural casts** form when flowing water removes all of the original bone or tissue, leaving just an impression in sediment. Minerals fill in the mold, recreating the original shape of the organism.
- **Trace fossils** record the activity of an organism. They include nests, burrows, imprints of leaves, and footprints.
- **Amber-preserved fossils** are organisms that become trapped in tree resin that hardens into amber after the tree gets buried underground.
- **Preserved remains** form when an entire organism becomes encased in material such as ice or volcanic ash or immersed in bogs.

FIGURE 12.1 The fossil record includes fossils that formed in many different ways.

Permineralized skeleton of a *Velociraptor* dinosaur

Natural cast of a crinoid, a marine animal

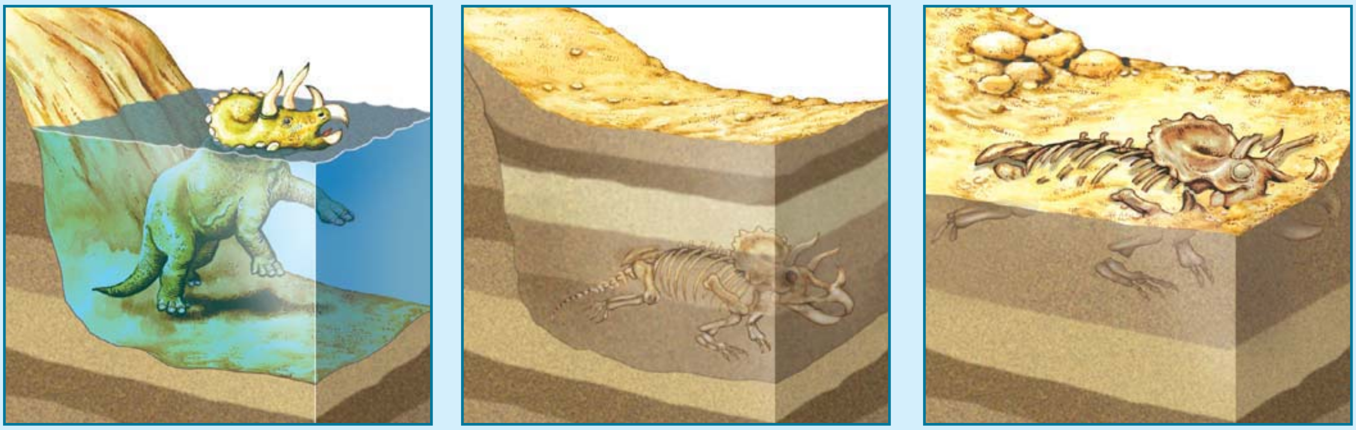
Trace fossils of footprints from a *Dimetrodon* dinosaur

Amber-preserved spider

Ice-preserved 5000-year-old remains of a man found in the Italian Alps

FIGURE 12.2 The Process of Permineralization

The process of permineralization requires rapid burial in an area with water and continuous sedimentation.



An organism dies in a location, such as a riverbed, where sediments can rapidly cover its body.

Over time, pressure from additional sediment compresses the body, and minerals slowly replace all hard structures, such as bone.

Earthquakes or erosion may expose the fossil millions of years after formation, or it may be uncovered by paleontologists, hikers, or road-building crews.

Infer What conditions could occur that would prevent an organism from being preserved through permineralization?

Most fossils form in sedimentary rock, which is made by many layers of sediment or small rock particles. The best environments for any type of fossilization include wetlands, bogs, and areas where sediment is continuously deposited, such as river mouths, lakebeds, and floodplains.

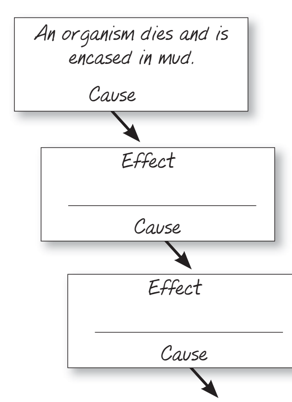
The most common fossils result from permineralization. Several circumstances are critical for this process, as shown in **FIGURE 12.2.** The organism must be buried or encased in some type of material—such as sand, sediment, mud, or tar—very soon after death, while the organism's features are still intact. After burial, groundwater trickles into tiny pores and spaces in plants, bones, and shells. During this process, the excess minerals in the water are deposited on the remaining cells and tissues. Many layers of mineral deposits are left behind, creating a fossilized record by replacing organic tissues with hard minerals. The resulting fossil has the same shape as the original structure and may contain some original tissue.

With such specific conditions needed for fossilization, it is easy to see why only a tiny percentage of living things that ever existed became fossils. Most remains decompose or are destroyed before they can be preserved. Even successful fossilization is no guarantee that an organism's remains will be added to the fossil record. Natural events such as earthquakes and the recycling of rock into magma can destroy fossils that took thousands of years to form.

Summarize Why are so few complete fossils discovered?

TAKING NOTES

Make a cause-and-effect chain of the conditions required for fossilization. Fill in important details.

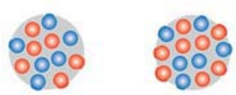


MAIN IDEA

Radiometric dating provides an accurate estimate of a fossil's age.

Connecting CONCEPTS

Chemistry of Life Recall from **Chapter 2** that all atoms of a given element have the same number of protons. Isotopes are named for the total number of protons and neutrons in their nuclei.



Recall from Chapter 10 that geologists in the 1700s had realized that rock layers at the bottom of an undisturbed sequence of rocks were deposited before those at the top, and therefore are older. The same logic holds true for the fossils found in rock layers. **Relative dating** estimates the time during which an organism lived by comparing the placement of fossils of that organism with the placement of fossils in other layers of rock. Relative dating allows scientists to infer the order in which groups of species existed, although it does not provide the actual ages of fossils.

To estimate a fossil's actual, or absolute, age, scientists use **radiometric dating**—a technique that uses the natural decay rate of unstable isotopes found in materials in order to calculate the age of that material. **Isotopes** are atoms of an element that have the same number of protons but a different number of neutrons. Most elements have several isotopes. For example, the element carbon (C) has three naturally occurring isotopes. All carbon isotopes have six protons. Isotopes are named, however, by their number of protons plus their number of neutrons. Thus, carbon-12 (^{12}C) has six neutrons, carbon-13 (^{13}C) has seven neutrons, and carbon-14 (^{14}C) has eight neutrons. More than 98 percent of the carbon in a living organism is ^{12}C.

Some isotopes have unstable nuclei. As a result, their nuclei undergo radioactive decay—they break down—over time. This releases radiation in the form of particles and energy. As an isotope decays, it can transform into a different element. The decay rate of many radioactive isotopes has been measured and is expressed as the isotope's half-life, as shown in **FIGURE 12.3.** A **half-life** is the amount of time it takes for half of the isotope in a sample to decay into a different element, or its product isotope. An element's half-life is not affected by environmental conditions such as temperature or pressure. Both ^{12}C and ^{13}C are stable, but ^{14}C decays into nitrogen-14 (^{14}N), with a half-life of roughly 5700 years.

Radiocarbon Dating

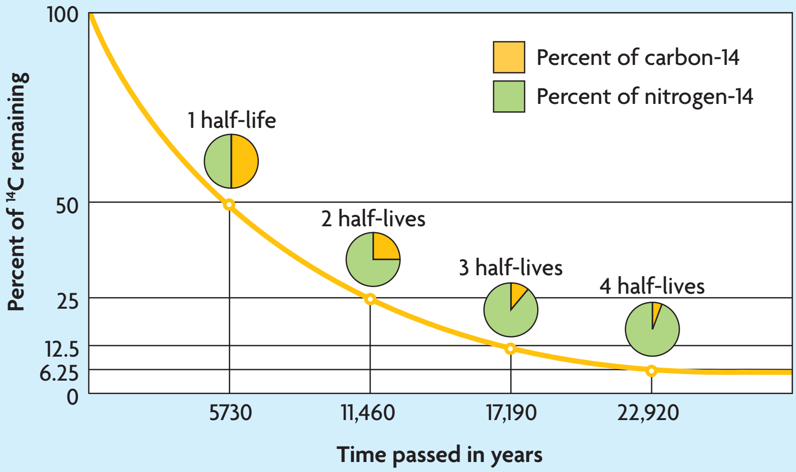
The isotope ^{14}C is commonly used for radiometric dating of recent remains, such as those of Tollund Man shown at the beginning of this chapter. Organisms absorb carbon through eating and breathing, so ^{14}C is constantly being resupplied. When an organism dies, its intake of carbon stops, but the decay of ^{14}C continues. The fossil's age can be estimated by comparing the ratio of a stable isotope, such as ^{12}C, to ^{14}C. The longer the organism has been dead, the larger the difference between the amounts of ^{12}C and ^{14}C there will be. ^{14}C has a half-life of roughly 5700 years. This means that after 5700 years, half of the ^{14}C in a fossil will have decayed into ^{14}N, its decay product. The other half remains as ^{14}C. After 11,400 years, or two half-lives, 75 percent of the ^{14}C will have decayed.

FIGURE 12.3 DECAY OF ISOTOPES

Isotope (parent)	Product (daughter)	Half-life (years)
rubidium-87	strontium-87	48.8 billion
uranium-238	lead-206	4.5 billion
chlorine-36	argon-36	300,000
carbon-14	nitrogen-14	5730

FIGURE 12.4 Radiometric Dating Using Carbon-14

Radiometric dating uses the natural decay rate of unstable isotopes to calculate the age of a fossil.



One-quarter of the original ^{14}C remains. Radioactive decay of ^{14}C is shown in **FIGURE 12.4.** Carbon-14 dating can be used to date objects only up to about 45,000 years old. If the objects are older than that, the fraction of ^{14}C will be too small to accurately measure. Older objects can be dated using isotopes with longer half-lives.

Determining Earth's Age

Scientists have used radiometric dating to determine the age of Earth. Because Earth constantly undergoes erosion and rock recycling, rocks on Earth do not remain in their original state. Unlike Earth, meteorites—which are mostly pieces of rock and iron that have fallen to Earth's surface from space—do not get recycled or undergo erosion. Meteorites are thought to have formed at about the same time as Earth. Therefore, meteorites provide an unspoiled sample for radiometric dating. Uranium-to-lead isotope ratios in many meteorite samples consistently estimate Earth's age at about 4.5 billion years.

Summarize **Why are meteorites helpful for determining the age of Earth?**

12.1 ASSESSMENT

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REVIEWING ▶ MAIN IDEAS

1. What types of evidence of ancient life can be preserved as fossils?
2. Why is a uranium **isotope** often used rather than ^{14}C in **radiometric dating** to determine the age of Earth?

CRITICAL THINKING

3. **Apply** Considering that millions of species have lived on Earth, why are there relatively few fossils?
4. **Contrast** Explain the difference between **relative dating** and absolute dating.

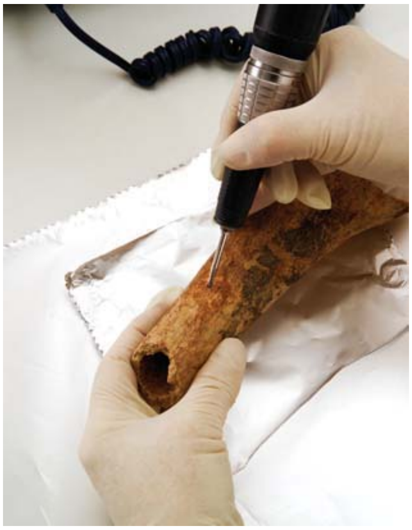
Connecting CONCEPTS

5. **Earth Science** When mountains form, the order of rock layers can be disturbed. How could radiometric dating be used to sort out the relative ages of such rock layers?

MATERIALS
- 10 pennies
- graph paper
- 3 pencils of different colors

PROCESS SKILLS
- **Analyzing**
- **Interpreting Data**
- **Modeling**

Radioactive Decay



In this lab, you will model how scientists determine the age of a fossil. Whereas the scientist pictured is measuring the decay of carbon from a sample of bone, you will model the decay of a fictitious radioactive isotope called “tailsium.”

PROBLEM How is the half-life of an unstable isotope used to determine the age of a material?

PROCEDURE
1. Arrange your pennies so that they are all tails-side-up. These pennies represent 10 atoms of “tailsium,” a radioactive isotope.
2. Pick up all 10 tailsium atoms and drop them on the table. The pennies that fall heads-side-up represent atoms of a more stable element, “headsium.” Put the headsium atoms off to the side. Count the number of tailsium atoms. Record that value in a table under toss 1.
3. Pick up only the tailsium atoms and drop them again. Put the newly formed headsium atoms off to the side with the other headsium atoms. Count the number of tailsium atoms and record this value in your table.
4. Repeat step 3 until there is no more tailsium, or until you have run 10 tosses.
5. Share your results with your class. Using the class data, determine the average number of tailsium atoms that remained after each toss.

ANALYZE AND CONCLUDE
1. **Graph Data** Graph your group results along with the average for the class on the same sheet of graph paper. The number of tosses should be on the *x*-axis, and the number of tailsium atoms remaining should be on the *y*-axis.
2. **Calculate** Using the class average, calculate an average half-life for tailsium. This is the number of tosses it took for half of the pennies to “decay” to headsium.
3. **Analyze** Below is the ideal rate of decay for tailsium. Graph these data on the same axes as your other graphs, using a different colored pencil to differentiate between the data sets. Which data set was closer to the ideal rate of decay, your group’s data or the class average? Explain.

TABLE 1. IDEAL RATE OF TAILSIUM DECAY

Time	Start	1	2	3	4	5	6	7	8	9	10
# tailsium atoms	10	5	2.5	1.25	0.625	0.313	0.156	0.078	0.039	0.019	0

4. **Apply** Assume that there are 20 years between tosses. According to your data from the penny lab, how old would a material be that had 3 tailsium atoms and 7 headsium atoms? How old would it be according to the class data?

12.2 The Geologic Time Scale

KEY CONCEPT The geologic time scale divides Earth's history based on major past events.

MAIN IDEAS

- Index fossils are another tool to determine the age of rock layers.
- The geologic time scale organizes Earth's history.

VOCABULARY

index fossil, p. 365
geologic time scale, p. 367
era, p. 367
period, p. 367
epoch, p. 367

Review
mass extinction, adaptive radiation

REVIEW AT CLASSZONE.COM

Connect As you just read, radiometric dating has shown that Earth is very old. It formed about 4.5 billion years ago. Scientists have divided this vast amount of time into manageable units based on major geologic changes.

MAIN IDEA

Index fossils are another tool to determine the age of rock layers.

You have learned that both relative dating and radiometric dating can help scientists determine the age of rock layers. Scientists who are trying to determine the age of a rock layer almost always use two or more methods to confirm results. Index fossils provide an additional tool to determine the age of fossils or the strata in which they are found. **Index fossils** are fossils of organisms that existed only during specific spans of time over large geographic areas.

Using index fossils for age estimates of rock layers is not a new idea. In the late 1700s, English geologist William Smith discovered that certain rock layers contained fossils unlike those in other layers. Using these key fossils as markers, Smith could identify a particular layer of rock wherever it was exposed.

The shorter the life span of a species, the more precisely the different strata can be correlated. The best index fossils are common, easy to identify, found widely around the world, and only existed for a relatively brief time. The extinct marine invertebrates known as fusulinids (FYOO-zuh-LY-nihdz), shown in **FIGURE 12.5**, are one example of an index fossil. They were at one time very common but disappeared after a mass extinction event about 251 million years ago. The presence of fusulinids indicates that a rock layer must be between 251 million and 359 million years old. Fossil fusulinids are useful for dating fossils of other organisms in strata because the presence of both organisms in one layer shows that they lived during the same time period.

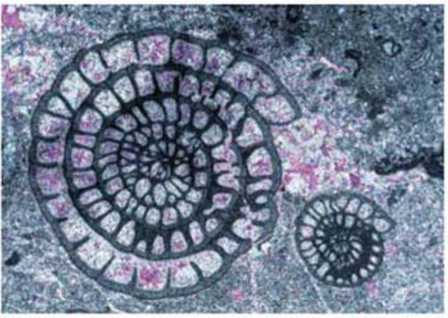
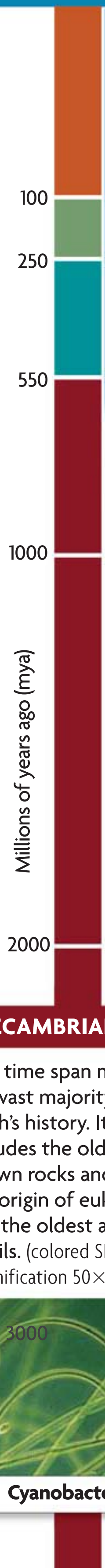


FIGURE 12.5 Fusulinids, tiny fossils usually less than 2 millimeters wide, make good index fossils. They are very abundant in marine sediment, widely distributed, and existed during a specific period of time.

Apply **Could a rock layer with fusulinid fossils be 100 million years old? Explain.**

FIGURE 12.6 Geologic Time Scale



X = Major extinction

CENOZOIC ERA

QUATERNARY PERIOD (NEOGENE)

1.8 mya–present This period continues today and includes all modern forms of life.

TERTIARY PERIOD (PALEOGENE)

65–1.8 mya Mammals, flowering plants, grasslands, insects, fish, and birds diversified. Primates evolved.

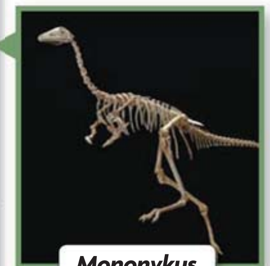
Primate

MESOZOIC ERA

X

CRETACEOUS PERIOD

145–65 mya Dinosaur populations peaked and then went extinct. Birds survived to radiate in the Tertiary period. Flowering plants arose.



Mononykus

JURASSIC PERIOD

200–145 mya Dinosaurs diversified, as did early trees that are common today. Oceans were full of fish and squid. First birds

X

TRIASSIC PERIOD

251–200 mya Following the largest mass extinction to date, dinosaurs evolved, as did plants such as ferns and cycads. Mammals and flying reptiles (pterosaurs) arose.

PALEOZOIC ERA

X

PERMIAN PERIOD

299–251 mya Modern pine trees first appeared, and Pangaea supercontinent was formed as major landmasses joined together.

Pine tree

CARBONIFEROUS PERIOD

359–299 mya Coal-forming sediments were laid down in vast swamps. Fish continued to diversify. Life forms included amphibians, winged insects, early conifers, and small reptiles.

X

DEVONIAN PERIOD

416–359 mya Fish diversified. First sharks, amphibians, and insects appeared. First trees and forests arose.

SILURIAN PERIOD

444–416 mya Earliest land plants arose. Melting of glaciers allowed seas to form. Jawless and freshwater fishes evolved.

Jawless fish

X

ORDOVICIAN PERIOD

488–444 mya Diverse marine invertebrates evolved, as did the earliest vertebrates. Massive glaciers formed, causing sea levels to drop and a mass extinction of marine life to occur.

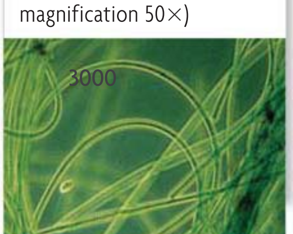
CAMBRIAN PERIOD

542–488 mya All existing animal phyla developed over a relatively short period of time known as the Cambrian Explosion.

Trilobite

PRECAMBRIAN TIME

This time span makes up the vast majority of Earth's history. It includes the oldest known rocks and fossils, the origin of eukaryotes, and the oldest animal fossils. (colored SEM; magnification 50×)



Cyanobacteria

MAIN IDEA

The geologic time scale organizes Earth's history.

The **geologic time scale,** shown in **FIGURE 12.6**, is a representation of the history of Earth. It organizes Earth's history by major changes or events that have occurred, using evidence from the fossil and geologic records. Scientists worked out the entire geologic time scale during the 1800s and early 1900s. Although they are still being changed a little bit here and there, the main divisions of geologic time have stayed the same for over a hundred years.

The time scale is divided into a series of units based on the order in which different groups of rocks and fossils were formed. The geologic time scale consists of three basic units of time.

- **Eras** last tens to hundreds of millions of years and consist of two or more periods.
- **Periods** are the most commonly used units of time on the geologic time scale, lasting tens of millions of years. Each period is associated with a particular type of rock system.
- **Epochs** (EHP-uhks) are the smallest units of geologic time and last several million years.

The names of the eras came from early ideas about life forms preserved as fossils. *Paleozoic* means "ancient life," *Mesozoic* means "middle life," and *Cenozoic* means "recent life." Within the eras, the boundaries between many of the geologic periods are defined by mass extinction events. These events help to define when one period ends and another begins. The largest adaptive radiations tend to follow large mass extinctions. Recall that adaptive radiation happens when a group of organisms diversifies into several species. Those species adapt to different ecological niches because mass extinctions make many niches available. Over generations, the adaptive traits favored within these newly opened niches may become common for that population of organisms, and speciation may occur.

Connecting CONCEPTS

Adaptive Radiation Recall from **Chapter 11** that *adaptive radiation* refers to the change of a single species into several forms that are each adapted to a specific environmental niche.

Summarize **Why do adaptive radiations often occur after mass extinctions?**

12.2 ASSESSMENT

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REVIEWING MAIN IDEAS

1. How are **index fossils** used to date rock layers?
2. What is the usefulness of categorizing Earth's history into the **geologic time scale**?

CRITICAL THINKING

3. **Infer** The most common index fossils are shells of invertebrates. Give two reasons why this is so.
4. **Analyze** Scientists have inferred that there have been at least five mass extinctions in Earth's history. How would fossil evidence support this inference?

Connecting CONCEPTS

5. **Scientific Process** French physicist Henri Becquerel discovered radioactivity in 1896, after geologists had developed the geologic time scale. How did Becquerel's discovery help later geologists as they refined the time scale?