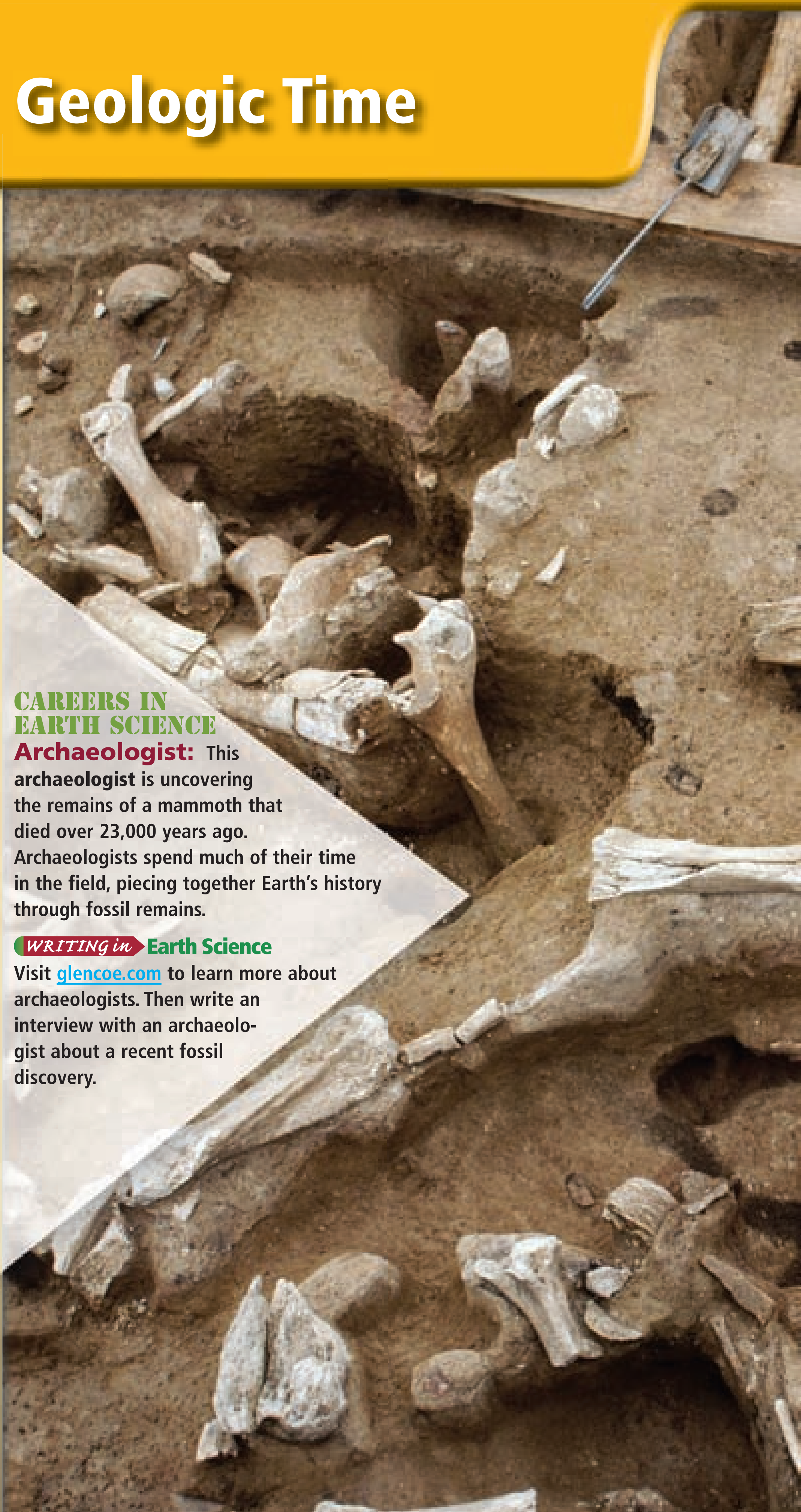
UNIT 6 Geologic Time



Chapter 21
Fossils and the Rock Record
BIG Idea Scientists use several methods to learn about Earth's long history.

Chapter 22
The Precambrian Earth
BIG Idea The oceans and atmosphere formed and life began during the three eons of the Precambrian, which spans nearly 90 percent of Earth's history.

Chapter 23
The Paleozoic, Mesozoic, and Cenozoic Eras
BIG Idea Complex life developed and diversified during the three eras of the Phanerozoic as the continents moved into their present positions.

CAREERS IN EARTH SCIENCE

Archaeologist: This **archaeologist** is uncovering the remains of a mammoth that died over 23,000 years ago. Archaeologists spend much of their time in the field, piecing together Earth's history through fossil remains.

WRITING in Earth Science
Visit glencoe.com to learn more about archaeologists. Then write an interview with an archaeologist about a recent fossil discovery.

Earth Science Online

To learn more about archaeologists, visit glencoe.com.

Ira Block/National Geographic Image Collection

CHAPTER 21 Fossils and the Rock Record

BIG Idea Scientists use several methods to learn about Earth's long history.

21.1 The Rock Record
MAIN Idea Scientists organize geologic time to help them communicate about Earth's history.

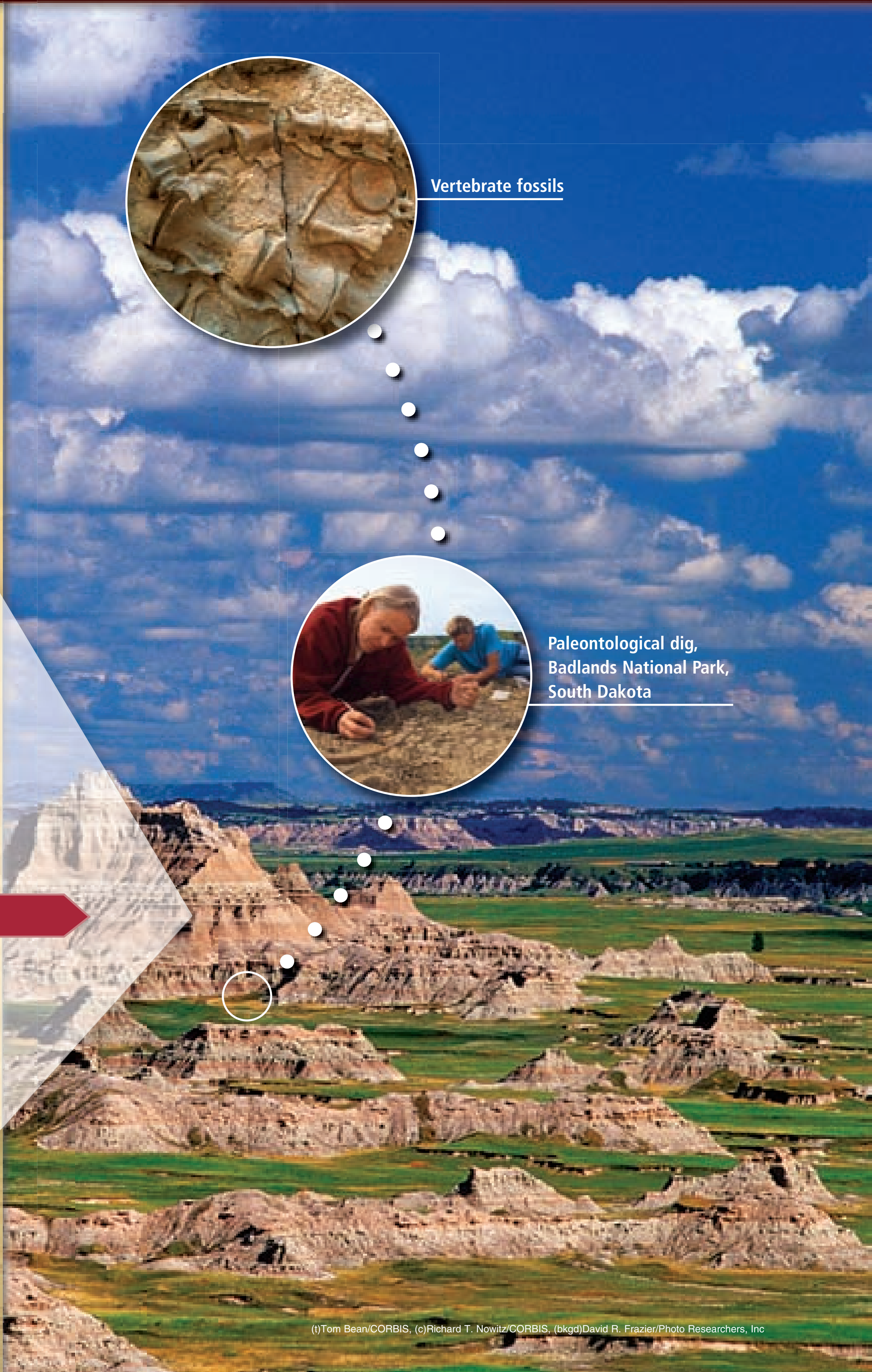
21.2 Relative-Age Dating
MAIN Idea Scientists use geologic principles to learn the sequence in which geologic events occurred.

21.3 Absolute-Age Dating
MAIN Idea Radioactive decay and certain kinds of sediments help scientists determine the numeric age of many rocks.

21.4 Fossil Remains
MAIN Idea Fossils provide scientists with a record of the history of life on Earth.

GeoFacts

- The land that is now Badlands National Park in South Dakota was once covered by forest, then by swamp, and later by grasslands.
- Ancestors of alligators, camels, and rhinoceroses once thrived in the Badlands.
- The Badlands are considered the birthplace of vertebrate paleontology in North America.



Vertebrate fossils

Paleontological dig, Badlands National Park, South Dakota

LAUNCH Lab

How are fossils made?

Have you ever wandered through a museum and stood beneath the fossilized bones of a *Tyrannosaurus rex*? Fossilized bones provide evidence that dinosaurs and other ancient organisms existed. A fossil forms when a bone or other hard body part is quickly covered by mud, sand, or other sediments, and after long periods of time, the bones absorb minerals from Earth and become petrified.

Procedure

1. Read and complete the lab safety form.
2. Pour 500 mL of **sand** into a **plastic milk carton** with the top cut off.
3. Bury a **sponge** in the center of the sand.
4. Pour 250 mL of **hot tap water** into a **500 mL beaker.**
5. Measure 100 mL of **salt,** add the salt to the water, and use a **stirring rod** to stir the mixture vigorously.
6. Pour the water over the sand and place the container in direct sunlight for 5 to 7 days, leaving it undisturbed.
7. Dig up your fossilized sponge.

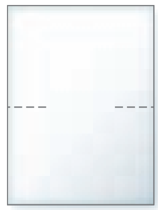
Analysis

1. **Describe** in your science journal what happened to the sponge.
2. **Explain** how this activity models the formation of a fossil.

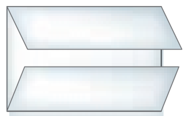
FOLDABLES™ Study Organizer

Relative-Age v. Absolute-Age Dating Make this Foldable to compare and contrast relative-age dating to absolute-age dating of rocks.

STEP 1 Find the center of a vertical sheet of paper.



STEP 2 Fold the top and bottom to the center line to make a shutter fold.



STEP 3 Label the tabs *Relative-Age Dating* and *Absolute-Age Dating.*

FOLDABLES **Use this Foldable with Sections 21.2 and 21.3.** As you learn about age dating of rocks, summarize that information on your Foldable. Be sure to include examples along with advantages and disadvantages of each type.

Earth Science Online

Visit glencoe.com to

- **study entire chapters online;**
- **explore Concepts In Motion animations:**
  - **Interactive Time Lines**
  - **Interactive Figures**
  - **Interactive Tables**
- **access Web Links for more information, projects, and activities;**
- **review content with the Interactive Tutor and take Self-Check Quizzes.**

Section 21.1

Objectives

- **Explain** why scientists need a geologic time scale.
- **Distinguish** among eons, eras, periods, and epochs.
- **Characterize** the groups of plants and animals that dominated eras in Earth's history.

Review Vocabulary

fossil: the remains, trace, or imprint of a once-living plant or animal

New Vocabulary

geologic time scale
eon
Precambrian
era
period
epoch
mass extinction

The Rock Record

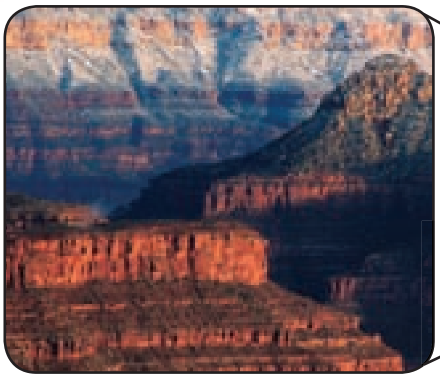
MAIN Idea Scientists organize geologic time to help them communicate about Earth's history.

Real-World Reading Link Imagine how difficult it would be to plan a meeting with a friend if time were not divided into units of months, weeks, days, hours, and minutes. By organizing geologic time into time units, scientists can communicate more effectively about events in Earth's history.

Organizing Time

A hike down the Grand Canyon reveals the multicolored layers of rock, called strata, that make up the canyon walls, as shown in **Figure 21.1.** Some of the layers contain fossils, which are the remains, traces, or imprints of ancient organisms. By studying rock layers and the fossils within them, geologists can reconstruct aspects of Earth's history and interpret ancient environments.

To help in the analysis of Earth's rocks, geologists have divided the history of Earth into time units. These time units are based largely on the fossils contained within the rocks. The time units are part of the **geologic time scale,** a record of Earth's history from its origin 4.6 billion years ago (bya) to the present. Since the naming of the first geologic time unit, the Jurassic (joo RA sihk), in 1795, development of the time scale has continued to the present day. Some of the units have remained unchanged for centuries, while others have been reorganized as scientists have gained new knowledge. The geologic time scale is shown in **Figure 21.2.**



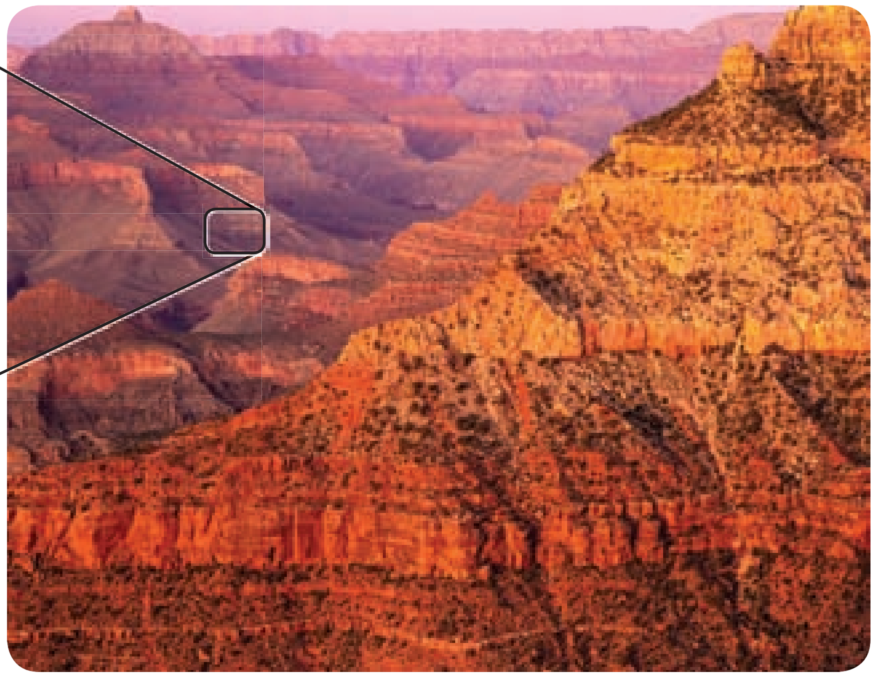


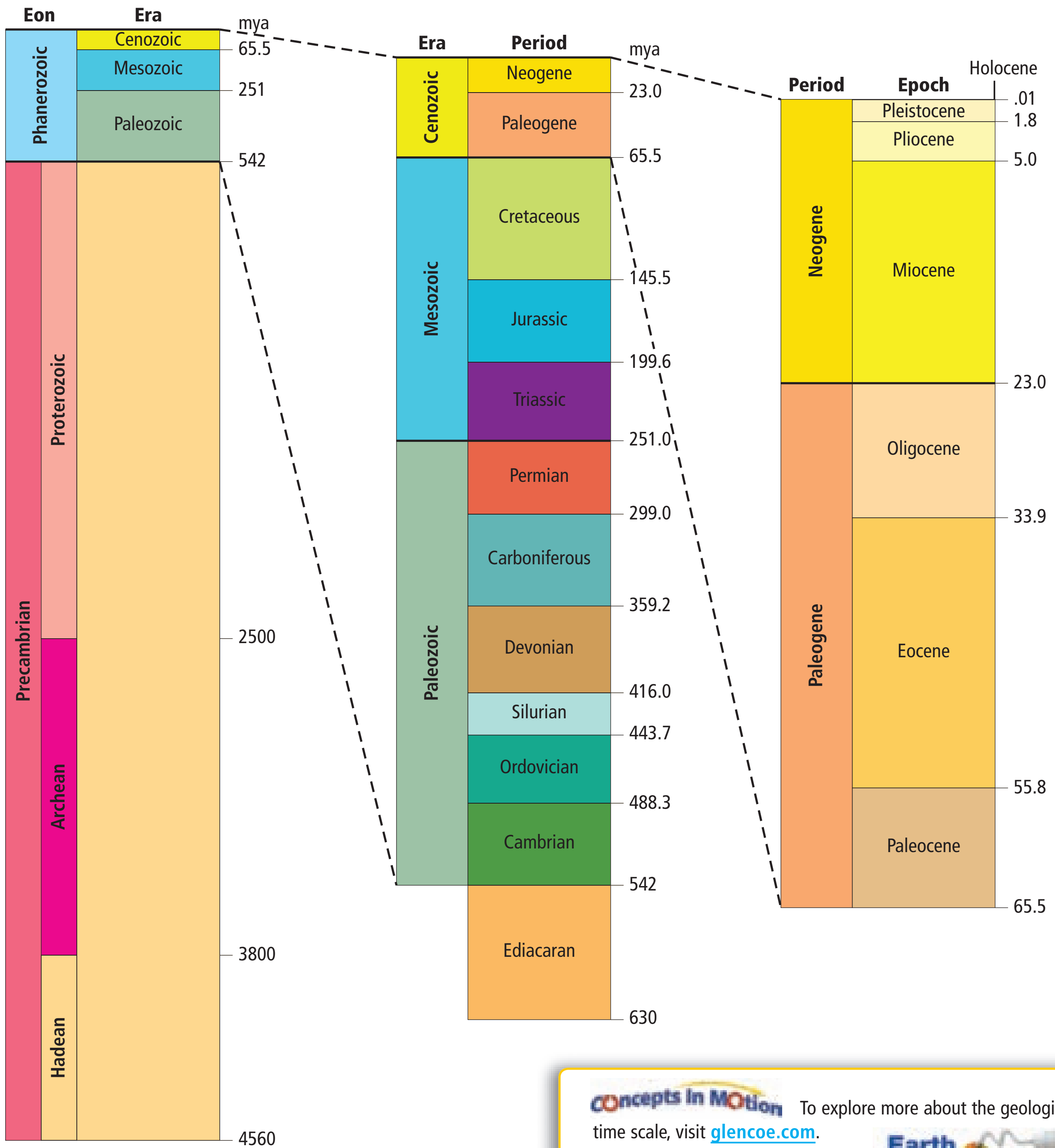
Figure 21.1 The rock layers of the Grand Canyon represent geologic events spanning nearly 2 billion years. Geologists study the rocks and fossils in each layer to learn about Earth history during different units of time.

Visualizing The Geologic Time Scale

NATIONAL GEOGRAPHIC

Figure 21.2 The geologic time scale begins with Earth's formation 4.6 billion years ago (bya). Geologists organize Earth's history according to groupings called eons. Each eon contains eras, which in turn contain periods. Each period in the geologic time scale contains epochs. The current geologic epoch is called the Holocene Epoch. Each unit on the scale is labelled with its range of time in millions of years ago (mya).
Identify ***the period, era, and eon representing the most modern unit of time.***

CLICK HERE



Concepts In Motion To explore more about the geologic time scale, visit glencoe.com.

Earth Science Online

■ **Figure 21.3** This is a well-preserved fossil of an arthropod-like organism, found in a sedimentary rock of the late Precambrian. It represents one of the first complex life-forms on Earth.
Infer *how this organism might have moved.*

The Geologic Time Scale

The geologic time scale enables scientists to find relationships among the geological events, environmental conditions, and fossilized life-forms that are preserved in the rock record. The oldest division of time is at the bottom of the scale, shown in **Figure 21.2.** Moving upward, each division is more recent, just as the rock layers in the rock record are generally younger toward the surface.

Reading Check **Explain** why scientists need a geologic time scale.

Eons The time scale is divided into units called eons, eras, periods, and epochs. An **eon** is the largest of these time units and encompasses the others. They consist of the Hadean (HAY dee un), the Archean (ar KEE un), Proterozoic (pro tuh ruh ZOH ihk), and Phanerozoic (fa nuh ruh ZOH ihk) Eons.

The three earliest eons make up 90 percent of geologic time, known together as the **Precambrian** (pree KAM bree un). During the Precambrian, Earth was formed and became hospitable to modern life. Fossil evidence suggests that simple life-forms began in the Archean Eon and that by the end of the Proterozoic Eon, life had evolved to the point that some organisms might have been able to move in complex ways. Most of these fossils, such as the one shown in **Figure 21.3,** were soft-bodied organisms, many of which resembled modern animals. Others had bodies with rigid parts. All life-forms until then had soft bodies without shells or skeletons.

Fossils dating from the most recent eon, the Phanerozoic, are the best-preserved, not only because they are younger, but because they represent organisms with hard parts, which are more easily preserved. The time line in **Figure 21.4** shows some important fossil and age-dating discoveries.

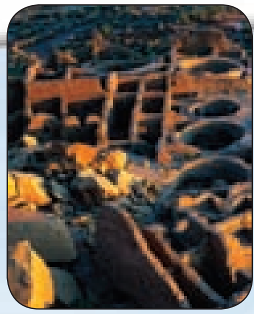
■ **Figure 21.4**
Fossil Discoveries and Technology

Fossil discoveries and dating technology have changed our understanding of life on Earth.

1796 William Smith, a canal surveyor, creates the first geologic map based on distinct fossil layers.

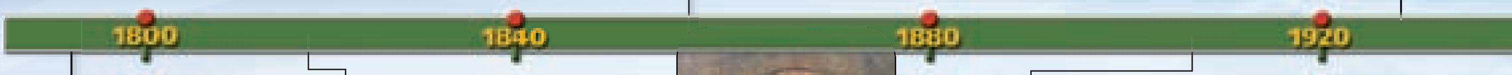
1820s Mary Anning, the daughter of a cabinet-maker, finds and identifies fossils of many ancient creatures, sparking great interest in paleontology.

1857 Quarry workers uncover a skeleton identified as Neanderthal, a species similar to modern humans.



1909 The discovery of the Burgess Shale fossils in the Rocky Mountains reveals the diversity of invertebrate life that thrived during the Cambrian Period.

1929 An Anasazi ruin becomes the first prehistoric site to be dated using tree-ring chronology.



Eras All eons are made up of eras, the next-largest unit of time. **Eras** are usually tens to hundreds of millions of years in duration. Like all other time units, they are defined by the different life-forms found in the rocks; the names of the eras are based on the relative ages of these life-forms. For example, in Greek, *paleo* means *old, meso* means *middle,* and *ceno* means *recent. Zoic* means *of life* in Greek; thus, *Mesozoic* means *middle life* and *Cenozoic* means *recent life.*

Periods All eras are divided into periods. **Periods** are generally tens of millions of years in duration, though some periods of the Precambrian are considerably longer. Some periods are named for the geographic region in which the rocks or fossils characterizing the age were first observed and described. Consider, for example, the Ediacaran (ee dee A kuh run) Period at the end of the Precambrian. It is named for the Ediacara Hills in Australia, shown in **Figure 21.5.** It was here that fossils typical of the period were first found, as shown in **Figure 21.4.** The Ediacaran Period was added to the geologic time scale in 2004.

Epochs Epochs (EE pahks) are even smaller divisions of geologic time. Although the time scale in **Figure 21.2** shows epochs only for periods of the Cenozoic Era, all periods of geologic time are divided into epochs. **Epochs** are generally hundreds of thousands to millions of years in duration. Rocks and sediments from the epochs of the Cenozoic Era are the most complete because there has been less time for weathering and erosion to remove evidence of this part of Earth's history. For this reason, the epochs of the Cenozoic are relatively short in duration. For example, the Holocene (HOH luh seen) Epoch, which includes modern time, began only about 11,000 years ago.

Figure 21.5 The Ediacara Hills of Australia yielded the first fossils typical of the Ediacaran Period. Fossils from that time found anywhere in the world are called Ediacaran fossils.

1946 University of Chicago scientists show that the age of relatively recent organic objects and artifacts can be determined with radiocarbon dating.

1993 Fossils found in western Australia provide evidence that bacteria existed 3.5 bya.

2006 A 164-million-year-old, beaverlike fossil unearthed by Chinese researchers suggests that aquatic mammals might have thrived alongside dinosaurs.

1940 1970 2000

1987 Jenny Clack leads an expedition to Greenland that unearths fossils of animals that lived 360 mya, showing that animals developed legs prior to moving onto land.

Concepts In Motion

Interactive Time Line To learn more about these discoveries and others, visit glencoe.com. Earth Science Online

Figure 21.6 Trilobites are Paleozoic fossils found all over the world. Like 90 percent of life-forms of that era, they perished during a mass extinction.

Succession of Life-Forms

Multicellular life began to diversify during the Phanerozoic Eon. Fossils from the Phanerozoic are abundant, while those from the Precambrian are relatively few. The word *Phanerozoic* means *visible life* in Greek. During the first era of the Phanerozoic, the Paleozoic (pay lee uh ZOH ihk), the oceans became full of many different kinds of organisms. Small, segmented animals called trilobites, shown in **Figure 21.6,** were among the first hard-shelled life-forms. Trilobites dominated the oceans in the early part of the Paleozoic Era; land plants appeared later, followed by land animals. Swamps of the Carboniferous (kar buh NIH fuh rus) Period provided the plant material that developed into the coal deposits of today. The end of the Paleozoic is marked by the largest mass extinction event in Earth's history. In a **mass extinction,** many groups of organisms disappear from the rock record at about the same time. At the end of the Paleozoic, 90 percent of all marine organisms became extinct.

The age of dinosaurs The era following the Paleozoic—the Mesozoic (mez uh ZOH ihk)—is known for the emergence of dinosaurs, but many other organisms also appeared during the Mesozoic. Large predatory reptiles ruled the oceans, and corals closely related to today's corals built huge reef systems. Water-dwelling amphibians began adapting to terrestrial environments. Insects, some as large as birds, lived. Mammals evolved and began to diversify. Flowering plants and trees emerged. The end of the Mesozoic is marked by a large extinction event. Many groups of organisms became extinct, including the non-avian dinosaurs and large marine reptiles.

The rise of mammals During the era that followed—the Cenozoic (sen uh ZOH ihk)—mammals increased both in number and diversity. Human ancestors, the first primates, emerged in the epoch called the Paleocene, and modern humans appeared in the Pleistocene (PLYS tuh seen) Epoch.

Section 21.1 Assessment

Section Summary

- Scientists organize geologic time into eons, eras, periods, and epochs.
- Scientists divide time into units based on fossils of plants and animals.
- The Precambrian makes up nearly 90 percent of geologic time.
- The geologic time scale changes as scientists learn more about Earth.

Understand Main Ideas

1. MAIN Idea **Explain** the purpose of the geologic time scale.
2. **Distinguish** among eons, eras, periods, and epochs, using specific examples.
3. **Describe** the importance of extinction events to geologists.
4. **Explain** why scientists know more about the Cenozoic than they do about other eras.

Think Critically

5. **Discuss** why scientists know so little about Precambrian Earth.

MATH in Earth Science

6. Make a bar graph that shows the relative percentage of time spanned by each era of the Phanerozoic Eon. For more help, refer to the *Skillbuilder Handbook*.

Earth Science Online Self-Check Quiz glencoe.com

Section 21.2

Objectives

- **Describe** uniformitarianism and explain its importance to geology.
- **Apply** geologic principles to interpret rock sequences and determine relative ages.
- **Compare and contrast** different types of unconformities.
- **Explain** how scientists use correlation to understand the history of a region.

Review Vocabulary

granite: a coarse-grained, intrusive igneous rock

New Vocabulary

uniformitarianism
relative-age dating
original horizontality
superposition
cross-cutting relationship
principle of inclusions
unconformity
correlation
key bed

Relative-Age Dating

MAIN Idea Scientists use geologic principles to learn the sequence in which geologic events occurred.

Real-World Reading Link If you were to put the following events into a time sequence of first to last, how would you do it? Go to school. Wake up. Put on your clothes. Eat lunch. You would probably rely on your past experiences. Scientists also use information from the past to place events into a likely time sequence.

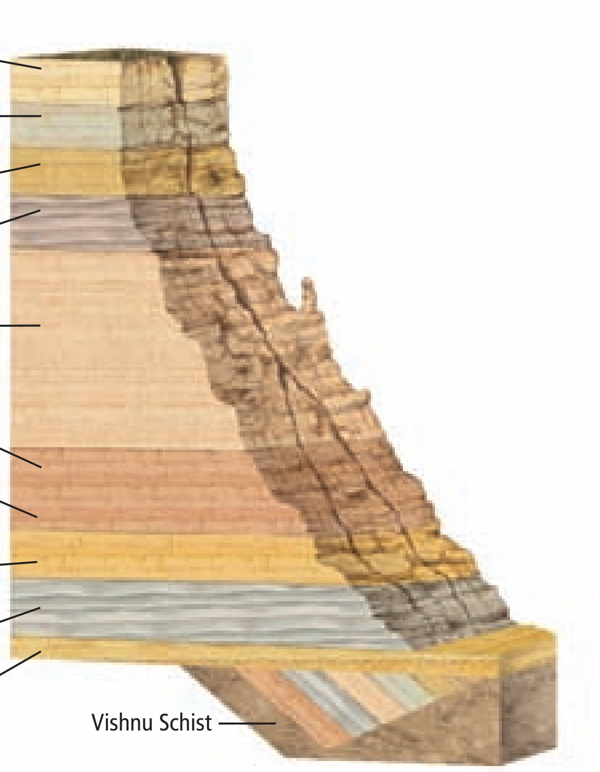
Interpreting Geology

Recall from Section 21.1 that Earth's history stretches back billions of years. Scientists have not always thought that Earth was this old. Early ideas about Earth's age were generally placed in the context of time spans that a person could understand relative to his or her own life. This changed as people began to explore Earth and Earth processes in scientific ways. James Hutton, a Scottish geologist who lived in the late 1700s, was one of the first scientists to think of Earth as very old. He attempted to explain Earth's history in terms of geologic forces, such as erosion and sea-level changes, that operate over long stretches of time. His work helped set the stage for the development of the geologic time scale.

Uniformitarianism Hutton's work lies at the foundation of **uniformitarianism,** which states that geologic processes occurring today have been occurring since Earth formed. For example, if you stand on the shore of an ocean and watch the waves come in, you are observing a process that has not changed since the oceans were formed. The waves crashing on a shore in the Jurassic Period were much like the waves crashing on a shore today. The photo in **Figure 21.7** was taken recently on a beach in Oregon, but a beach in the Jurassic Period probably looked very similar.

Figure 21.7 An ancient Jurassic beach probably looked much like this beach in Oregon. The geologic processes that formed it are unchanged.

■ **Figure 21.8** The horizontal layers of the Grand Canyon were formed by deposition of sediment over millions of years. The principle of original horizontality states that the tilted strata at the bottom were formed horizontally.



Principles for Determining Relative Age

Because of uniformitarianism, scientists can learn about the past by studying the present. One way to do this is by studying the order in which geologic events occurred using a method called **relative-age dating.** This does not allow scientists to determine exactly how many years ago an event occurred, but it gives scientists a clearer understanding about geologic events in Earth's history. Scientists use several ways to determine relative ages, called the principles of relative dating. They include original horizontality, superposition, cross-cutting relationships, and inclusions.

FOLDABLES Incorporate information from this section into your Foldable.

Original horizontality **Original horizontality** is the principle that sedimentary rocks are deposited in horizontal or nearly horizontal layers. This can be seen in the walls of the Grand Canyon, illustrated in **Figure 21.8.** Sediment is deposited in horizontal layers for the same reason that layers of sand on a beach are mostly flat; that is, gravity combined with wind and water spreads them evenly.

VOCABULARY

ACADEMIC VOCABULARY

Principle
a general hypothesis that has been tested repeatedly; sometimes also called a law
The geologic principle was illustrated in the rock layers the students observed.

Superposition Geologists cannot determine the numeric ages of most rock layers in the Grand Canyon using relative-age dating methods. However, they can assume that the oldest rocks are at the bottom and that each successive layer above is younger. Thus, they can infer that the Kaibab Limestone at the top of the canyon is much younger than the Vishnu Group, which is at the bottom. This is an application of **superposition,** the principle that in an undisturbed rock sequence, the oldest rocks are at the bottom and each consecutive layer is younger than the layer beneath it.

Cross-cutting relationships Rocks exposed in the deepest part of the Grand Canyon are mostly igneous and metamorphic. Within the metamorphic schist of the Vishnu Group in the bottom sequence are intrusions—also called dikes—of granite, as shown in **Figure 21.9.** You learned in Chapter 5 that intrusions are rocks that form when magma solidifies in existing rock. The principle of **cross-cutting relationships** states that an intrusion is younger than the rock it cuts across. Therefore, the granite intrusion in the Grand Canyon is younger than the schist because the granite cuts across the schist.

The principle of cross-cutting relationships also applies to faults. Recall from Chapter 20 that a fault is a fracture in Earth along which movement takes place. Many faults exist in earthquake-prone areas, such as California, and in ancient, mountainous regions, such as the Adirondacks of New York. A fault is younger than the strata and surrounding geologic features because the fault cuts across them.

Inclusions Relative age can also be determined where one rock layer contains pieces of rock from the layer next to it. This might occur after an exposed layer has eroded and the loose material on the surface has become incorporated into the layer deposited on top of it. The **principle of inclusions** states that the fragments, called inclusions, in a rock layer must be older than the rock layer that contains them.

As you learned in Chapter 6, once a rock has eroded, the resulting sediment might be transported and redeposited many kilometers away. In this way, a rock formed in the Triassic Period might contain inclusions from a Cambrian rock. Inclusions can also form from pieces of rock that are trapped within a lava flow.

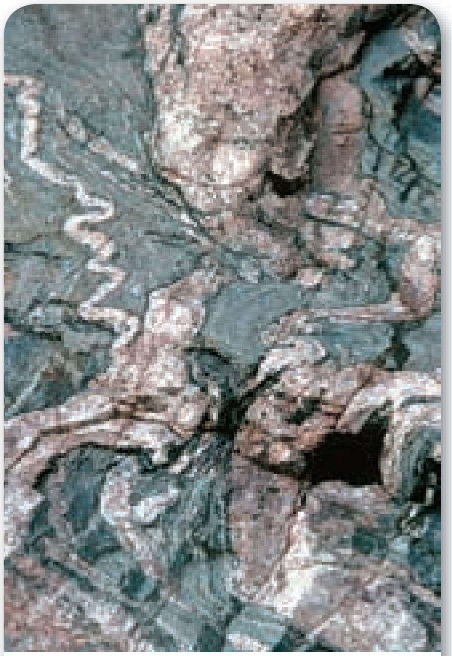


Figure 21.9 According to the principle of cross-cutting relationships, this igneous intrusion is younger than the schist it cuts across.
Infer *how the igneous intrusion was formed.*

MiniLab

Determine Relative Age

How is relative age determined? Scientists use geologic principles to determine the relative ages of rock layers.

Procedure

1. Read and complete the lab safety form.
2. Draw a diagram showing four horizontal layers of rock. Starting from the bottom, label the layers *1* through *4.*
3. Draw a vertical intrusion from Layer 1 through Layer 3.
4. Label a point at the bottom left corner of the diagram *X* and a point at the top right corner *Y.*
5. Cut the paper in a diagonal line from X to Y. Move the top-left piece 1.5 cm along the cut.

Analysis

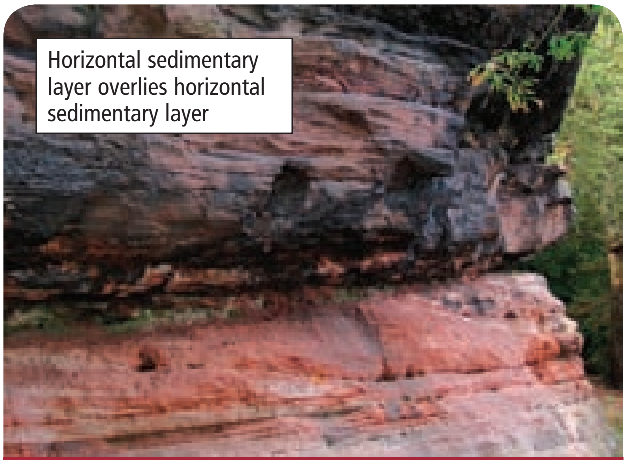
1. **Describe** what principles you would use to determine the relative ages of the layers in your diagram.
2. **Explain** how the principle of cross-cutting relationships can help you determine the relative age of the vertical intrusion.
3. **Infer** what the XY cut represents. Is the XY cut older or younger than the surrounding layers?

Concepts In Motion

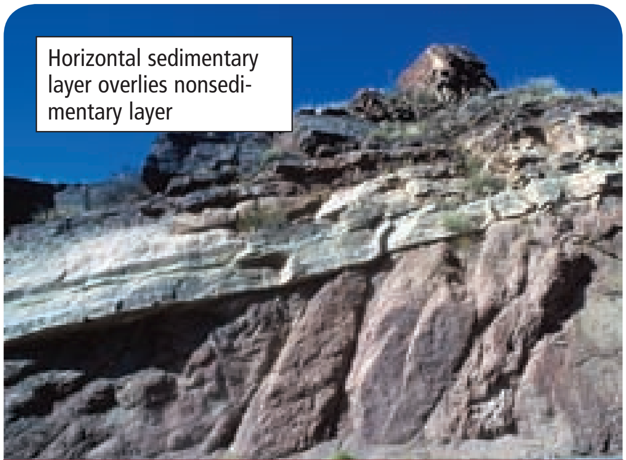
Interactive Figure To see an animation of an angular unconformity, visit glencoe.com.

CLICK HERE

Figure 21.10 An unconformity is any erosional surface separating two layers of rock that have been deposited at different times. The three types of unconformities are illustrated below.



Disconformity



Nonconformity

Angular unconformity

Unconformities Earth's surface is constantly changing as a result of weathering, erosion, earthquakes, volcanism, and other processes. This makes it difficult to find a sequence of rock layers in the geologic record in which a layer has not been disturbed. Sometimes, the record of a past event or time period is missing entirely. For example, if rocks from a volcanic eruption erode, the record of that eruption is lost. If an eroded area is covered at a later time by a new layer of sediment, the eroded surface represents a gap in the rock record. Buried surfaces of erosion are called **unconformities.** The rock layer immediately above an unconformity is sometimes considerably younger than the rock layer immediately below it. Scientists recognize three different types of unconformities, which are illustrated in **Figure 21.10.**

Disconformity When a horizontal layer of sedimentary rock overlies another horizontal layer of sedimentary rock, the eroded surface is called a disconformity. Disconformities can be easy to identify when the eroded surface is uneven. Where the eroded surface is smooth, disconformities are often hard to see.

Nonconformity When a layer of sedimentary rock overlies a layer of igneous or metamorphic rock, such as granite or marble, the eroded surface is easier to identify. This kind of eroded surface is called a nonconformity. Both granite and marble form deep in Earth. A nonconformity indicates a gap in the rock record during which rock layers were uplifted, eroded at Earth's surface, and new layers of rock formed on top.

Reading Check **Distinguish** between a disconformity and a nonconformity.

Angular unconformity As you learned in Chapter 20, when horizontal layers of sedimentary rock are deformed during mountain building, they are usually uplifted and tilted. During this process, the layers are exposed to weathering and erosion. If a horizontal layer of sedimentary rock is later laid down on top of the tilted, eroded layers, the resulting unconformity is called an angular unconformity. **Figure 21.10** shows how angular unconformities record the complex history of mountain formation and erosion.

Correlation The Kaibab Limestone layer rims the top of the Grand Canyon in Arizona, but it is also found more than 100 km away at the bottom of Zion National Park in Utah. How do geologists know that these layers, which are far apart from each other, formed at the same time? One method is by correlation (kor uh LAY shun). **Correlation** is the matching of unique rock outcrops or fossils exposed in one geographic region to similar outcrops exposed in other geographic regions. Through correlation of many different layers of rocks, geologists have determined that Zion, Bryce Canyon, and the Grand Canyon are all part of one layered sequence called the Grand Staircase, illustrated in **Figure 21.11.**

Key beds Distinctive rock layers are sometimes deposited over wide geographic areas as a result of a large meteorite strike, volcanic eruption, or other brief event. Because these layers are easy to recognize, they help geologists correlate rock formations in different geographic areas where the layers are exposed. A rock or sediment layer used as a marker in this way is called a **key bed.** Geologists know that the layers above a key bed are younger than the layers below it. The key-bed ash layer that marks the 1980 eruption of Mount St. Helens deposited volcanic ash over many states.

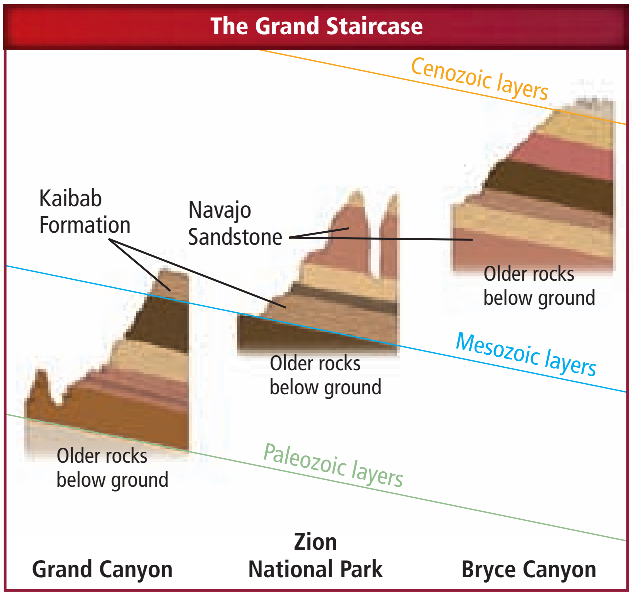
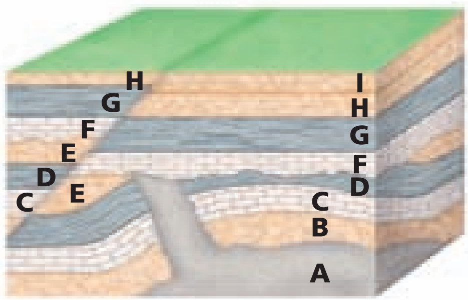


Figure 21.11 The top layers of rocks at the Grand Canyon are identical to the bottom layers at Zion National Park, and the top layers at Zion are the bottom layers at Bryce Canyon.
Infer *the makeup of the buried layer below Zion's Kaibab layer.*

PROBLEM-SOLVING LAB

Interpret the Diagram

How do you interpret the relative ages of rock layers? The diagram at right illustrates a sequence of rock layers. Geologists use the principles of relative-age dating to determine the order in which layers such as these were formed.



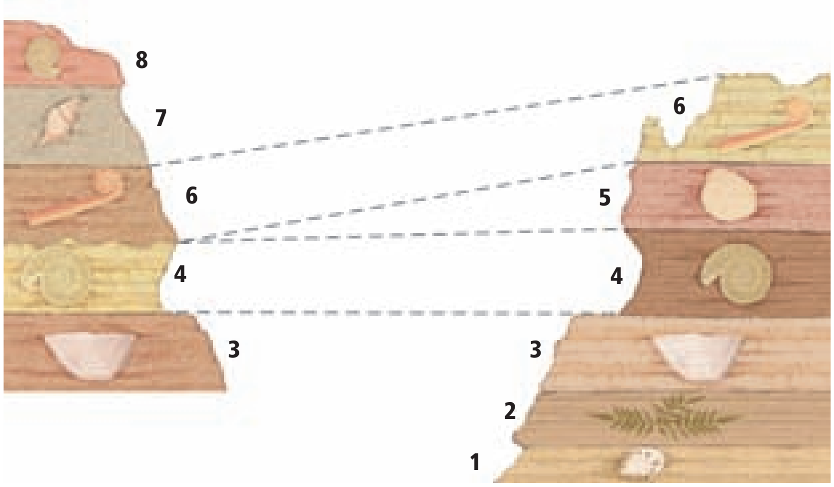
Analysis

1. **Identify** a type of unconformity between any two layers of rock. Justify your answer.
2. **Interpret** which rock layer is oldest.
3. **Infer** where inclusions might be found. Explain.
4. **Compare and contrast** the rock layers on the right and left sides of the diagram. Why do they not match?

Think Critically

5. **Apply** Which feature is younger, the dike or the folded strata? What geologic principle did you use to determine your answer?
6. **Propose** why there is no layer labeled *I* on the left side of the diagram.

Figure 21.12 Correlating fossils from rock layers in one location to rock layers in another location shows that the layers were deposited during roughly the same time period, even though the layers are of different material.



CAREERS IN EARTH SCIENCE

Petroleum Geologist Petroleum geologists use geologic principles to identify petroleum and natural gas reserves in the rock record. To learn more about Earth science careers, visit glencoe.com.

Fossil correlation Geologists also use fossils to correlate rock formations in locations that are geographically distant. As shown in **Figure 21.12,** fossils can indicate similar times of deposition even though the layers might be made of entirely different material.

The correlation of fossils and rock layers aids in the relative dating of rock sequences and helps geologists understand the history of larger geographic regions. Petroleum geologists also use correlation to help them locate reserves of oil and gas. For example, if a sandstone layer in one area contains oil, it is possible that the same layer in other areas also contains oil. It is largely through correlation that geologists have constructed the geologic time scale.

Section 21.2 Assessment

Section Summary

- The principle of uniformitarianism states that processes occurring today have been occurring since Earth formed.
- Scientists use geologic principles to determine the relative ages of rock sequences.
- An unconformity represents a gap of time in the rock record.
- Geologists use correlation to compare rock layers in different geographic areas.

Understand Main Ideas

1. MAIN Idea **Summarize** the principles that geologists use to determine relative ages of rocks.
2. **Make a diagram** to compare and contrast the three types of unconformities.
3. **Explain** how geologists use fossils to understand the geologic history of a large region.
4. **Discuss** how a coal seam might be used as a key bed.
5. **Apply** Explain how the principle of uniformitarianism would help geologists determine the source of a layer of particular igneous rock.

Think Critically

6. **Propose** how a scientist might support a hypothesis that rocks from one quarry were formed at the same time as rocks from another quarry 50 km away.

WRITING in Earth Science

7. Write a paragraph that explains how an event, such as a large hurricane, might result in a key bed. Use a specific example in your paragraph.

Section 21.3

Objectives

- **Compare and contrast** absolute-age dating and relative-age dating.
- **Describe** how scientists date rocks and other objects using radioactive elements.
- **Explain** how scientists can use certain non-radioactive material to date geologic events.

Review Vocabulary

isotope: one of two or more forms of an element with differing numbers of neutrons

New Vocabulary

absolute-age dating
radioactive decay
radiometric dating
half-life
radiocarbon dating
dendrochronology
varve

CLICK HERE

Absolute-Age Dating

MAIN Idea Radioactive decay and certain kinds of sediments help scientists determine the numeric age of many rocks.

Real-World Reading Link If a TV programming guide listed only the order of TV shows but not the times they aired, you would not know when to watch a program. Scientists, too, find it helpful to know exactly when events occurred.

Radioactive Isotopes

As you learned in Section 21.2, relative-age dating is a method of comparing past geologic events based on the order of strata in the rock record. In contrast, **absolute-age dating** enables scientists to determine the numerical age of rocks and other objects. In one type of absolute-age dating method, scientists measure the decay of the radioactive isotopes in igneous and metamorphic rocks in addition to some remains of organisms preserved in sediments.

Radioactive decay Radioactive isotopes emit nuclear particles at a constant rate. Recall from Chapter 3 that an element is defined by the number of protons it contains. As the number of protons changes with each emission, the original radioactive isotope, called the parent, is gradually converted to a different element, called the daughter. For example, a radioactive isotope of uranium, U-238, will decay into the daughter isotope lead-206 (Pb-206) over a specific span of time, as illustrated in **Figure 21.13.** Eventually, enough of the parent decays that traces of it are undetectable, and only the daughter product is measurable. The emission of radioactive particles and the resulting change into other isotopes over time is called **radioactive decay.** Because the rate of radioactive decay is constant regardless of pressure, temperature, or any other physical changes, scientists use it to determine the absolute age of the rock or object in which it occurs.

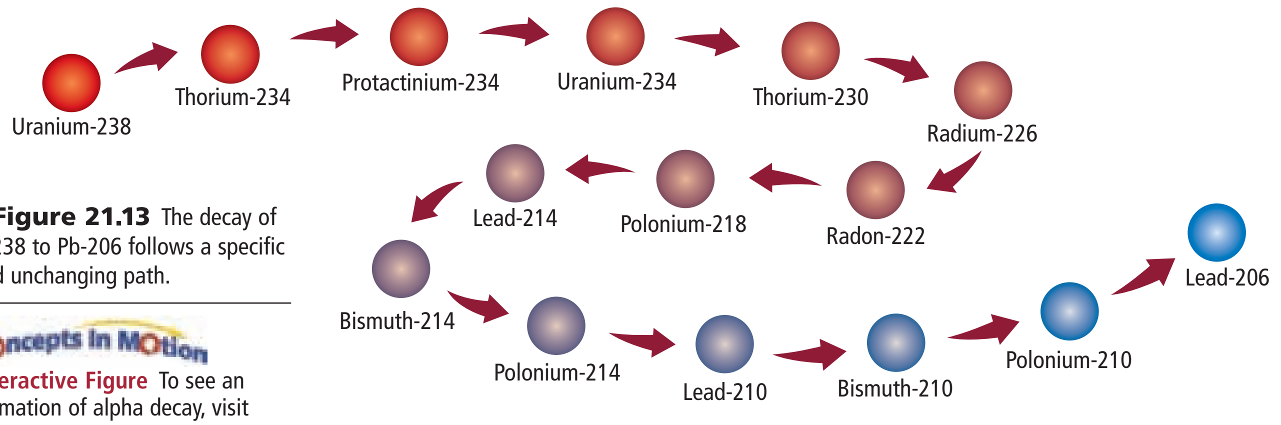
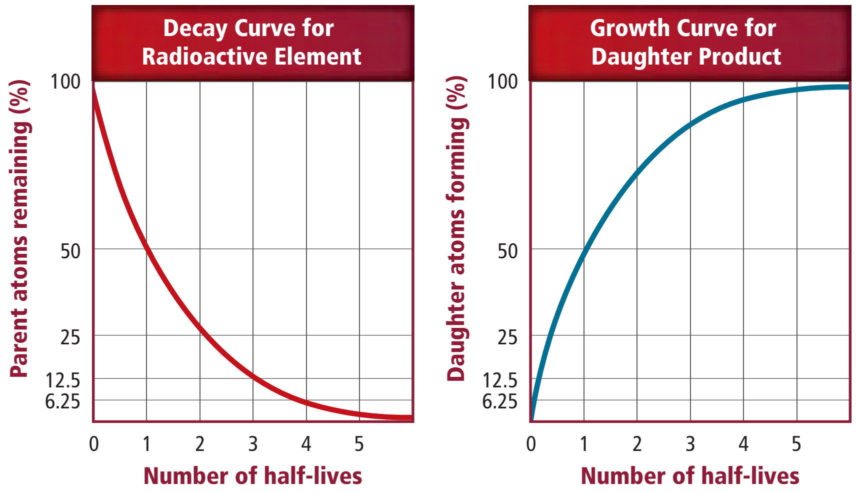


Figure 21.13 The decay of U-238 to Pb-206 follows a specific and unchanging path.

Concepts In Motion Interactive Figure To see an animation of alpha decay, visit glencoe.com.

■ **Figure 21.14** As the number of parent atoms decreases during radioactive decay, the number of daughter atoms increases by the same amount.
Interpret *What percentage of daughter isotope would exist in a sample containing 50 percent parent isotope?*



Radiometric Dating

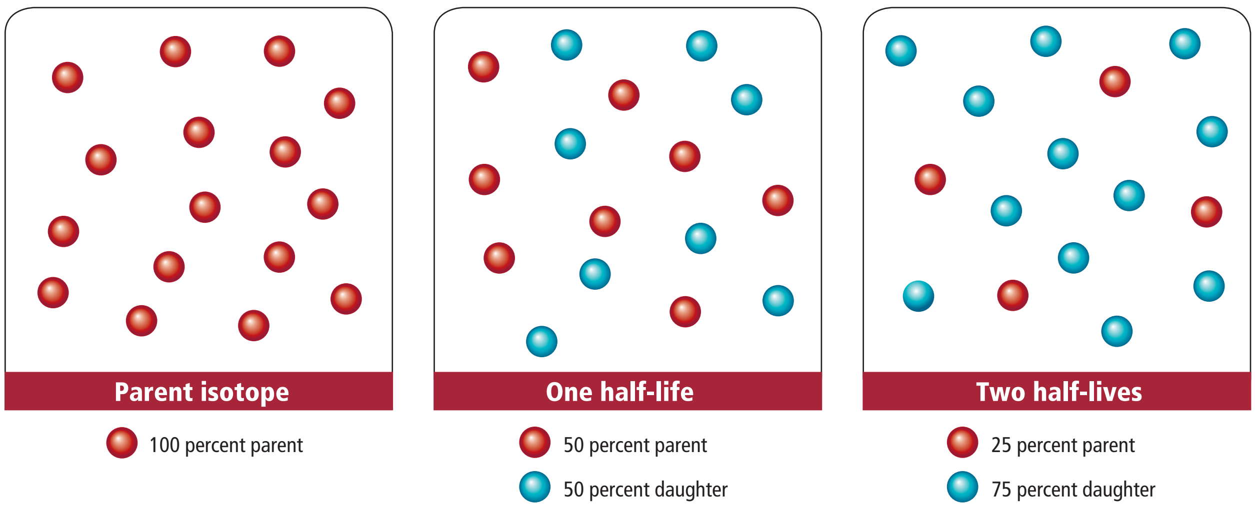
As the number of parent atoms decreases during radioactive decay, the number of daughter atoms increases, shown in **Figure 21.14.** The ratio of parent isotope to daughter product in a mineral indicates the amount of time that has passed since the object formed. For example, by measuring this ratio in the minerals of an igneous rock, geologists pinpoint when the minerals first crystallized from magma. When scientists date an object using radioactive isotopes, they are using a method called **radiometric dating.**

Half-life Scientists measure the length of time it takes for one-half of the original isotope to decay, called its **half-life.** After one half-life, 50 percent of the parent remains, resulting in a 1:1 ratio of parent-to-daughter product. After two half-lives, one-half of the remaining 50 percent of the parent decays. The result is 25:75 percent ratio of the original parent to the daughter product—a 1:3 ratio. This process is shown in **Figure 21.15.**

Concepts In Motion
Interactive Figure To see an animation of half-lives, visit glencoe.com.

■ **Figure 21.15** After one half-life, a sample contains 50 percent parent and 50 percent daughter. After two half-lives, the sample contains 25 percent parent and 75 percent daughter.

CLICK HERE



CLICK HERE

Table 21.1	Half-Lives of Selected Radioactive Isotopes	
Radioactive Parent Isotope	**Approximate Half-life**	**Daughter Product**
Rubidium-87 (Rb-87)	48.6 billion years	strontium-87 (Sr-87)
Thorium-232 (Th-232)	14.0 billion years	lead-208 (Pb-208)
Potassium-40 (K-40)	1.3 billion years	argon-40 (Ar-40)
Uranium-238 (U-238)	4.5 billion years	lead-206 (Pb-206)
Uranium-235 (U-235)	0.7 billion years	lead-207 (Pb-207)
Carbon-14 (C-14)	5730 years	nitrogen-14 (N-14)

Concepts In Motion
Interactive Table To explore more about radioactive decay visit glencoe.com.

Dating rocks To date an igneous or metamorphic rock using radiometric dating, scientists examine the parent-daughter ratios of the radioactive isotopes in the minerals that comprise the rock. **Table 21.1** lists some of the radioactive isotopes they might use. The best isotope to use for dating depends on the approximate age of the rock being dated. For example, scientists might use uranium-235 (U-235), which has a half-life of 700 million years, to date a rock that is a few tens of millions of years old. Conversely, to date a rock that is hundreds of millions of years old, scientists might use U-238, which has a longer half life. If an isotope with a shorter half-life is used for an ancient rock, there might be a point when the parent-daughter ratio becomes too small to measure.

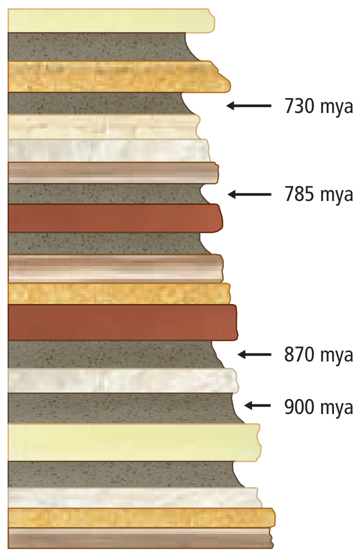
Radiometric dating is not useful for dating sedimentary rocks because, as you learned in Chapter 6, the minerals in most sedimentary rocks were formed from pre-existing rocks. **Figure 21.16** shows how geologists can learn the approximate age of sedimentary layers by dating layers of igneous rock that lie between them.

Reading Check **Explain** why radiometric dating is not useful for sedimentary rocks.

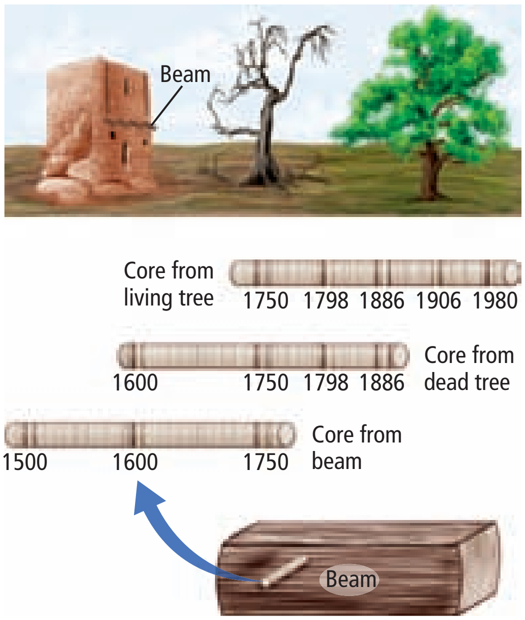
Radiocarbon dating Notice in **Table 21.1** that the half-life of carbon-14 (C-14) is much shorter than the half-lives of other isotopes. Scientists use C-14 to determine the age of organic materials, which contain abundant carbon, in a process called **radiocarbon dating.** Organic materials used in radiocarbon dating include plant and animal material such as bones, charcoal, and amber.

The tissues of all living organisms, including humans, contain small amounts of C-14. During an organism's life the C-14 decays, but is continually replenished by the process of respiration. When the organism dies, it no longer takes in C-14, so over time, the amount of C-14 decreases. Scientists can measure the amount of C-14 in organic material to determine how much time has passed since the organism's death. This method is particularly useful for dating recent geologic events for which organic remains exist.

Figure 21.16 To help them determine the age of sedimentary rocks, scientists date layers of igneous rock or volcanic ash above and below the sedimentary layers.



Radiometric Dating of Volcanic Ash



■ **Figure 21.17** Tree-ring chronologies can be established by matching tree rings from different wood samples, both living and dead. The science of using tree rings to determine absolute age is called dendrochronology.
Calculate ***the number of years represented in this tree-ring chronology.***

■ **Figure 21.18** Ice cores are stored in facilities such as the one in Denver, Colorado. Scientists use ice cores to date glacier deposits and to learn about ancient climates.

Other Ways to Determine Absolute Age

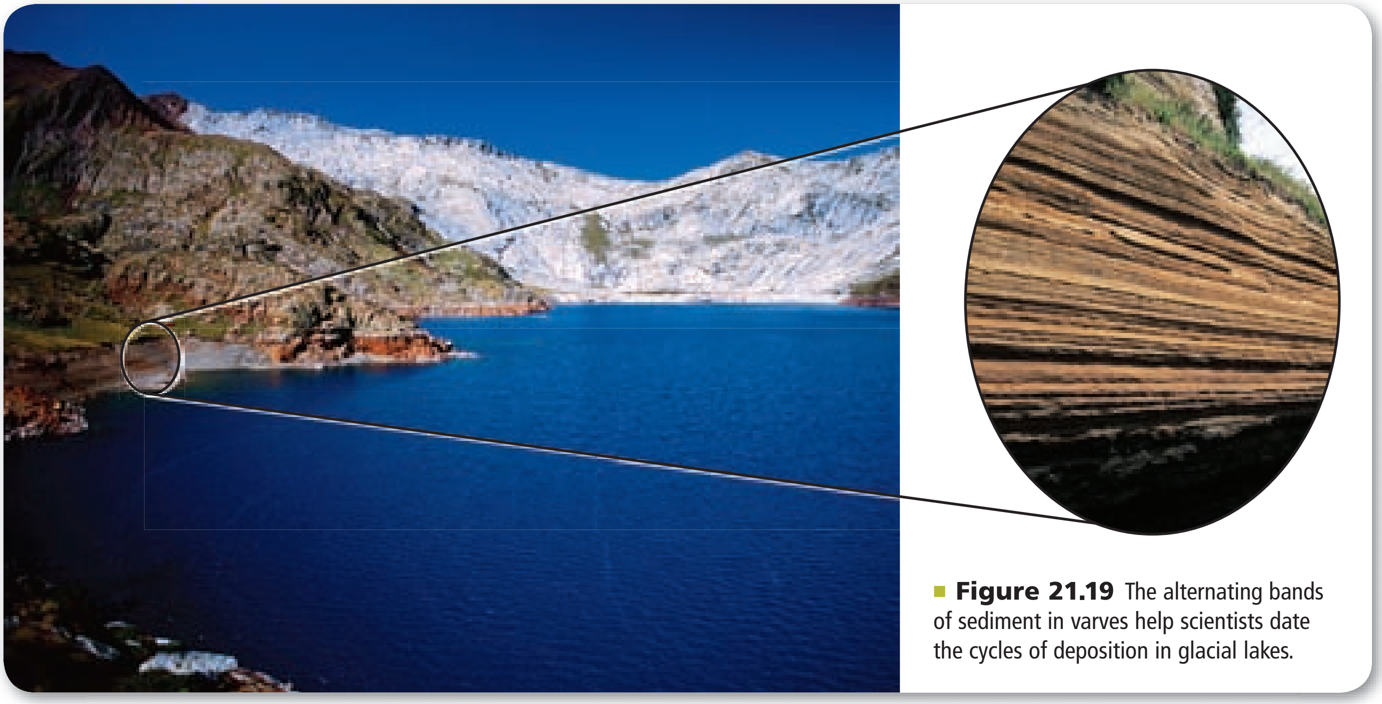
Radiometric dating is one of the most common ways for geologists to date geologic material. Many other dating methods are available. Geologists can also use other materials, such as tree rings, ice cores, and lake-bottom and ocean-bottom sediments, to help determine the ages of some objects or events.

Tree rings Many trees contain a record of time in the rings of their trunks. These rings are called annual tree rings. Each annual tree ring consists of a pair of early season and late season growth rings. The width of the rings depends on certain conditions in the environment. For example, when rain is plentiful, trees grow fast and rings are wide. The harsh conditions of drought result in narrow rings. Trees from the same geographic region tend to have the same patterns of ring widths for a given time span. By matching the rings in these trees, as shown in **Figure 21.17,** scientists have established tree-ring chronologies that can span time periods up to 10,000 years.

Reading Check **Describe** how tree rings can show past environmental conditions.

The science of using tree rings to determine absolute age is called dendrochronology and has helped geologists date relatively recent geologic events that toppled trees, such as volcanic eruptions, earthquakes, and glaciation. **Dendochronology** is also useful in archaeological studies. In Mesa Verde National Park in Colorado, archaeologists used dendrochronology to determine the age of the wooden rafters in the pueblos of the Anasazi, an ancient group of Native Americans. Also, dendrochronology provides a reliable way for geologists to confirm the results from radiocarbon dating.

Ice cores Ice cores are analogous to tree rings. Like tree rings, they contain a record of past environmental conditions in annual layers of snow deposition; summer ice tends to have more bubbles and larger crystals than winter ice. Geologists use ice-core chronologies to study glacial cycles through geologic history. The National Ice Core Facility in Colorado is one of several facilities around the world that store thousands of meters of ice cores from ice sheets, as shown in **Figure 21.18.** Because ice cores contain information about past environmental conditions, many scientists also use them to study climate change.



■ **Figure 21.19** The alternating bands of sediment in varves help scientists date the cycles of deposition in glacial lakes.

Varves Bands of alternating light- and dark-colored sediments of sand, clay, and silt are called **varves.** Varves represent the seasonal deposition of sediments, usually in lakes. Summer deposits are generally sand-sized particles with traces of living matter, compared to the thinner, fine-grained sediments of winter. Varves are typical of lake deposits near glaciers, where summer meltwaters actively carry sand into the lake, and little to no sedimentation occurs in the winter. Using varved cores, such as shown in **Figure 21.19,** scientists can date cycles of glacial sedimentation over periods as long as 120,000 years.

Section 21.3 Assessment

Section Summary

- Techniques of absolute-age dating help identify numeric dates of geologic events.
- The decay rate of certain radioactive elements can be used as a kind of geologic clock.
- Annual tree rings, ice cores, and sediment deposits can be used to date recent geologic events.

Understand Main Ideas

1. MAIN Idea **Point out** the differences between relative-age dating and absolute-age dating.
2. **Explain** how the process of radioactive decay can provide more accurate measurements of age compared to relative-age dating.
3. **Compare and contrast** the use of U-238 and C-14 in absolute-age dating.
4. **Describe** the usefulness of varves to geologists who study glacial lake deposits.
5. **Discuss** the link between uniformitarianism and absolute-age dating.

Think Critically

6. **Infer** why scientists might choose to use two different methods to date a tree felled by an advancing glacier. What methods might the scientists use?

MATH in Earth Science

7. A rock sample contains 25 percent K-40 and 75 percent daughter product Ar-40. If K-40 has a half-life of 1.3 billion years, how old is the rock?

Section 21.4

Objectives

- **Explain** methods by which fossils are preserved.
- **Describe** how scientists use index fossils.
- **Discuss** how fossils are used to interpret Earth's past physical and environmental history.

Review Vocabulary

groundwater: water beneath Earth's surface

New Vocabulary

evolution
original preservation
altered hard part
mineral replacement
mold
cast
trace fossil
index fossil

Fossil Remains

MAIN Idea Fossils provide scientists with a record of the history of life on Earth.

Real-World Reading Link Think about the last time you bought souvenirs while on a vacation or at an event. You might have brought back pictures of the places you saw or the people you visited, or you might have brought back objects with inscribed names and dates. Like souvenirs, fossils are a record of the past.

The Fossil Record

Fossils are the preserved remains or traces of once-living organisms. They provide evidence of the past existence of a wide variety of life-forms, most of which are now extinct. The diverse fossil record also provides evidence that species—groups of closely related organisms—have evolved. **Evolution** (eh vuh LEW shun) is the change in species over time.

When geologists find fossils in rocks, they know that the rocks are about the same age as the fossils, and they can infer that the same fossils found elsewhere are also of the same age. Some fossils, such as the radiolarian microfossils shown in **Figure 21.20,** also provide information about past climates and environments. Radiolarians are unicellular organisms with hard shells that have populated the oceans since the Cambrian Period. When they die, their shells are deposited in large quantities in ocean sediment called radiolarian ooze.

Petroleum geologists use radiolarians and other microfossils to determine the age of rocks that might produce oil. Microfossils provide information about the ages of rocks and can indicate whether the rocks had ever been subjected to the temperatures and pressures necessary to form oil or gas.

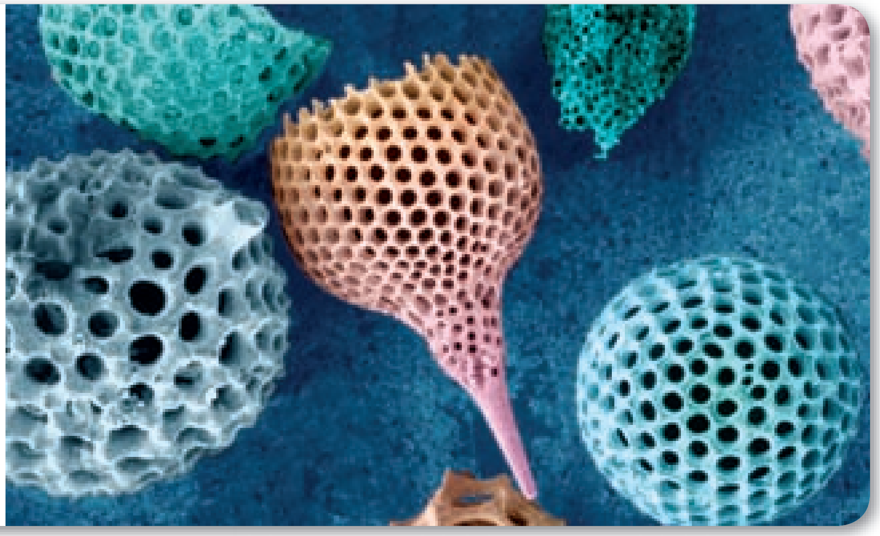


Figure 21.20 These tiny radiolarian microfossils—each no bigger than 1 mm in diameter—provide clues to geologists about ancient marine environments. This photograph is a color-enhanced SEM magnification at 80×.

Original preservation Fossils with **original preservation** are the remains of plants and animals that have been altered very little since the organisms' deaths. Such fossils are uncommon because their preservation requires extraordinary circumstances, such as either freezing, arid, or oxygen-free environments. For example, soft parts of mammoths are preserved in the sticky ooze of California's La Brea Tar Pit. Original woody parts of plants are embedded in the permafrost of 10,000-year-old Alaskan bogs. Tree sap from prehistoric trees sometimes hardens into amber that contains insects, as illustrated in **Figure 21.21.** Soft parts are also preserved when plants or animals are dried and their remains are mummified.

Original preservation fossils can be surprisingly old. For example, in 2005, a scientist from North Carolina discovered soft tissue in a 70-million-year-old dinosaur bone excavated in Montana. Scientists have since found preserved tissue in other dinosaur bones.

Figure 21.21 This insect was trapped in tree sap millions of years ago.

Reading Check **Explain** why fossils with original preservation are rare.

Altered hard parts Under most circumstances, the soft organic material of plants and animals decays quickly. However, over time, the remaining hard parts, such as shells, bones, or cell walls, can become fossils with **altered hard parts.** These fossils are the most common type of fossil, and can form from two processes.

Mineral replacement In the process of **mineral replacement,** the pore spaces of an organism's buried hard parts are filled in with minerals from groundwater. The groundwater comes in contact with the hard part and gradually replaces the hard part's original mineral material with a different mineral. A shell's calcite ($CaCO_3$), for example, might be replaced by silica (SiO_2). Mineral replacement can occur in trees that are buried by volcanic ash. Over time, minerals dissolved from the ash solidify into microscopic spaces within the wood. The result is a fossil called petrified wood, shown in **Figure 21.22.**

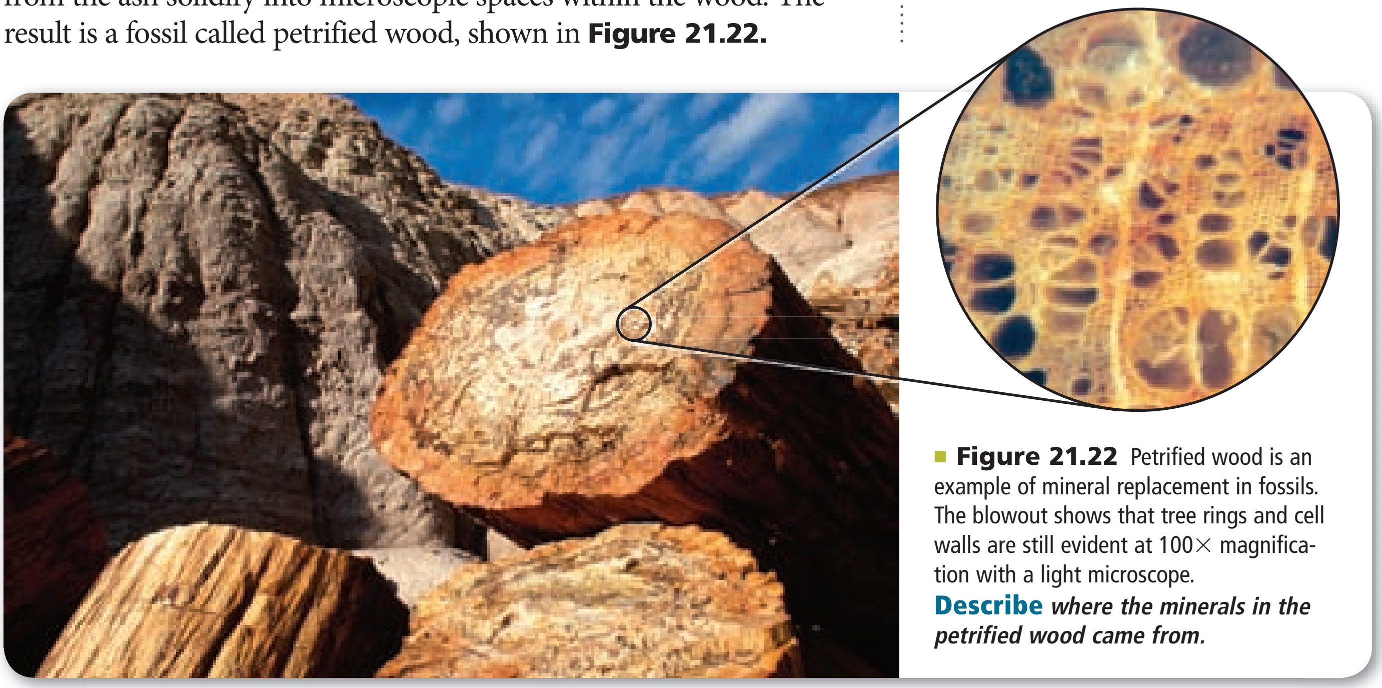
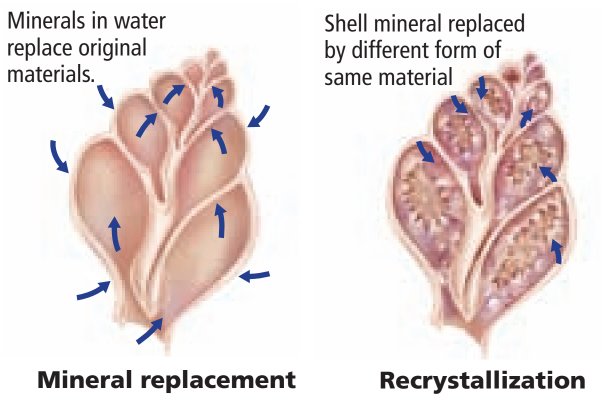
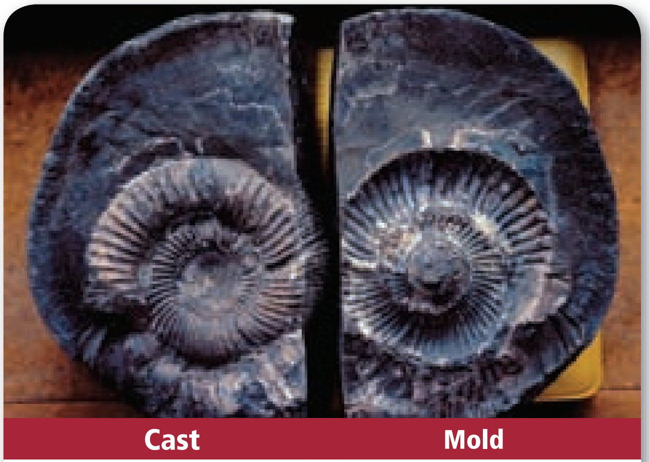


Figure 21.22 Petrified wood is an example of mineral replacement in fossils. The blowout shows that tree rings and cell walls are still evident at 100× magnification with a light microscope.
Describe *where the minerals in the petrified wood came from.*



■ **Figure 21.23** During mineral replacement, the minerals in a buried hard part are replaced by other minerals in groundwater. During recrystallization, temperature and pressure change the crystal structure of the hard part's original material.
Explain *why the internal structure of the shell changes during recrystallization.*



■ **Figure 21.24** A mold of this ammonite was formed when the dead animal's shell eroded. The cavity was later filled with minerals to create a cast.

Recrystallization Another way in which hard parts can be altered and preserved is the process of recrystallization (ree krihs tuh luh ZAY shun). Recrystallization can occur when a buried hard part is subjected to changes in temperature and pressure over time. The process of recrystallization is similar to that of mineral replacement, although in mineral replacement the original mineral is replaced by a mineral from the water, whereas in recrystallization the original mineral is transformed into a new mineral. A snail shell, for example, is composed of aragonite ($CaCO_3$). Through recrystallization, the aragonite undergoes a change in internal structure to become calcite, the basic material of limestone or chalk. Though calcite has the same composition ($CaCO_3$) as aragonite, it has a crystal structure that is more stable than aragonite over long periods of time. **Figure 21.23** shows how mineral replacement and recrystallization differ.

Reading Check **Compare and contrast** recrystallization and mineral replacement.

Molds and casts Some fossils do not contain any original or altered material of the original organism. These fossils might instead be molds or casts. A **mold** forms when sediments cover the original hard part of an organism, such as a shell, and the hard part is later removed by erosion or weathering. A hollowed-out impression of the shell, called the mold, is left in its place. A mold might later become filled with material to create a **cast** of the shell. A mold and a cast of a distinctive animal called an ammonite are shown in **Figure 21.24.**

Trace fossils Sometimes the only fossil evidence of an organism is indirect. Indirect fossils, called trace fossils, include traces of worm trails, footprints, and tunneling burrows. **Trace fossils** can provide information about how an organism lived, moved, and obtained food. For example, dinosaur tracks provide scientists with clues about dinosaur size and walking characteristics. Other trace fossils include gastroliths (GAS truh lihths) and coprolites (KAH pruh lites). Gastroliths are smooth, rounded rocks once present in the stomachs of dinosaurs to help them grind and digest food. Coprolites are the fossilized solid waste materials of animals. By analyzing coprolites, scientists learn about animal eating habits.

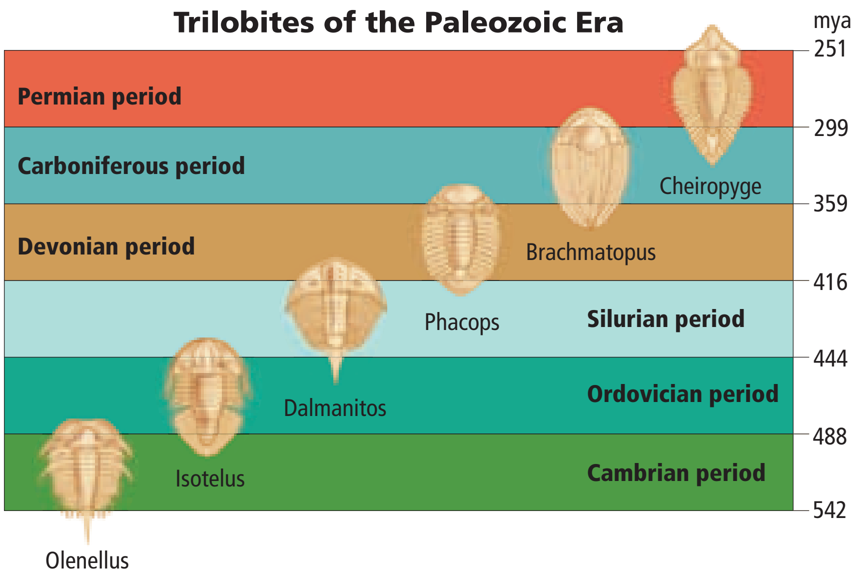


Figure 21.25 These trilobite species make excellent index fossils because each species lived for a relatively short period of time before becoming extinct.

Index Fossils

As you learned in the previous sections, fossils help scientists determine the relative ages of rock sequences through the process of correlation. Some fossils are more useful than others for relative-age dating. **Index fossils** are fossils that are easily recognized, abundant, and widely distributed geographically. They also represent species that existed for relatively short periods of geologic time. The different species of trilobites shown in **Figure 21.25** make excellent index fossils for the Paleozoic Era because each was distinct, abundant, and existed for a certain range of time. If a geologist finds one in a rock layer, he or she can immediately determine an approximate age of the layer.

Section 21.4 Assessment

Section Summary

- Fossils provide evidence that species have evolved.
- Fossils help scientists date rocks and locate reserves of oil, gas, and minerals.
- Fossils can be preserved in several different ways.
- Index fossils help scientists correlate rock layers in the geologic record.

Understand Main Ideas

1. MAIN Idea **Describe** how the fossil record helps scientists understand Earth's history.
2. **List** ways in which fossils can form, and give an example of each.
3. **Explain** how scientists might be able to determine the relative age of a layer of sediment if they find a fossilized trilobite in the layer.
4. **Compare and contrast** a mold and a cast.

Think Critically

5. **Evaluate** Why are the best index fossils widespread?

WRITING in Earth Science

6. Imagine that you have just visited a petrified forest. Write a letter to a friend describing the forest. Explain what the forest looks like and how it was fossilized.

EARTH SCIENCE AND TECHNOLOGY

DISCOVERING DINOSAUR TISSUES

Helicopters, explosives, and bulldozers are some of the tools paleontologists use to excavate and transport large dinosaur fossils. CT scans, microscopes, and computer modeling are among the latest technology used to analyze the soft tissues found recently in several dinosaur fossils.

Soft tissue During the summer of 2000, paleontologists digging in Montana uncovered a well-preserved hadrosaur, a type of plant-eating dinosaur that lived about 77 mya. The most exciting part of the discovery came when scientists realized that the fossil contained soft tissues including skin, muscle tissue on the shoulder, and tissue from the throat—a rare find. As the fossil was uncovered, scientists found well-preserved stomach contents which revealed that the dinosaur's last meal included ferns and magnolia leaves.

Bone tissue from *Tyrannosaurus rex* In 2003, the fossil of a small *T. rex* was discovered. After excavating it, scientists realized that it was too big to transport by helicopter. As a result, they carefully broke the thighbone into two pieces. Breaking a fossil is unusual because every effort is made to keep bones intact during the transport of a specimen. However, the break led to another surprise. The bone held preserved soft tissues including the connective tissue that makes up bone, blood vessels, and possibly even blood cells.

New technology for old questions Although other dinosaur specimens with soft tissue were discovered in the early twentieth century, the technology for preservation and analysis did not exist. These recent discoveries, coupled with modern technology, allow scientists new insights for answering old questions. Analysis of soft tissue could help scientists determine whether dinosaurs were warm-blooded or cold-blooded.

The soft tissue from the *T. rex* discovered in 2003 was almost perfectly preserved, and provides clues about how the dinosaur lived.

The tissues can give clues about a dinosaur's evolutionary relationship to modern species. Tissue analysis can also reveal more information about the diet of a species, which leads to more information about the environment at that time. For example, when the stomach contents of the hadrosaur were analyzed, scientists found over 36 types of pollen samples, including some from plants that could only survive in warm, humid conditions. Muscle tissue provides clues to scientists such as whether a dinosaur walked on two legs or four.

Further steps in the analysis of recently discovered fossils include performing a CT, which could give scientists a glimpse of the internal organs of a dinosaur, such as the heart, kidneys, and digestive system. Scientists might also extract DNA from the blood cells found in the tissues of the *T. rex's* thighbone. Information learned from these procedures could revolutionize our understanding of dinosaurs.

WRITING in Earth Science

Poster Make a poster that shows examples of the most recent dinosaur soft tissue discoveries and the types of information scientists can gather by analyzing them.
To learn more about recent dinosaur discoveries, visit glencoe.com.

GEOLAB

DESIGN YOUR OWN: INTERPRET HISTORY-SHAPING EVENTS

Background: **Volcanoes, earthquakes, mountain building, floods, and other geologic events affect the surface of Earth—and the life that inhabits it—in important ways. However, not all events affect Earth equally. Some events in Earth's history have been more critical than others in shaping Earth.**

Question: *What have been the most important events in Earth's history?*

The Sierra Nevadas that extend through California resulted from a series of Earth-shaping events.

Materials

list of Earth-shaping events found at glencoe.com or provided by your teacher
colored pencils
poster board
geologic time scale
reference books
internet access

Procedure

Imagine that NASA is planning to send a space probe to a distant galaxy. You are part of a team that has been assigned the task of listing the most important events that have shaped Earth's history. This list will be carried as part of the spaceship's payload. It will be used to help describe Earth to any possible residents of the galaxy.

1. Read and complete the lab safety form.
2. Form into groups. Each group should have three or four team members.
3. Obtain a list of Earth-shaping events from either glencoe.com or your teacher.
4. Choose two other resources where you can find at least ten more events to add to your list.
5. Brainstorm about the events that you think had the most impact on the direction that Earth's development has taken over time.
6. Discuss the best way to display your list.
7. Make sure your teacher approves your plan.
8. Put your plan into effect.

Analyze and Conclude

1. **Interpret Data** Plot your list on a copy of the geologic time scale. Compare the number of events in each era. Did more Earth-shaping events occur early in Earth's history or later on? Explain.
2. **Compare** your list with the lists of others in your class. What events do all lists share? Do these events share common features?
3. **Infer** Choose one event in the Mesozoic Era, and infer how Earth's history might have progressed had the event not occurred.
4. **Evaluate** How do extinction events influence the development of life on Earth?

SHARE YOUR DATA

Peer Review Visit glencoe.com and post a list of the ten most important events that you think shaped Earth's history. Compare your list with lists of other groups of students who have completed this lab.

CHAPTER 21

Study Guide

Download quizzes, key terms, and flash cards from glencoe.com.

BIG Idea Scientists use several methods to learn about Earth's long history.

Vocabulary	Key Concepts
Section 21.1 The Rock Record	
• eon (p. 592) • epoch (p. 593) • era (p. 593) • geologic time scale (p. 590) • mass extinction (p. 594) • period (p. 593) • Precambrian (p. 592)	**MAIN Idea** Scientists organize geologic time to help them communicate about Earth's history. • Scientists organize geologic time into eons, eras, periods, and epochs. • Scientists divide time into units based on fossils of plants and animals. • The Precambrian makes up nearly 90 percent of geologic time. • The geologic time scale changes as scientists learn more about Earth.
Section 21.2 Relative-Age Dating	
• correlation (p. 599) • cross-cutting relationship (p. 597) • key bed (p. 599) • principle of inclusion (p. 597) • original horizontality (p. 596) • relative-age dating (p. 596) • superposition (p. 596) • unconformity (p. 598) • uniformitarianism (p. 595)	**MAIN Idea** Scientists use geologic principles to learn the sequence in which geologic events occurred. • The principle of uniformitarianism states that processes occurring today have been occurring since Earth formed. • Scientists use geologic principles to determine the relative ages of rock sequences. • An unconformity represents a gap of time in the rock record. • Geologists use correlation to compare rock layers in different geographic areas.
Section 21.3 Absolute-Age Dating	
• absolute-age dating (p. 601) • dendrochronology (p. 604) • half-life (p. 602) • radioactive decay (p. 601) • radiocarbon dating (p. 603) • radiometric dating (p. 602) • varve (p. 605)	**MAIN Idea** Radioactive decay and certain kinds of sediments help scientists determine the numeric age of many rocks. • Techniques of absolute-age dating help identify numeric dates of geologic events. • The decay rate of certain radioactive elements can be used as a kind of geologic clock. • Annual tree rings, ice cores, and sediment deposits can be used to date recent geologic events.
Section 21.4 Fossil Remains	
• altered hard part (p. 607) • cast (p. 608) • evolution (p. 606) • index fossil (p. 609) • mineral replacement (p. 607) • mold (p. 608) • original preservation (p. 607) • trace fossil (p. 608)	**MAIN Idea** Fossils provide scientists with a record of the history of life on Earth. • Fossils provide evidence that species have evolved. • Fossils help scientists date rocks and locate reserves of oil, gas, and minerals. • Fossils can be preserved in several different ways. • Index fossils help scientists correlate rock layers in the geologic record.

CHAPTER 21

Assessment

Vocabulary Review

Match each definition with the correct vocabulary term from the Study Guide.

1. the record of Earth's history from its origin to the present
2. a gap in the rock record caused by erosion
3. the emission of radioactive isotopes and the resulting change into other products over time
4. the largest time unit in the geologic time scale
5. the matching of unique outcrops among regions

Distinguish between the vocabulary terms in each pair.

6. period, epoch
7. altered hard part, original preservation
8. absolute-age dating, relative-age dating
9. fossil, index fossil
10. mold, cast

The sentences below are incorrect. Make each sentence correct by replacing the italicized word or phrase with a term from the Study Guide.

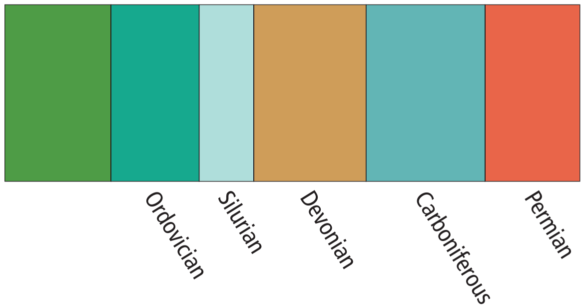
11. *Original horizontality* is the principle that a fault or intrusion is younger than the rock it intersects.
12. *Relative-age dating* states that processes operating today have been operating since Earth formed.
13. A *varve* is a sedimentary layer used to match rock layers across large areas.
14. *Correlation* is the change in species over time.

Understand Key Concepts

15. The end of which era is marked by the largest extinction event in Earth's history?
    A. Cenozoic
    B. Mesozoic
    C. Paleozoic
    D. Precambrian

16. How old is a mammoth's tusk if 25 percent of the original C-14 remains in the sample? The half-life of C-14 is 5730 years.
    A. 5730 years
    B. 11,460 years
    C. 17,190 years
    D. 22,920 years

Use the figure below to answer Question 17.



17. Which time period is missing in the diagram?
    A. Cambrian
    B. Permian
    C. Triassic
    D. Paleogene

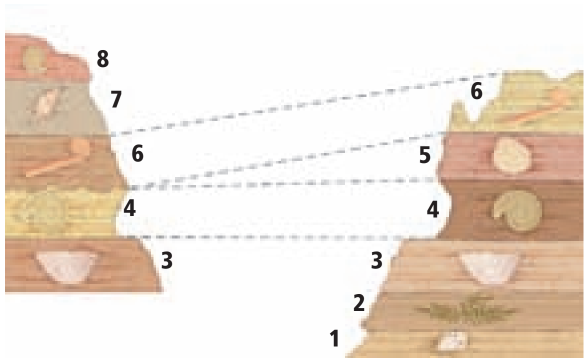
18. Which is not a typical characteristic of an index fossil?
    A. was commonplace while alive
    B. existed for a long period of time
    C. is geographically widespread
    D. is easily recognizable

19. Which is the smallest division of geologic time?
    A. period
    B. eon
    C. era
    D. epoch

20. Which geologic principle is used when a geologist observes an outcrop of rocks and determines that the bottom layer is the oldest?
    A. uniformitarianism
    B. original horizontality
    C. superposition
    D. inclusion

21. Uranium-238 breaks down into thorium-234. Which is thorium-234 in relation to uranium-238?
A. parent
B. brother
C. son
D. daughter

Use the figure below to answer Question 22.



22. What does the diagram show?
A. uniformitarianism
B. inclusion
C. cross-cutting relationships
D. correlation

23. Trees that have been buried by volcanic ash are likely to be preserved in which manner?
A. original preservation
B. mummification
C. mineral replacement
D. recrystallization

24. Which are glacial lake sediments that show cycles of deposition?
A. annual rings
B. tillites
C. varves
D. unconformities

Constructed Response

25. Sequence the steps by which a mold and a cast are formed.

26. Explain why mass extinctions are important to geologists.

27. Compare and contrast absolute-age dating and relative-age dating.

28. Assess the usefulness of a universally accepted geologic time scale.

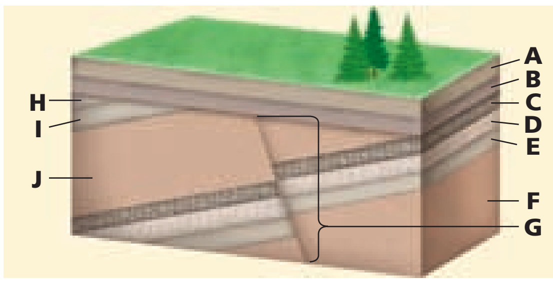
29. Explain, in your own words, why an unconformity is any gap in the rock record.

30. Argue for or against making the time units of the geologic time scale of equal duration.

31. Relate How are microscopic fossils associated with discovering oil at a particular site?

Think Critically

Use the diagram below to answer Questions 32 to 34.



32. Identify the oldest rock layer in the diagram.

33. Find an angular unconformity in the diagram.

34. Apply List the order of geologic events in the diagram from oldest to youngest along with the geologic principles that you used.

35. Critique this statement: The principles for determining relative age are based on common sense.

36. Create One way to remember the order of words in a sequence is to create a phrase, called an acrostic, that uses the same first letter of each word in the sequence. For example, "**M**y **D**ear **A**unt **S**ally" is often used to remember the mathematical order of operations: **M**ultiply and **D**ivide before you **A**dd and **S**ubtract. Create an acrostic to help you remember the periods of the Phanerozoic Eon.

Earth Science Online Chapter Test glencoe.com

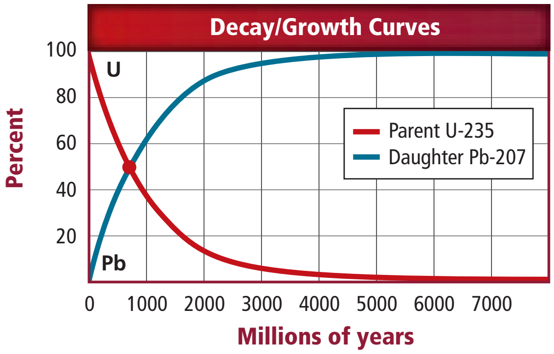
37. **Solve** The half-life of K-40 is 1.3 billion years. What is the age of an ancient igneous rock that contains a mineral with 12.5 percent K-40 and 87.5 percent Ar-40?

38. **Compare and contrast** an index fossil and a key bed.

39. **Assess** whether a clam or a spider has a better chance at becoming a fossil.

40. **Evaluate** Can radiocarbon dating be used to determine the age of a dinosaur bone? Explain.

Use the diagram below to answer Question 41.



41. **Analyze** What does the red dot signify on the graph?

42. **CAREERS IN EARTH SCIENCE** A geologist discovers wood buried within sediments of a landslide that is thought to have been caused by an ancient earthquake. Explain two methods that the geologist could use to determine when the earthquake occurred.

Concept Mapping

43. Create a concept map using the following terms: *absolute-age dating, geologic time scale, relative-age dating, fossils, unconformities,* and *radiometric dating.*

Challenge Question

44. **Assess** Do you think domestic dogs might make good index fossils for future geologists? Explain.

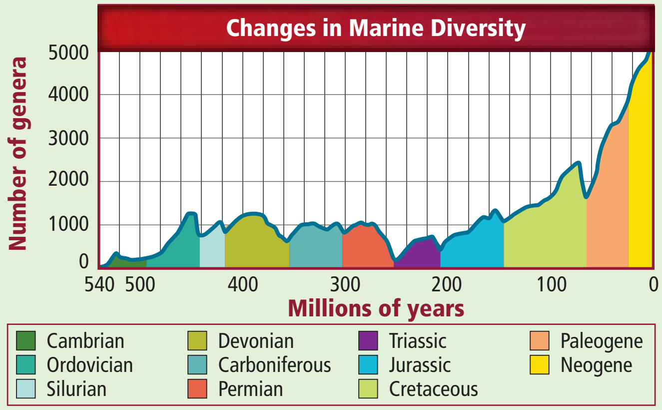
Additional Assessment

45. **WRITING in Earth Science** Imagine that you are a bacterium that lives for only 20 minutes. Explain how your observations about the world would be different from those of a human being who lives for about 80 years. Evaluate the difference between human time and geologic time.

DBQ Document–Based Questions

Data obtained from: Bambach, R.K., et al. 2004. Origination, extinction, and mass depletion of marine diversity. *Paleobiology* 30: 522–542.

The figure below plots the diversity, measured as the number of different types, of marine animals throughout the Phanerozoic. The animals are grouped into levels of organization called genera that include closely related species. Use the data to answer the questions below.



46. With what do the largest drops in diversity coincide on the geologic time scale?

47. Explain what the decreases in diversity mean.

48. Use the information in the graph to support adding one or more new eras to the Phanerozoic.

Cumulative Review

49. What subatomic particles make up the nucleus of an atom? **(Chapter 3)**

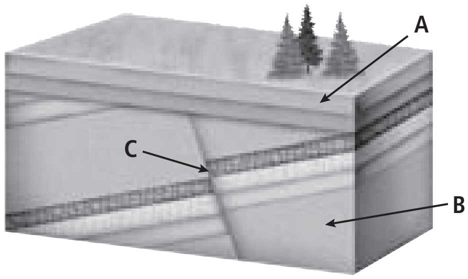
50. Why do tornadoes occur most frequently in the central United States? **(Chapter 13)**

Standardized Test Practice

Multiple Choice

1. Which type of mountains form as the result of uplift far from plate boundaries?
   A. ocean ridges
   B. fault block mountains
   C. folded mountains
   D. volcanic ranges

Use the diagram below to answer Questions 2 and 3.



2. Which principle for determining relative age is relevant to Point A in this diagram of a rock region?
   A. the principle of original horizontality
   B. the principle of superposition
   C. the principle of cross-cutting relationships
   D. the principle of uniformitarianism

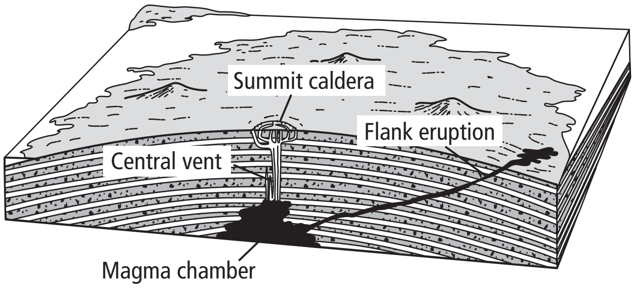
3. Which principle is relevant to Point C in this diagram?
   A. the principle of original horizontality
   B. the principle of superposition
   C. the principle of cross-cutting relationships
   D. the principle of uniformitarianism

4. What aspect of the discovery of ocean ridges was important in the scientific community?
   A. their location
   B. their volcanic activity
   C. their height
   D. their age

5. Which is not a factor affecting the formation of magma?
   A. time
   B. temperature
   C. pressure
   D. water

6. Earth's crust is broken up into a dozen or more enormous slabs called what?
   A. boundaries
   B. tectonic plates
   C. subduction zones
   D. subduction plates

Use the diagram below to answer Questions 7 and 8.



7. Which type of volcano is shown?
   A. cinder cone
   B. composite
   C. shield
   D. pyroclastic

8. What level of threat might the development of this volcano pose to humans?
   A. Low; it is built as layer upon layer and accumulates during nonexplosive eruptions.
   B. Low; it is considered to be an inactive volcano.
   C. Moderate; it forms when pieces of magma explode and build around a vent, but is rather small.
   D. High; it has a violently explosive nature.

9. What happened to the magnetic fields generated by magnetic rocks along the ocean floor?
   A. There were no reversals of the magnetic field along the ocean floor.
   B. Each side of an ocean ridge had its own magnetic pattern.
   C. Normal and reverse polarity regions formed stripes that ran perpendicular to ocean ridges.
   D. Normal and reverse polarity regions formed stripes that ran parallel to ocean ridges.

10. What does orogeny refer to?
    A. the drifting of microcontinents
    B. the building of mountain ranges
    C. the formation of volcanic islands
    D. the breaking apart of supercontinents

Short Answer

Use the map below to answer Questions 11–13.

11. According to the map, where was the epicenter of the earthquake located? How can the epicenter be determined?

12. Why is it important to use three stations to locate the epicenter of an earthquake?

13. How might this earthquake affect Los Angeles?

14. The Florida peninsula gets more thunderstorms than any other part of the United States. What geographic feature of Florida causes it to get so many thunderstorms? How does this feature allow thunderstorms to form?

15. Why is the Appalachian Mountain Belt divided into several regions?

16. Describe acid precipitation in terms of the pH scale and the reason for its pH value.

Reading for Comprehension

Dating Gold

The radioactive decay of metal inside South African gold nuggets helped scientists determine the origin of the world's largest gold deposit. The placer model indicates the gold is older than surrounding rock. The hydrothermal model indicates that the hot spring fluids deposited the gold inside the rocks. It was decided to determine the age of the gold itself. If the gold is older than the rocks in which it is found, then the rocks must have built up around the gold, bolstering the placer model. If the gold is younger than the rocks, that means it must have seeped in with fluids, supporting the hydrothermal model. Two elements found inside gold, rhenium and osmium, serve as a radioactive clock. Rhenium decays into osmium over very long spans of time—it takes about 42.3 billion years for half of a sample of rhenium to transmute. By dissolving gold grains in acid and measuring the ratio of rhenium to osmium, scientists can determine the gold's age. Gold from places in the Rand is three billion years old—a quarter of a billion years older than its surrounding rock, thus supporting the placer model.

Article obtained from: Choi, C. 2002. Origin of world's largest gold deposit found? *United Press International Science News* (September): 1-2.

17. What is the half-life of rhenium?
    A. 42.3 years
    B. 42.3 thousand years
    C. 42.3 million years
    D. 42.3 billion years

18. Why was this study conducted?
    A. to determine the origin of the gold deposit
    B. to disprove the hydrothermal model
    C. to support the placer model
    D. to explain radioactive decay

NEED EXTRA HELP?																
If You Missed Question . . .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Review Section . . .	20.3	21.2	21.2	21.3	18.2	17.3	18.1	18.1	17.2	20.2	19.3	19.3	19.3	13.1	20.2	7.1