Unit 6

Geologic Time

Volcanic eruptions, glaciations, tectonic collisions and mountain building have all occurred many times in various places on Earth. What information do we have today that tells us of these events? The rocks themselves! It has been said that a picture tells a thousand words. The photograph at right is worth many more than that. Recorded in the rock layers is evidence of geologic events that have helped to shape Earth's history. Along with these dramatic events, countless species of plants and animals have appeared and disappeared. Fossils of these organisms are evidence of these occurrences. By studying the characteristics of layered rocks and the changes in life through time, geologists have been able to unravel Earth's history.

Unit Contents

NATIONAL GEOGRAPHIC

Go to the **National Geographic Expedition** on page 892 to learn more about topics that are connected to this unit.

Capital Reef National Park, Utah

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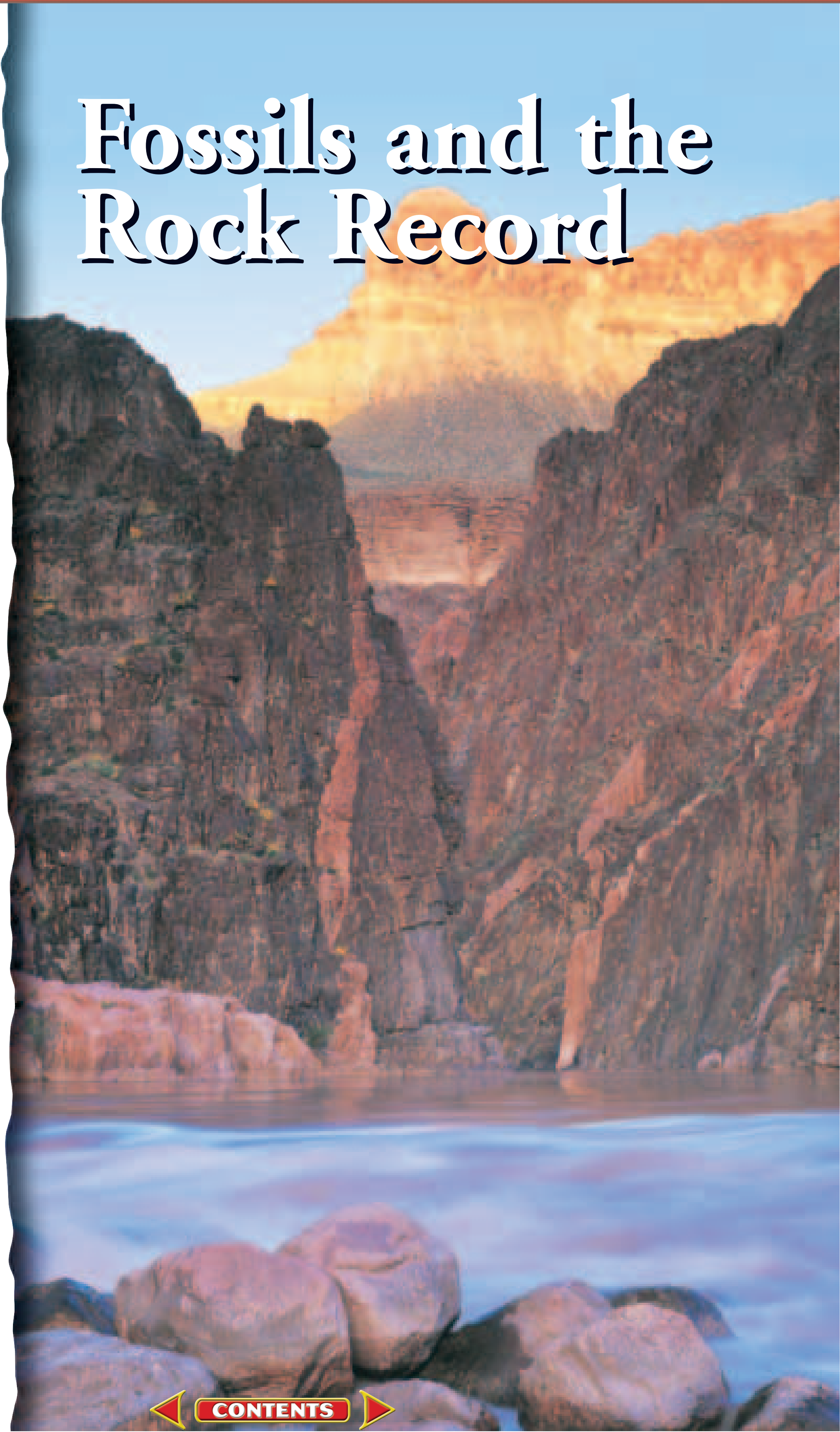
Chapter 21

Fossils and the Rock Record



What You'll Learn

- How geologists divide Earth's long history.
- How certain geologic principles can be used to interpret age relations in layered rocks.
- How different techniques to determine the ages of rocks are used.
- What fossils are, how they form, and how they are used to interpret Earth's history.

Why It's Important

Fossils and rocks contain a record of Earth's history and can be used to make predictions about Earth's future. Some fossils can help identify potential sites of energy resources.

Earth Science Online

To learn more about fossils and the rock record, visit the Earth Science Web Site at earthgeu.com

Discovery Lab

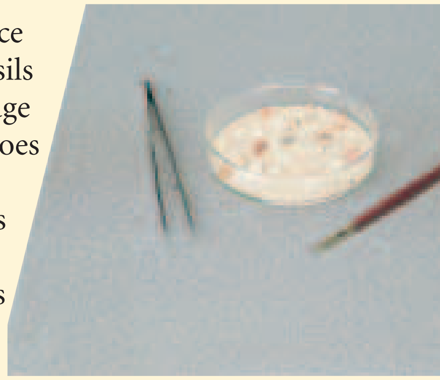
Fossil Hunt Activity

Have you ever found shells at a beach, along a river, or by a pond? If so, did you wonder where they came from or what type of animal might have lived in them? The shape, size, and composition of shells provide clues about the environment in which individual animals once lived. In this activity, you will make inferences about shells that you examine.

1. Obtain a mixture of sand and microfossils from your teacher.
2. Place the mixture on a petri dish or a small, shallow tray.
3. Use tweezers or a small, dry paint-brush to separate the fossils from the sandy sediment.
4. Categorize the fossils by shape, size, and composition.

CAUTION: Always wear safety goggles and an apron in the lab. Wash your hands when lab is completed.

Observe In your science journal, explain how fossils can help determine the age of sediment or a rock. Does categorizing the fossils provide any further clues about the environment in which the fossiliferous sediment formed? Explain.



Section 21.1 The Geologic Time Scale

OBJECTIVES

- **Describe** *the geologic time scale.*
- **Distinguish** *among the following geologic time scale divisions: eon, era, period, and epoch.*

VOCABULARY

geologic time scale
eon
era
period
epoch

A hike down the Kaibab Trail in the Grand Canyon reveals the multicolored layers of rock that make up the canyon walls. These layers, or strata, are made of different types of sedimentary rock. Some of the rock layers have fossils in them. At the bottom of the Grand Canyon, is the Colorado River, which has been cutting downward through the rocks of the canyon for millions of years. Also at the bottom are rocks that date back 400 million years or more. These rocks record the many advances and retreats of oceans and the development of plants and animals. By studying the characteristics of rocks and the fossils within them, geologists can interpret the environments the rocks were deposited in, reconstruct Earth's history, and possibly predict events or conditions in the future.

The Rock Record

To help in the analysis of Earth's rocks, geologists have divided the history of Earth into time units based upon the fossils contained

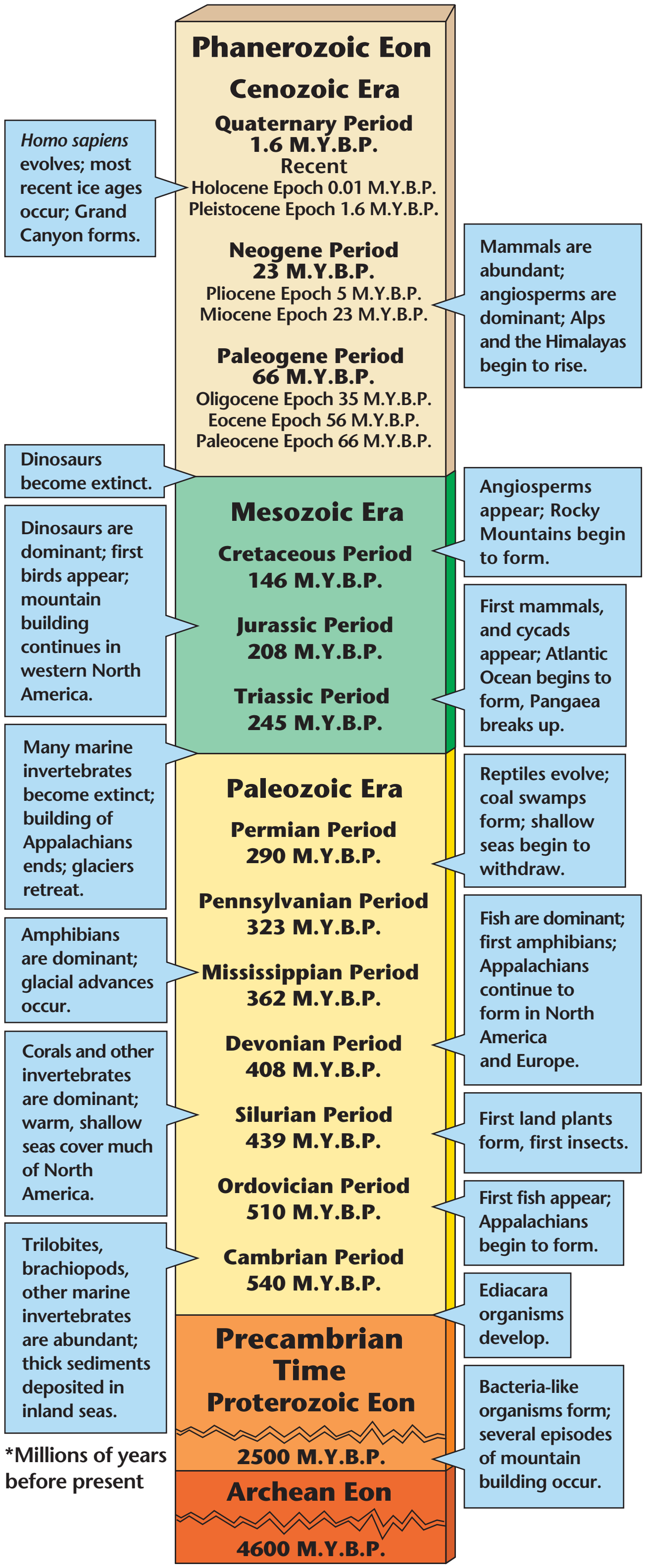


Figure 21-1 Earth's long history is divided into specific units of time in the geologic time scale.

within the rocks. These time units are part of the **geologic time scale,** a record of Earth's history from its origin 4.6 billion years ago to the present. Since the naming of the first geologic time period, the Jurassic, in 1797, development of the time scale has continued to the present. The names of the periods do not change, but the years marking the beginning and end of each unit of time are continually being refined. The geologic time scale is shown in ***Figure 21-1.*** This scale enables scientists from around the world to correlate the geologic events, environmental changes, and the development of life-forms that are preserved in the rock record.

GEOLOGIC TIME

The oldest division of time is at the bottom of the geologic time scale. Moving upward on the scale, each division is younger, just as the rock layers in the rock record grow generally younger as you move upward. The time scale is divided into units called eons, eras, periods, and epochs. An **eon** is the longest time unit and is measured in billions of years. The Archean, the Proterozoic, and the Phanerozoic are eons. An **era** is the next-longest span of time; it is measured in hundreds of millions to billions of years. Eras are defined by the differences in life-forms found in rocks; the names of 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, and thus *Mesozoic* means "middle life." Precambrian Time, which makes up approximately 90 percent of geologic time, is divided into the Archean and Proterozoic Eons. The Proterozoic is the more recent of the two, and the end of it is marked by the first appearance of organisms with hard parts. All life-forms up until then had soft bodies and no shells or skeletons. Some of these resembled organisms that exist today, such as sponges, snails, and worms, while others cannot be accurately assigned to any known animal or plant group.

Plants and Animals Evolve During the Paleozoic Era, the oceans became full of a wide diversity of plants and animals. Trilobites dominated the oceans in the Cambrian Period; land plants appeared and were followed by land animals; and swamps provided the plant material that became the coal deposits of the Pennsylvanian. The end of the Paleozoic Era is marked by the largest extinction event in Earth's history. As many as 90 percent of all marine invertebrate species became extinct. The era following the Paleozoic Era, the Mesozoic Era, is known for the emergence of dinosaurs, but other important developments occurred then as well. Reef-building corals and large predatory reptiles developed in the oceans. Amphibians began living on land as well as in water. Dinosaur populations began a slow decline in numbers throughout the Cretaceous Period as mammals evolved and grew in number. Flowering plants and trees evolved during the Cretaceous.

The end of the Mesozoic is also marked by a large extinction event. In addition to the remaining dinosaurs, many other groups of organisms, became extinct. Mammals increased both in number and diversity in the Cenozoic. Human ancestors developed at this time. Grasses and flowering plants expanded on land while ocean life remained relatively unchanged throughout this era.

Periods of Geologic Time **Periods** are defined by the life-forms that were abundant or became extinct during the time in which specific rocks were deposited. Periods are usually measured in terms of tens of millions of years to hundreds of millions of years. Some were named for the geographic region in which the rocks of that age were first observed, studied, and described. For example, the Mississippian Period was named for the distinctive limestone bluffs along the Mississippi River, as shown in ***Figure 21-2.*** The Jurassic Period was named for the rocks that were described in the Jura Mountains in Europe.

Figure 21-2 These Mississippian-aged limestone bluffs border the Mississippi River in Iowa.

NATIONAL GEOGRAPHIC

To learn more about dinosaurs and their evolution, go to the **National Geographic Expedition** on page 892.

Earth Science Online

Topic: Time Scales
To find out more about the geologic time scale, visit the Earth Science Web Site at earthgeu.com

Activity: Compare the span of time represented by the geologic time scale to the span of time represented by a 24-hour day. Apply the geologic time span to the 24-hour time span. How much time in a 24-hour day is represented by each era? Each period?

Figure 21-3 This fossil sycamore leaf is preserved in the Eocene-aged, Green River Formation in Wyoming.

Historically, the Cenozoic Era was divided into two periods, the Tertiary and the Quaternary. Currently, however, the Cenozoic is divided into three periods: the Paleogene, Neogene, and Quaternary. In contrast to the boundaries between the Paleozoic and the Mesozoic Eras, the boundaries between the periods of the Cenozoic are not marked by extinction events.

Epochs of Geologic Time **Epochs** are even smaller divisions of geologic time and are usually measured in millions of years to tens of millions of years. The fossil record of the Cenozoic Era is relatively complete because there has been less time for weathering and erosion to remove evidence of this part of Earth's history. Thus, rocks and fossils from this era are easily accessed and studied. Accordingly, the Cenozoic Periods have been further divided into epochs, such as the Paleocene and the Oligocene. Different groups of organisms have been used to distinguish the various epochs. For example, marine fossils were used to mark the Oligocene Epoch, and terrestrial plant fossils, such as those shown in ***Figure 21-3,*** were used to mark the Eocene Epoch.

Regardless of how a geologic period was defined, each unit contains specific characteristics that set it apart from the rest of geologic history. In the *Design Your Own GeoLab* at the end of this chapter, you will find out what makes each time unit unique.

Section Assessment

1. How did geologists determine the divisions of the geologic time scale?
2. What does the geologic time scale indicate about the change in life-forms over time?
3. What do the names of the three eras of the Phanerozoic mean?
4. What major change occurred in life-forms at the end of the Proterozoic?
5. How were the geologic time periods named? On what basis are they defined?
6. **Thinking Critically** Explain why the use of living faunas is acceptable for defining the periods and epochs of the Cenozoic Era.

Skill Review

7. **Graphing** Make a bar graph that shows the relative percentages of time that each period of the geologic time scale spans. For more help, refer to the *Skill Handbook.*

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SECTION 21.2 Relative-Age Dating of Rocks

As late as the turn of the nineteenth century, the majority of the world believed that Earth was only about 6000 years old. This age had been determined by Archbishop James Ussher of Ireland, who used a chronology of human and Earth history to calculate Earth's age. As early as 1770, James Hutton, a Scottish physician and geologist, had begun to observe and to attempt to explain Earth's landscapes. Hutton's observations in Great Britain helped him to develop the principle of uniformitarianism, which attempts to explain the forces that continually change the surface features of Earth. Such processes include mountain building, erosion, earthquakes, and sea-level changes. The principle of **uniformitarianism** states that the processes occurring today have been occurring since Earth formed. Only the rate, intensity, and scale with which they occur have changed. For example, if you stand on the shore of an ocean watching the waves come in, you are observing a process that has not changed since the oceans were formed. The waves crashing on a Cambrian shore, a Jurassic shore, and a modern shore all share the same process. The resulting sediments and rocks all record a beach environment, where the sediments become finer with distance from shore and the fossils within the rocks preserve evidence of the lifeforms that lived during the time of deposition.

OBJECTIVES

- **Apply** *the principles for determining relative age to interpret rock sequences.*
- **Describe** *an unconformity and how it is formed within the rock record.*

VOCABULARY

uniformitarianism
original horizontality
superposition
cross-cutting relationships
unconformity
correlation

PRINCIPLES FOR DETERMINING RELATIVE AGE

The concept of relative-age dating places the ages of rocks and the events that formed them in order, but without exact dates. This is done by comparing one event or rock layer to another.

Figure 21-4 The Colorado River, in Grand Canyon National Park, has cut through rock layers that span the Triassic through the Precambrian.

MiniLab

How is relative age determined?

Demonstrate how the principles of superposition, original horizontality, and cross-cutting relationships are used to determine the relative ages of rock layers.

Procedure

1. Draw a diagram of an outcrop with four horizontal layers. Label the layers 1 through 4.
2. Draw a vertical intrusion from layer 1 to layer 3.
3. Label the bottom-left corner of the diagram *X* and the top-right corner *Y.*
4. Cut the paper diagonally from *X* to *Y*. Move the left-hand piece 1.5 cm along the cut.

Analyze and Conclude

1. How can you determine the relative ages of the strata in your diagram?
2. How does the principle of cross-cutting relationships explain the age of the vertical intrusion?
3. What does line XY represent? Is line XY older or younger than the vertical intrusion and surrounding strata? Explain.

Geologic Principles Many different horizontal or nearly horizontal layers of rocks make up the walls of the Grand Canyon, shown in ***Figure 21-4.*** Most of the rocks are sedimentary and were originally deposited millions of years ago by water or wind. The principle of **original horizontality** states that sedimentary rocks are deposited in horizontal or nearly horizontal layers. While we may not know the actual ages of the rock layers, we can assume that the oldest rocks are at the bottom and that each successive layer going toward the top is younger. Thus, we can infer that the Moenkopi Formation, which rims the top of the Grand Canyon, is much younger than the Vishnu Group found at the bottom of the gorge as shown in ***Figure 21-5.*** This is an application of the principle of **superposition,** which states that in an undisturbed rock sequence, the oldest rocks are at the bottom and each successive layer is younger than the layer beneath.

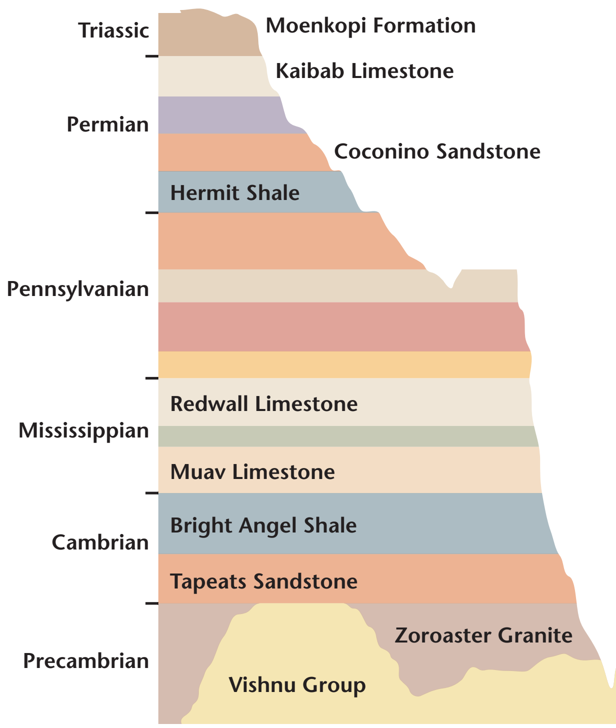


Figure 21-5 Using the principle of superposition, geologists have determined the relative ages of these rock layers.

Rocks exposed in the deepest part of the Grand Canyon are some of the oldest in North America. These are mostly igneous and metamorphic rocks. Within the Vishnu Group at the bottom of the Grand Canyon sequence are dikes of granite. The principle of **cross-cutting relationships** states that an intrusion or a fault is younger than the rock it cuts across. Therefore, the granite is younger than the schist, because the granite cuts across the schist. In earthquake-prone areas, such as California, and in ancient, mountainous regions, such as the Adirondacks of New York, there are many faults. As you learned in Chapter 20, a fault is a fracture in Earth along which movement takes place. A fault is younger than the strata and surrounding geologic features because it cuts across them. You used geologic principles to determine relative ages of rocks in the *MiniLab* on the previous page.

Inclusions Relative age also can be determined where an overlying rock layer contains particles of rock material from the layer beneath it. The bottom layer was eroded, and the loose material on the surface became incorporated in the newly deposited top layer. These particles, called inclusions, indicate that the rocks in the lower layer are older than those on top. As you learned in Chapter 6, once a rock has been eroded, the resulting sediment may be transported and redeposited and recemented many kilometers away. In this case, although this newly formed rock may be Jurassic in age, the grains that make up the rock may be Cambrian in age. Another example of the use of eroded sediments to determine the relative ages of rocks is a cooled lava flow that has bedrock particles trapped within it. An inclusion layer that is formed during a lava flow is illustrated in ***Figure 21-6.***

Other Means of Determining Relative Age

The fact that Earth is constantly changing as a result of processes such as weathering, erosion, earthquakes, and volcanism makes it difficult to find an undisturbed sequence of rock layers. For example, if rocks that record a volcanic eruption or the last occurrence of a particular fossil are eroded away, then the record of that particular

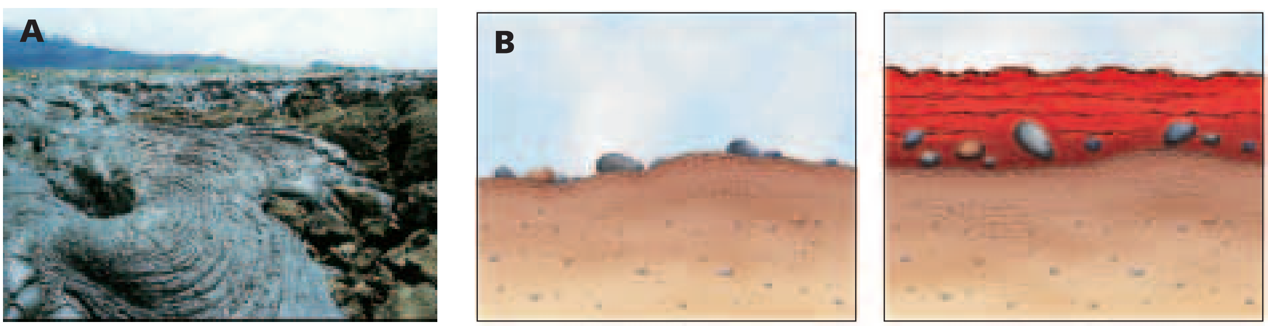


Figure 21-6 This pahoehoe lava flow in Hawaii most likely contains pieces, or inclusions, of the aa lava flow beneath it **(A).** When lava or sediments are deposited on top of an eroded surface that contains loose fragments, the fragments become incorporated as inclusions in the top layer **(B).**

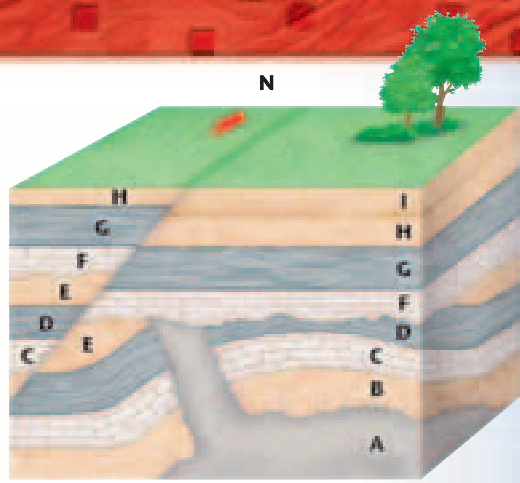
event has been lost. Further changes may occur if the area is covered by a river during a flood or by the sea. Additionally, an erosional surface might become buried by the deposition of younger rocks. This buried erosional surface results in a gap in the rock record and is called an **unconformity.** When horizontal sedimentary rocks overlie horizontal sedimentary rocks, the unconformity is called a disconformity. A different type of unconformity exists when sedimentary rocks overlie nonsedimentary rocks such as granite or marble. Such an unconformity suggests a possible uplifting of the marble or granite and exposure at the surface by weathering and erosion. The contact point between the nonsedimentary and sedimentary rock is called a nonconformity. The formation of unconformities are illustrated in ***Figure 21-7*** on the following page.

When horizontal sedimentary rocks are uplifted and tilted, they are exposed to the processes of weathering and erosion. When deposition resumes, horizontal layers of sedimentary rocks are laid down on top of the erosional surface. The layers beneath the eroded surface of the folded layers remain intact, but they are at an angle to the eroded surface. This type of unconformity is called an angular unconformity. You will use several geologic principles to interpret the geologic history of an area in the *Problem-Solving Lab* on the this page.

Problem-Solving Lab

Interpreting Diagrams

Interpret the relative ages of rock layers Use the diagram to answer the following questions.



Analysis

1. Which is the oldest rock unit in the diagram?
2. An unconformity exists between which two layers of rock? Explain.
3. What happened to the rock that came in contact with the molten material of the intruded dike?
4. Explain why the rock layers and features on the left side of the diagram do not match the rock layers and features on the right side.

Thinking Critically

5. Which is the younger feature in the outcrop, the dike or the folded strata? Explain.
6. List the order of geologic events represented by this diagram. Which geologic principles did you use?

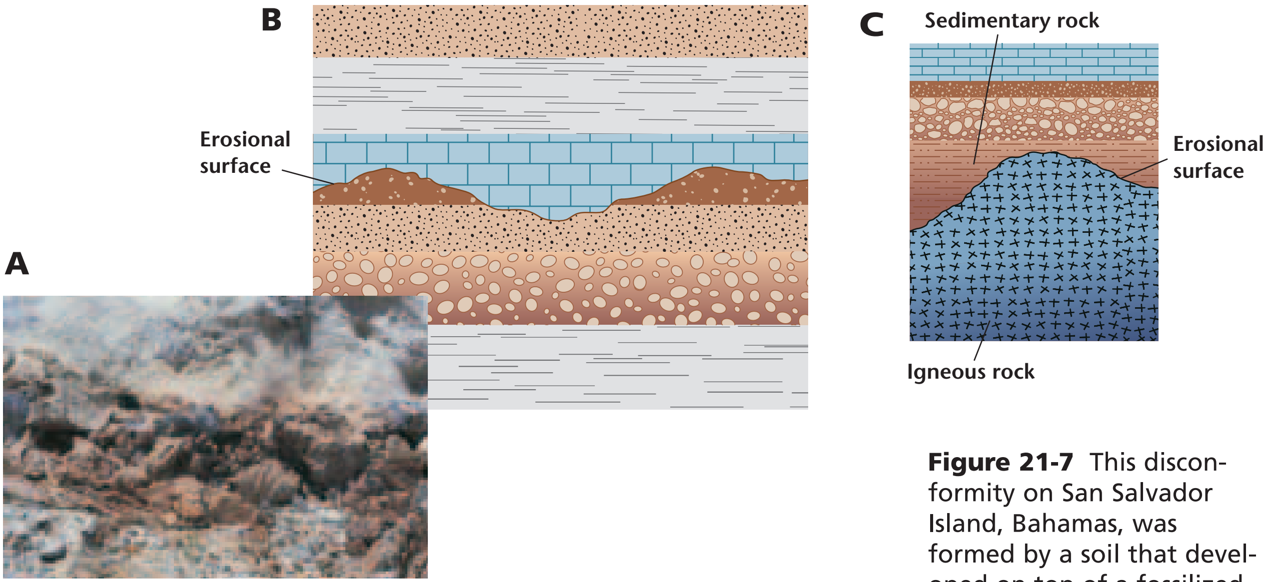


Figure 21-7 This disconformity on San Salvador Island, Bahamas, was formed by a soil that developed on top of a fossilized coral reef **(A).** A disconformity forms when a sedimentary rock layer is deposited on top of an eroded sedimentary rock layer **(B).** A nonconformity forms when a sedimentary rock layer is deposited on top of an eroded metamorphic or igneous rock layer **(C).**

Correlation of Rock Strata The Permian Kaibab Formation rims the top of the Grand Canyon, but is also found about 300 km away at the bottom of a 200-m gorge in Capitol Reef National Park in Utah. How do geologists match rock layers such as these, which are far apart from each other? One method is by correlation. **Correlation** is the matching of outcrops of one geographic region to another. Geologists examine rocks for distinctive fossils and unique rock or mineral features to help correlate the rock layers. This information can be used to help in the exploration for oil or valuable minerals. For example, if a sandstone layer in one area contains oil, it is possible that the same layer in a different area also contains oil. Correlation allows geologists to accurately locate that same sandstone layer in another location.

Section Assessment

1. How would a geologist use the principle of superposition to determine the relative ages of the rocks in the Grand Canyon?
2. What is an unconformity?
3. Explain how inclusions at the base of a lava flow can help determine the relative age of the layers.
4. A fault or a dike cuts across a sequence of rocks. What does this suggest about the relative ages of the rocks?
5. **Thinking Critically** Explain how the principle of uniformitarianism is used to interpret Earth's past.

Skill Review

6. **Interpreting Data** Discuss how a sequence of strata can be correlated from one side of a canyon to another. For more help, refer to the *Skill Handbook.*

SECTION 21.3 Absolute-Age Dating of Rocks

OBJECTIVES

- **Explain** *the several different methods used by scientists to determine absolute age.*
- **Describe** *how objects are dated by the use of certain radioactive elements.*
- **Explain** *how annual tree rings and glacial varves are used to date geologic events.*

VOCABULARY

radioactive decay
radiometric dating
half-life
dendrochronology
varve
key bed

As you have learned, relative-age dating is a method of comparing past geologic events based on the observed order of strata in the rock record. In contrast, absolute-age dating enables scientists to determine the actual age of a rock, fossil, or other object. Scientists have devised a method for dating very old objects using the decay rate of radioactive isotopes. These isotopes are found in igneous and metamorphic rocks, some fossils, and organic remains. Radioactive substances emit nuclear particles at a constant rate. As the numbers of protons and neutrons change with each nuclear emission, the element is converted to a different element. The original radioactive element is referred to as the "parent," and the new element is referred to as the "daughter." For example, a radioactive isotope of uranium, U-238, will decay into an isotope of lead, Pb-206, over a specific span of time, as illustrated in ***Figure 21-8.*** The emission of radioactive particles and the resulting change into other elements over time is called **radioactive decay.** Once the emission of these atomic particles begins, the rate remains constant regardless of environment, pressure, temperature, or any other physical changes. Thus, these atomic particles become accurate indicators of the absolute age of an object.

USE OF RADIOACTIVE ISOTOPES

In a process called **radiometric dating,** scientists attempt to determine the ratio of parent nuclei to daughter nuclei within a given sample of a rock or fossil. This ratio is then used to determine the absolute age of the rock or fossil. As the number of parent atoms decreases, the number of daughter atoms increases by the same amount and indicates the increasing age of an object. Because it often takes a long time for the entire amount of an isotope to decay, geologists use the length of time it takes for one-half of the original amount to decay. This

Figure 21-8 The decay of U-238 to Pb-206 follows a specific and never-changing path.

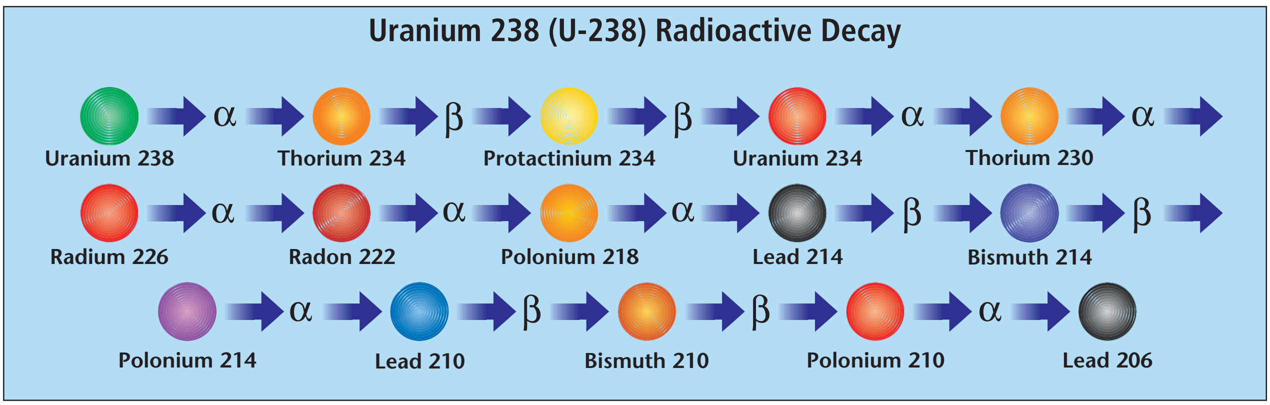


Table 21-1 Half-Lives of Selected Radioactive Isotopes		
Radioactive Isotope	**Approximate Half-Life**	**Decay Product**
Rubidium-87	48.6 billion years	Strontium-87
Thorium-232	14.0 billion years	Lead-208
Potassium-40	1.3 billion years	Argon-40
Uranium-238	4.5 billion years	Lead-206
Uranium-235	0.7 billion years	Lead-207
Carbon-14	5730 years	Nitrogen-14

period of time is called the **half-life.** ***Table 21-1*** lists some common radioactive isotopes and their half-lives.

Carbon-14 Another radioactive isotope that is commonly used to determine the absolute age of an object is carbon-14 (C-14). This isotope is especially useful for finding the age of materials that are of organic origin, such as amber, humanoid bones, papyrus, and charcoal fragments. This is because all organic materials contain carbon. C-14 decays into the stable, nonradioactive element nitrogen-14 (N-14). The half-life of C-14 is 5730 years, as shown in ***Table 21-2.*** When state-of-the-art technology is used, C-14 dating is accurate for objects up to 75 000 years old.

If U-238 is used for an object that is only a few hundred thousand years old, the ratio of parent to daughter atoms will be too large to be useful; therefore, a radioactive isotope with a shorter half-life than U-238, such as U-235, which has a half-life of 700 000 000 years, must be used. Conversely, for the dating of a particularly old rock sample, a radioactive isotope with a longer half-life must be used. Otherwise, there may come a point when the ratio of parent-to-daughter atoms is too small to measure but the age of the rock has not yet been determined. In essence, the isotope used for dating depends on the estimated general age of the rock or object being dated.

Using Math

Using Numbers A granite sample from Canada was dated using uranium-235, which has a half-life of 700 000 000 years. The rock was calculated to be 2.8 billion years old. How many half-lives have elapsed since the rock formed?

Table 21-2 Radioactive Decay of Carbon-14 to Nitrogen-14

	Percent Parent Element	Percent Daughter Element	Elapsed Years	Number of Half-Lives
Time 1	100	0	0	0
Time 2	50	50	5730	1
Time 3	25	75	11 560	2
Time 4	12.5	87.5	17 090	3

Update For an online update on the oldest rocks found to date, visit the Earth Science Web Site at earthgeu.com

OTHER WAYS TO DETERMINE AGE

Determining the relative or absolute age of an object or event is not limited to the use of rocks or chemical elements. Naturally occurring materials, such as trees, lake-bottom sediment, and volcanic ash can also be used to help geologists determine the age of an object or event, such as a forest fire, a drought, a flood, or a volcanic eruption.

Tree Rings With the use of a technique from the science of forestry, the age of a tree can be determined by counting the number of annual tree rings in a cross section of the tree. During the spring months, a tree experiences its greatest growth, while in the winter, its growth is less. Thus, the widths of tree rings are directly related to the climatic conditions during growth periods. A pair of spring and winter growth rings represents an annual tree ring. **Dendrochronology** is the science of comparing annual growth rings in trees to date events and changes in past environments. For example, in Mesa Verde National Park in Colorado, the age of the wooden rafters used to build the pueblos of the Anasazi have been determined with the use of dendrochronology. ***Figure 21-9*** shows a pueblo from Mesa Verde National Park. The Anasazi were a group of Native Americans that lived in the southwestern United States. It has been calculated by other methods, that the pueblos were built between A.D. 1150 and A.D. 1200. It also has been determined that pueblos in the southwestern United States were abandoned by the Anasazi around A.D. 1300, most likely because of a severe drought that lasted from A.D. 1276 to A.D. 1299.

Seasonal Climatic Changes About 11 000 years ago, continental glaciers covered the northern part of the United States. During the summer months, the ice would partially melt. Large volumes of water containing fine glacial sediment were carried downstream and deposited in large lakes. Summer deposits are generally light-colored and relatively thick compared to the thinner, organically enriched,

Figure 21-9 The Cliff Palace, in Mesa Verde National Park, was built by an ancient group of Native Americans known as the Anasazi.

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and dark-colored sediments of winter. These bands of alternating light- and dark-colored sediments of sand, clay, and silt are called **varves.** Varves are similar to tree rings in that they show evidence of cyclic events—in this case, a cycle of summer to winter. Varves from different lakes can be compared to determine the ages of glacial lake sediments from about 15 000 to 12 000 years ago.

Figure 21-10 This coal seam near Healy, Alaska can be used to correlate rock layers across a large area because it is exposed in many outcrops throughout the area.

Distinctive Sediment Layers Scientists hypothesize that about 66 million years ago, an asteroid 10 km in diameter struck Earth in the region known today as the Yucatan Peninsula in Mexico. The blast threw out large amounts of crushed rock into Earth's atmosphere. Much later, when the asteroid's impact debris settled onto the surface of Earth, it formed a sediment layer that can be found in many parts of the world today. This layer lies between rocks deposited at the end of the Cretaceous Period of the Mesozoic Era and the beginning of the Paleogene Period of the Cenozoic Era. These geologic time units are shown in ***Figure 21-1.*** When such a layer is formed by an instantaneous or short-lived event, geologists may be able to determine the time of the event through radiometric dating. The layer then becomes a time marker called a **key bed,** which can be used to correlate rock layers across large areas. Key beds, such as the black coal bed shown in ***Figure 21-10,*** contain material that is distinctive and easy to recognize in the rock record.

Volcanic eruptions also create key beds. For example, when Mount St. Helens erupted in 1980, vast amounts of volcanic ash were distributed over many states. The ash will eventually become a thin, clay layer and will mark the date of the eruption. Clay layers such as this one occur throughout the rock record and attest to Earth's volcanic history. You will learn more about this history in Chapter 22.

SECTION ASSESSMENT

1. What is the difference between relative-age dating and absolute-age dating?
2. A scientist finds the charred remains of a tree in a layer of volcanic ash thought to be from the eruption of Mt. Mazama some 6600 years ago. Which radioactive isotope, U-238 or C-14, would you use to verify the actual age of the charred wood? Explain.
3. What is a key bed?
4. **Thinking Critically** Potassium-40 decays to the noble gas argon-40. What problems might arise when these radioactive isotopes are used for age dating?

SKILL REVIEW

5. **Comparing and Contrasting** Compare and contrast the uses of tree rings and varves in relative-age dating. For more help, refer to the *Skill Handbook.*

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SECTION 21.4 Remains of Organisms in the Rock Record

OBJECTIVES

- **Define** *fossil.*
- **Explain** *several methods by which fossils can be preserved.*
- **Describe** *the characteristics of an index fossil.*
- **Discuss** *how fossils can be used to interpret Earth's past physical and environmental history.*

VOCABULARY

fossil
evolution
original preservation
altered hard part
permineralization
index fossil
mold
cast

Fossils are the evidence or remains of once-living plants or animals. They provide evidence of the past existence of a wide variety of life-forms, most of which have become extinct. The fossil record also provides evidence that populations have undergone change through time in response to changes in their environments. This change in populations as a result of environmental change is **evolution.** Fossils preserved in the rock record also provide information about past environmental conditions. They can even be used to correlate rock layers from one area to another.

TYPES OF FOSSILS

Fossils with **original preservation** are the soft and hard parts of plant and animal remains that have not undergone any kind of change since the organisms' deaths. Such fossils are uncommon because their preservation requires extraordinary circumstances such as freezing, drying out, or oxygen-free environments. In Alaska, original woody parts of plants are imbedded in the permafrost from 10 000-year-old bogs. Soft parts of mammoths and saber-toothed cats are preserved in the sticky ooze of the La Brea Tar Pits in California. Tree sap from prehistoric trees that hardened into amber sometimes has fossil insects imbedded in it. You will read about the recent discovery of a mammoth carcass that is at least 20 000 years old in the *Science in the News* feature at the end of this chapter. Soft parts are also preserved when plants or animals have been dried out and their remains have been mummified. Most mummified remains are found in dry caves or are buried in desert sands. For example, in 1935, the mummified remains of a Native American were found in Mammoth Cave National Park in Kentucky. ***Figure 21-11*** shows another fossil with original preservation.

Figure 21-11 The Graubelle man was found in 1952 in a bog in Jutland, Denmark. It dates from between A.D. 80 to 170 B.C. Fossils like these are called bog bodies.

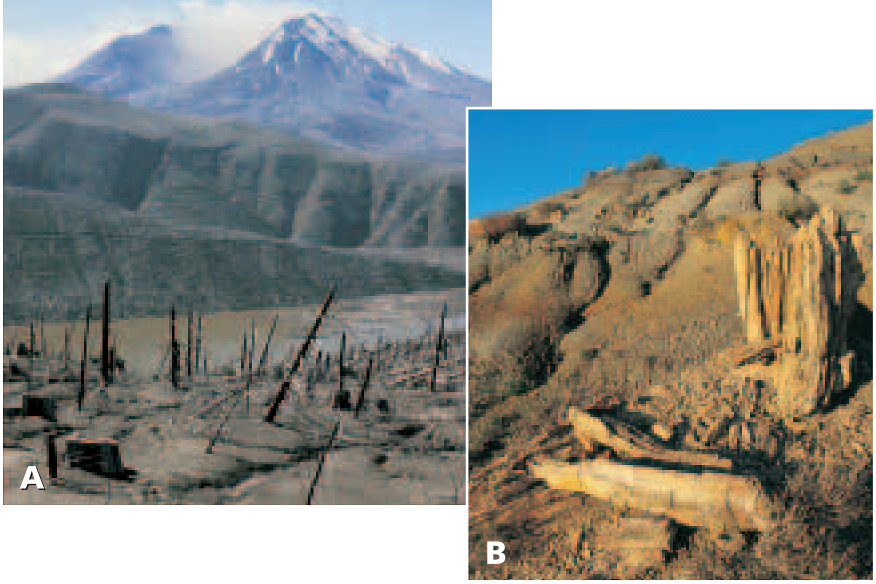
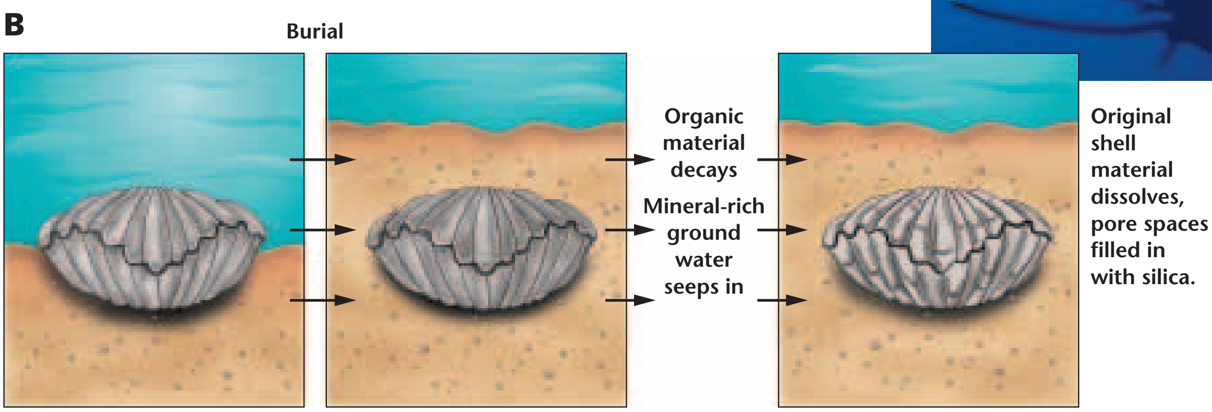


Figure 21-12 One year after the 1980 eruption of Mount St. Helens, in Washington State, these trees are slowly being converted to petrified wood **(A).** This petrified tree stump in Theodore Roosevelt National Park, North Dakota, stands as testimony to an ancient volcanic eruption **(B).**

Altered Hard Parts When all the organic material has been removed and the hard parts of a plant or animal have been changed either by mineral replacement or by recrystallization, their fossils are referred to as **altered hard parts.** The process by which pore spaces are filled in with mineral substances is called **permineralization.** For example, when volcanic ash spreads out and settles over a large geographic area, entire forests may become buried. Over a long period of time, quartz and other minerals in the ash combine with groundwater and slowly fill in the spaces between the cellular walls of the trees and silicify them. A common name for this type of fossilized tree is petrified wood. Modern and fossil examples are shown in ***Figure 21-12.*** Permineralization also occurs when groundwater combines with minerals in sediments. The mineral-rich water then reaches a buried organism and the replacement process begins, as illustrated in ***Figure 21-13.***

Changes in temperature and pressure may also result in changes in shell or bone material. Shells, such as those of clams, or exoskeletons, such as those of corals, may be affected by a process called recrystallization. The exterior of the shell remains the same, but the shell microstructures are destroyed during this process.

Figure 21-13 The shells of spectacularly preserved Brachiopods, such as this *Echinauris,* from Permian-aged rocks in the Glass Mountains of Texas, were replaced by silica during permineralization **(A).** This process is illustrated in **(B).**



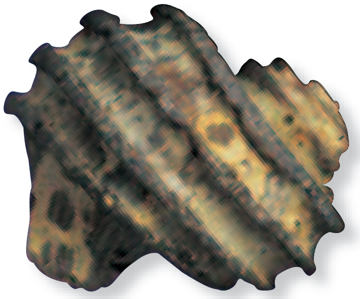


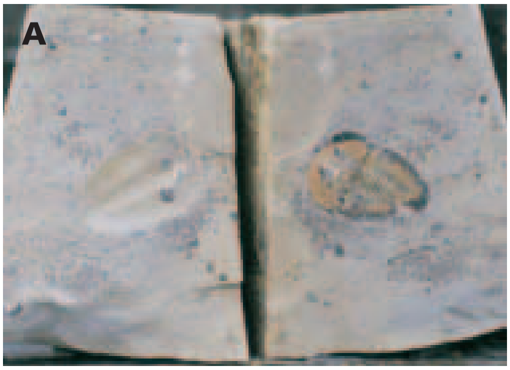
Figure 21-14 The characteristic shape of this mollusk, *Ecphora,* makes it easy to recognize and identify.

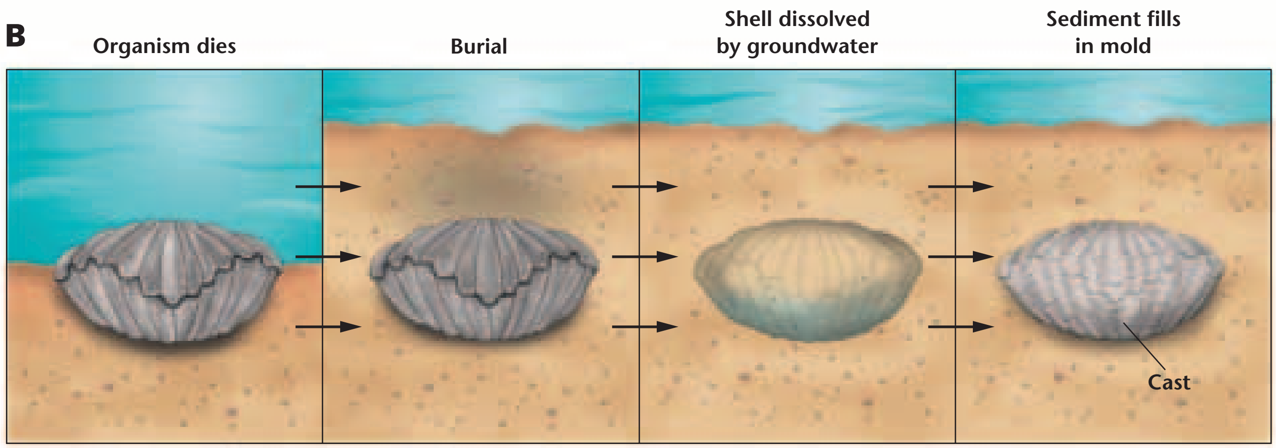
Index Fossils Some fossils are more useful than others in relative age dating. **Index fossils** are remains of plants or animals that can be used by geologists to correlate rock layers over large geographic areas or to date a particular rock layer. An index fossil is easily recognized, abundant, and widely distributed geographically. It must also have lived during a short period of time. For example, the mollusk *Ecphora,* shown in ***Figure 21-14,*** is an excellent index fossil for the Mesozoic because of its distinctive shape and its abundance.

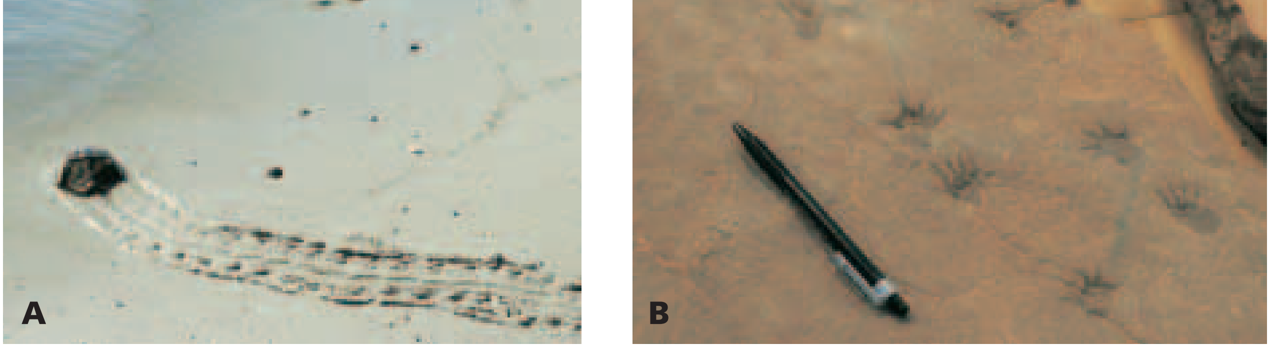
Molds and Casts Some fossils do not contain any shell or bone material. They may be molds and casts of shelled organisms, such as clams. A **mold** is formed when the original shell parts of an organism within a sedimentary rock are weathered and eroded. A hollowed-out impression, or mold, of the shells is left in their place. This cavity might later become filled with minerals or sediment to create a **cast** of the organism. A mold and cast are illustrated in ***Figure 21-15.***

Indirect Evidence of Past Life Indirect evidence of plant and animal life are called trace fossils. Some examples are worm trails, burrows, and footprints. Trace fossils such as those shown in ***Figure 21-16*** can provide information about how an organism lived, how it moved, or how it obtained food. Dinosaur trackways in Texas and Connecticut provide scientists with clues about the size and walking characteristics of dinosaurs. Other trace fossils include gastroliths, smooth and rounded rocks that dinosaurs had in their stomachs to help them digest and grind their food, and coprolites, the remains of solid waste materials of animals. By analyzing the content of coprolites, scientists can learn about the eating habits of ancient animals.

Figure 21-15 This mold and cast of the trilobite *Elrathia kingii,* from the Cambrian of Utah **(A),** shows the results of the process illustrated in **B.**







Why Study Fossils?

The study of fossils allows scientists to interpret and describe Earth's history. Fossils from different geologic time periods describe how organisms have changed through time. Fossils also show evidence of ancient environmental conditions. They also may help scientists find patterns and cycles that can be used to predict future phenomena, such as climatic changes. The study of fossils further allows geologists to locate energy resources. For example, petroleum geologists use certain index microfossils to determine whether oil might be present at a particular site. These fossils provide information about the ages of rocks and, in some cases, information that indicates whether the temperature and pressure conditions needed to form oil or gas were present in those layers.

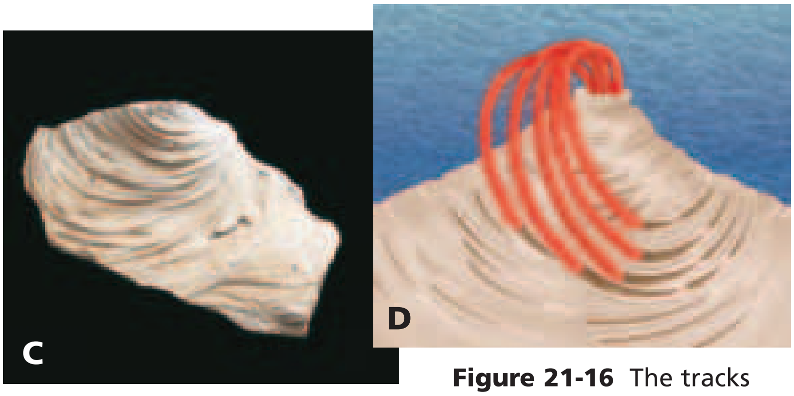


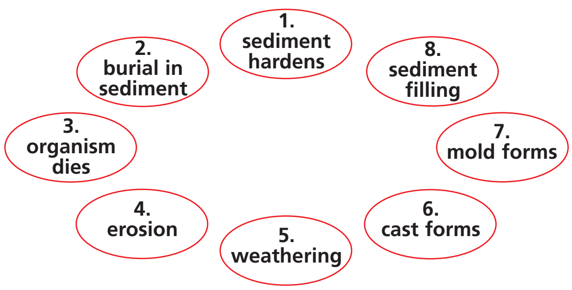
Figure 21-16 The tracks made by this horseshoe crab **(A)** may someday become preserved as did the tracks of this small Permian reptile **(B).** Zoophycus **(C)** is interpreted to be the feeding trace of a wormlike, burrowing organism **(D).** The sweeping lines are distinctive trace fossils.

Section Assessment

1. What is a fossil?
2. What is the difference between a fossil with original preservation and an altered hard part?
3. What are the characteristics of an index fossil?
4. Explain why the eruption of Mount St. Helens in 1980 resulted in the formation of a key bed.
5. **Thinking Critically** How might a mold or cast of a fossil help scientists to interpret the type of environment it lived in?

Skill Review

6. **Concept Mapping** Rearrange the following terms to construct a sequencing concept map to illustrate the formation of a mold and a cast. For more help, refer to the *Skill Handbook.*



DESIGN YOUR OWN GeoLab

Interpreting History-Shaping Events

What do volcanic eruptions, mountain building, flooding, and drought have in common? They are all events that in some way affect life and the surface of Earth. How strong an impact does each event have on the future of Earth? How different would things be if certain events in Earth's history had not happened?

Preparation

Problem

What are the most important events in Earth's history? Where do they fit in the long history of Earth's development? Why are these events important? Do some geologic time periods contain more history-shaping events than others?

Possible Materials

paper	colored pencils
pencil	geologic time scale
posterboard	calculator
meterstick	encyclopedia
tape measure	reference books

Hypothesis

Brainstorm about Earth's history and the changes that Earth has experienced over time. Hypothesize which events had the most impact on the direction that Earth's development has taken. Determine where additional data might be available and collect resources to use as your references. Describe the best way to list and illustrate your choices.

Objectives

In this GeoLab, you will:

- **Hypothesize** about important events in Earth's development.
- **Explain** why such events had a significant impact on Earth's history.
- **Communicate** your results and interpretations.

Plan the Experiment

1. Review the list of events in the table on the facing page.
2. As a group, decide on and make a list of events that you think can help support your hypothesis.
3. Choose two other resources and use them to find at least ten more events to add to your list.
4. Design and construct a way to exhibit and explain your results.
5. Check your plan. Make sure your teacher has approved your plan before you proceed.
6. Carry out your plan.

Analyze

1. **Interpreting Observations** Did more history-shaping events seem to have occurred early in Earth's history or later on? Explain.
2. **Comparing and Contrasting** Plot your list of events on a copy of the geologic time scale. Compare and constrast the number of events in each era. Does any geologic time period contain more history-shaping events than others? Explain.
3. **Observing and Inferring** Choose one event in the Mesozoic and infer how Earth's history might have progressed had the event not happened.

Conclude & Apply

1. How do extinction events influence the development of life on Earth?
2. How do mountain-building events and glaciations affect the development of life on Earth?
3. If another planet experienced the same events that you chose, would that planet be identical to Earth? What would be similar or different?

Earth History-Shaping Events

Origin of the solar system
Earth forms, 4.6 B.Y.B.P.
Oceans form, 4.0 B.Y.B.P
Primitive algae evolves, 3.3 B.Y.B.P
First fossil evidence of multicellular organisms, 1.2 B.Y.B.P.
Trilobites are abundant, algal reefs form, 600 M.Y.B.P.
First corals evolve, invertebrates dominate oceans, 500 M.Y.B.P.
First land plants evolve, insects appear, 440 M.Y.B.P.
Fishes are abundant, early amphibians evolve, 400 M.Y.B.P.
Forests that become coal swamps are present, 300 M.Y.B.P.
Earliest reptiles evolve, 300 M.Y.B.P.
Alleghenian Orogeny occurs, 270 M.Y.B.P.
Trilobites become extinct, 270 M.Y.B.P.
Earliest dinosaurs appear, 225 M.Y.B.P.
Pangaea breaks up, 225 M.Y.B.P.
Earliest mammals evolve, 200 M.Y.B.P.
Dinosaurs are abundant, 180 M.Y.B.P.
The first birds evolve, 180 M.Y.B.P.
Asteroid impact, 66 M.Y.B.P.
Modern groups of mammals appear, 60 M.Y.B.P.
Earliest horses evolve, 60 M.Y.B.P.
Large mammals evolve, 40 M.Y.B.P.
Carnivores abundant, 11 M.Y.B.P.
Adirondack mountains uplifted, 11 M.Y.B.P.
First humanoids evolve *(Australopithecus africanus),* 3 M.Y.B.P.
Ice Age of the Pleistocene begins, 1 M.Y.B.P.
Mammoths and mastodons are abundant, 1 M.Y.B.P.
Large ice sheets retreat ~ 10 000 years ago
Mount Vesuvius erupts and destroys Pompeii, A.D. 79
New Madrid Earthquake, 1811–1812
Chicago Fire, 1871
Krakatoa eruption in Java, 1883
Mt. St. Helens eruption in Washington, U.S., 1980

Science in the News

Frozen Mammoth

The sound of jackhammers echoed across the tundra. As a helicopter hovered nearby, the last few cuts were made into the permanently frozen ground. Many hours later, a cube of frozen earth weighing more than 26 metric tons went soaring across the Siberian steppe as it dangled from the bottom of the helicopter.

A chunk of tundra may not seem to be important, but this chunk found in 1997, contained a valuable prize: a complete specimen of a woolly mammoth that had died about 20 000 years ago and became buried in the permafrost. Many fossils represent only the partial remains of once-living organisms. Thus, a complete mammoth with bones, skin, hair, and internal organs intact represents a unique opportunity for scientists to investigate the lifestyle of this animal and the environment in which it lived.

The mammoth was a member of one of the great herds of the species *Mammuthus primigenius.* These herds roamed the vast grasslands of Siberia during the Pleistocene Epoch. The mammoths, cousins of today's elephants, were the largest land mammals ever. They ranged from 2.5 to 4.2 m high at the shoulder, had trunks and tusks like today's elephants, and were covered with thick hair for protection from the cold. This mammoth was a tusked male, about 3.5 m tall, and was about 47 years old when it died.

Solving the Mystery

The mammoth was flown to an ice cave near the town of Khatanga in Central Siberia, where scientists used hair dryers to thaw it out one tiny piece at a time. Every square centimeter of the mammoth and the soil surrounding it will be examined. One thing scientists hope to find out is why mammoths became extinct. They may have been unable to adapt to climatic changes, they may have been over-hunted by early humans, or they may have died of disease. Tissue samples from the mammoth may help to solve this mystery.

"Pleistocene Park"

The amount of knowledge to be gained from the mammoth is tremendous. Some scientists even hope to find cells in the mammoth that could be cloned, and from them, to grow a living woolly mammoth. Other scientists hope to find sperm cells that they can use to cross-breed it with a living female elephant. The hybrid offspring would also be fertilized with mammoth sperm, and a nearly pure-bred mammoth would result after several generations. In a scene right out of "Pleistocene Park," the woolly mammoth might be returned to the steppe as an ecological tourist attraction.

Activity

The woolly mammoth is one of several species in the family Proboscidea. Visit the Earth Science Web Site at earthgeu.com to research the other members of this family. Make a poster telling when, where, and how they lived.

CHAPTER 21

Study Guide

Summary

Section 21.1

The Geologic Time Scale

Main Ideas

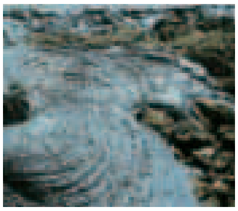
- Geologists have separated Earth's history into divisions based upon the fossil record.
- The divisions of the geologic time scale, in descending order and decreasing length of time spans, are eons, eras, periods, and epochs.

Vocabulary

eon (p. 554)
epoch (p. 556)
era (p. 554)
geologic time scale (p. 554)
period (p. 555)

Section 21.2

Relative Age-Dating of Rocks



Main Ideas

- The principles of uniformitarianism, original horizontality, superposition, and cross-cutting relationships are used to interpret Earth's rock record and, thus, to describe the planet's history.
- Unconformities caused by weathering and erosion or by periods of nondeposition mark missing layers in the rock record.

Vocabulary

correlation (p. 561)
cross-cutting relationships (p. 559)
original horizontality (p. 558)
superposition (p. 558)
unconformity (p. 560)
uniformitarianism (p. 557)

Section 21.3

Absolute Age-Dating of Rocks

Main Ideas

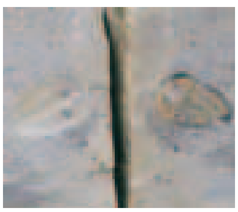
- Absolute-age dating measures the actual age of an object such as a mineral, rock, or fossil.
- Radioactive decay is the emission of particles from a radioactive atom. The decay rate can be used to determine the age of a rock or fossil. The time it takes a radioactive element to decay to 50 percent of its original mass is known as its half-life.
- Tree rings and varves can also determine the dates of events and changes in the environment. Volcanic ash and meteorite-impact debris create key beds that mark the time of the event.

Vocabulary

dendrochronology (p. 564)
half-life (p. 563)
key bed (p. 565)
radioactive decay (p. 562)
radiometric dating (p. 562)
varve (p. 565)

Section 21.4

Remains of Organisms in the Rock Record



Main Ideas

- The remains and evidence of plants and animals that once lived on Earth are called fossils.
- Fossils preserved in the rock record provide information about past environmental conditions, evolutionary changes in life-forms, and help geologists to correlate rock layers from one area to another.

Vocabulary

altered hard part (p. 567)
cast (p. 568)
evolution (p. 566)
fossil (p. 566)
index fossil (p. 568)
mold (p. 568)
original preservation (p. 566)
permineralization (p. 567)

earthgeu.com/vocabulary_puzzlemaker

CHAPTER 21

Assessment

Understanding Main Ideas

1. 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

2. What is a magma intrusion that cuts across pre-existing rock layers called?
a. sill **c.** fault
b. lava flow **d.** dike

3. Which term does NOT describe a gap in geologic time?
a. unconformity **c.** disconformity
b. nonconformity **d.** key bed

4. Which of the following is NOT a 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

5. How old is a mammoth's tusk if there is only 25 percent C-14 remaining in the sample?
a. 5700 years **c.** 17 100 years
b. 11 400 years **d.** 22 800 years

6. Trees that have been buried by volcanic ash are preserved in what manner?
a. original preservation **c.** mummification
b. permineralization **d.** recrystallization

7. What feature is formed when a sedimentary rock layer overlies a nonsedimentary rock layer?
a. unconformity
b. nonconformity
c. disconformity
d. contact metamorphism

8. Based on radioactive elements, what is the calculated age of Earth?
a. 4.6 billion years **c.** 15 billion years
b. 5 million years **d.** 1 million years

9. Which type of fossil forms when an organism's hard parts dissolve and leave a cavity that later fills with sediment?
a. mold **c.** cast
b. coprolite **d.** gastrolith

10. What are glacial sediments that show cyclic deposition called?
a. annual rings **c.** tillites
b. varves **d.** unconformities

Applying Main Ideas

11. Why is it difficult to interpret the rock record of Precambrian Time?

12. What evidence is preserved to indicate that a large meteorite impact occurred at the end of the Mesozoic?

13. How would you explain a horizontal sedimentary rock layer containing Cambrian fossils lying on top of a rock layer containing Ordovician fossils?

14. Does an outcrop containing Jurassic dinosaur fossils overlying Pennsylvanian coal deposits represent uninterrupted deposition? Explain.

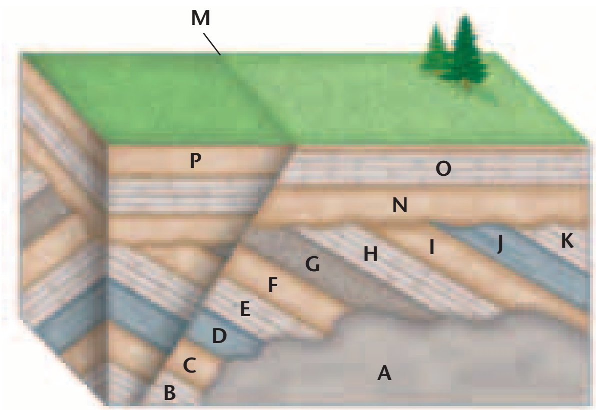
Test-Taking Tip

WRITE IT DOWN! Most tests ask you a large number of questions in a small amount of time. Write down your work wherever possible. Do math on paper, not in your head. Underline and reread important facts in passages and diagrams—don't try to memorize them.

15. What radioactive isotope would be best for determining the age of prehistoric human remains?
16. How is an index fossil like a key bed?

Thinking Critically

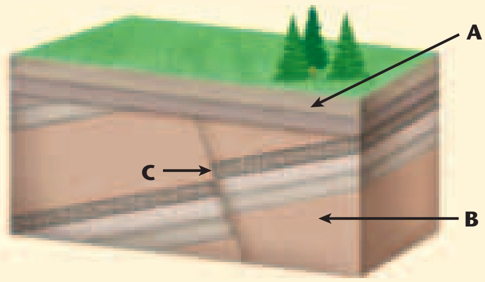
Use the diagram below to answer questions 17–23.



17. Which is the oldest rock unit in the diagram?
18. What has happened to the sedimentary rocks since they were first deposited?
19. Which is the youngest feature in the diagram, the fault or Layer P? Explain.
20. An unconformity exists between which two layers of rock? Explain your answer.
21. Why is rock unit P thicker on the left side of the diagram than on the right side?
22. Explain why the rock layers and features on the left side of the diagram do not match the rock layers and features on the right side.
23. List the order of geologic events represented in the diagram. List the principles you used to place the structures in order from oldest to youngest.

Standardized Test Practice

1. Which of the following constitutes the fewest number of years?
   a. eon
   b. era
   c. period
   d. epoch



INTERPRETING SCIENTIFIC ILLUSTRATIONS Use the diagram of the rock region above to answer questions 2 and 3.

2. Which principle for determining relative age is relevant to point A of 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 of the 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. In which of the following do original structures of an organism remain?
   a. mold fossil
   b. permineralized fossil
   c. cast fossil
   d. all of the above

earthgeu.com/standardized_test