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

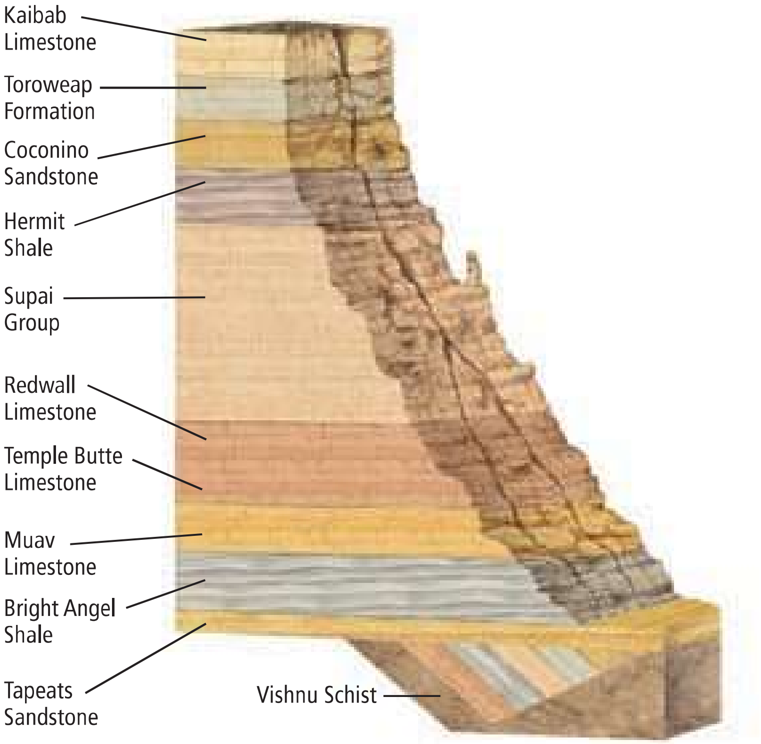
Recall from Section 21.1 that Earth's history stretches back billions of years. Scientists have not always thought that Earth was this old. Early ideas about Earth's age were generally placed in the context of time spans that a person could understand relative to his or her own life. This changed as 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.

John Lemker/Animals Animals

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

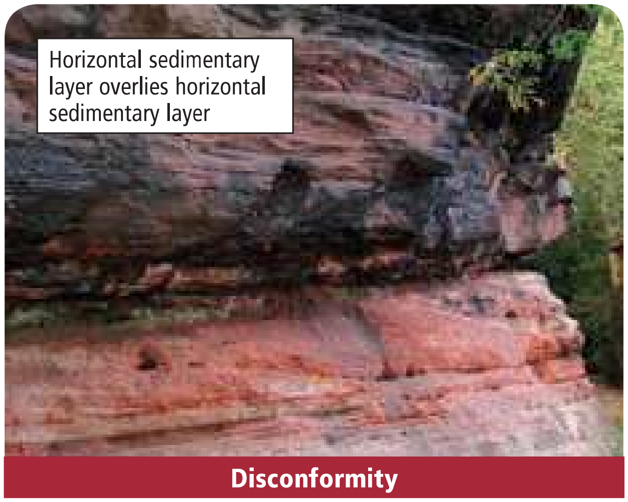
1. **Describe** what principles you would use to determine the relative ages of the layers in your diagram.
2. **Explain** how the principle of cross-cutting relationships can help you determine the relative age of the vertical intrusion.
3. **Infer** what the XY cut represents. Is the XY cut older or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

(tr)David Cavagnaro/Visuals Unlimited, (br)Dr. Marli Miller/Visuals Unlimited

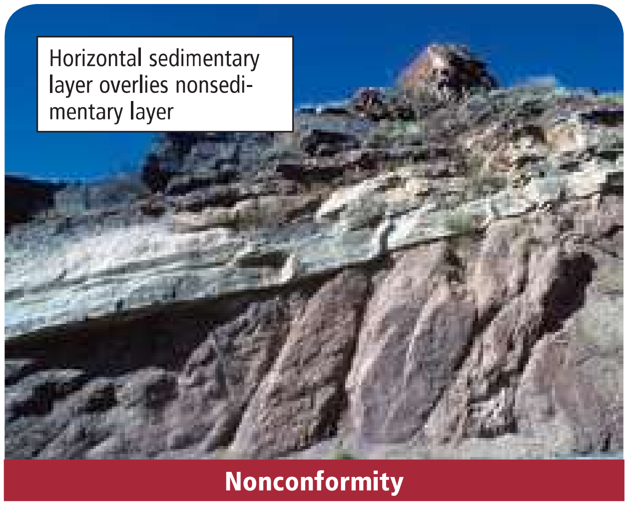
Concepts in Motion

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

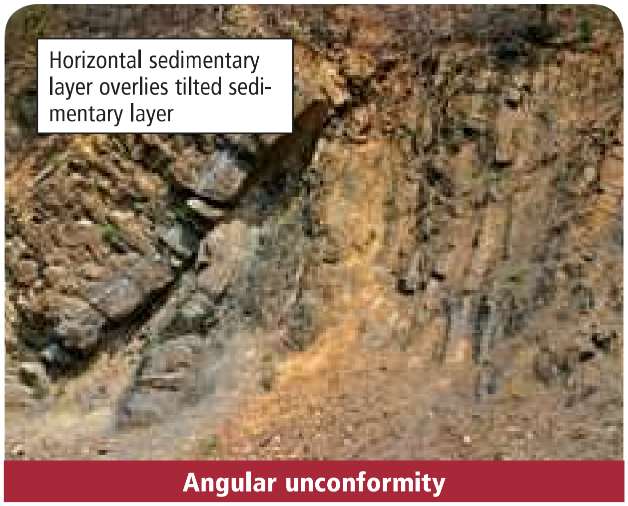
Figure 21.10 An unconformity is any erosional surface separating two layers of rock that have been deposited at different times. The three types of unconformities are illustrated below.



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.

(tl)David Turner (Craven & Pendle Geological Society), (cl)Albert Copley/Visuals Unlimited, (bl)Dr. Marli Miller/Visuals Unlimited

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.

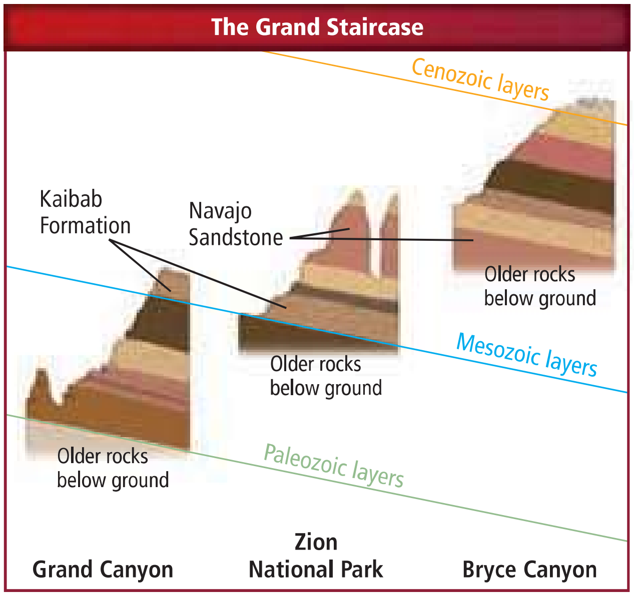
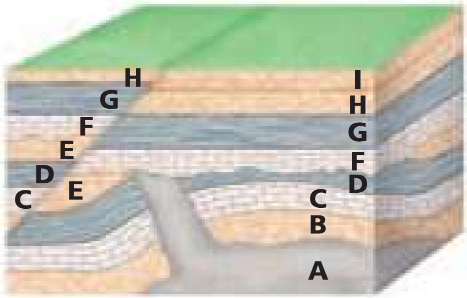


Figure 21.11 The top layers of rocks at the Grand Canyon are identical to the bottom layers at Zion National Park, and the top layers at Zion are the bottom layers at Bryce Canyon.
Infer *the makeup of the buried layer below Zion's Kaibab layer.*

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.



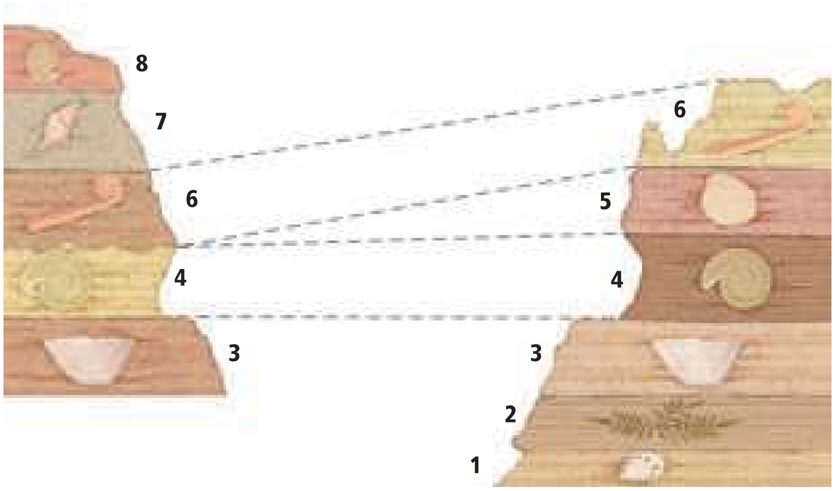
Analysis

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.

Earth Science Online Self-Check Quiz glencoe.com

Section 21.3

Absolute-Age Dating

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

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.

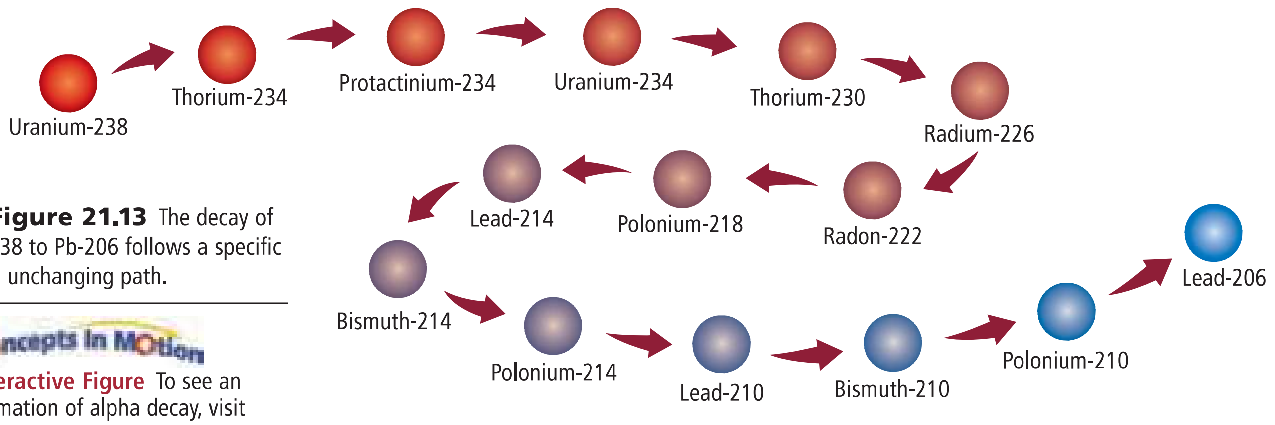


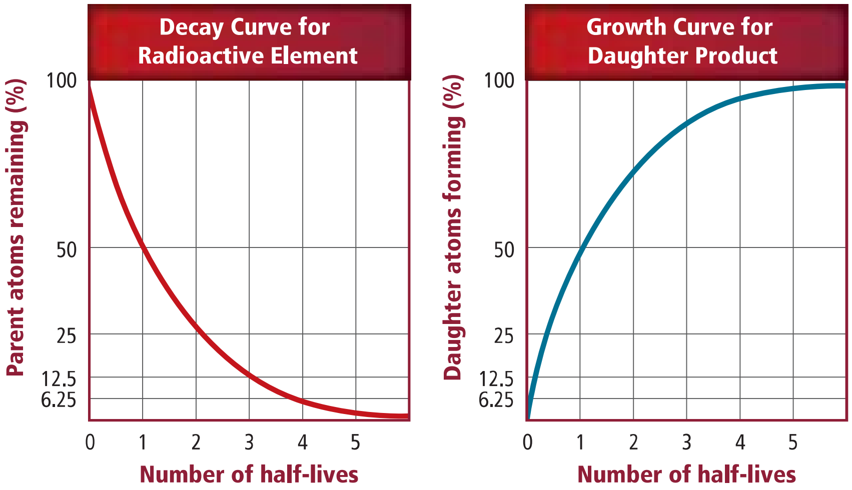
Figure 21.13 The decay of U-238 to Pb-206 follows a specific and unchanging path.

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.

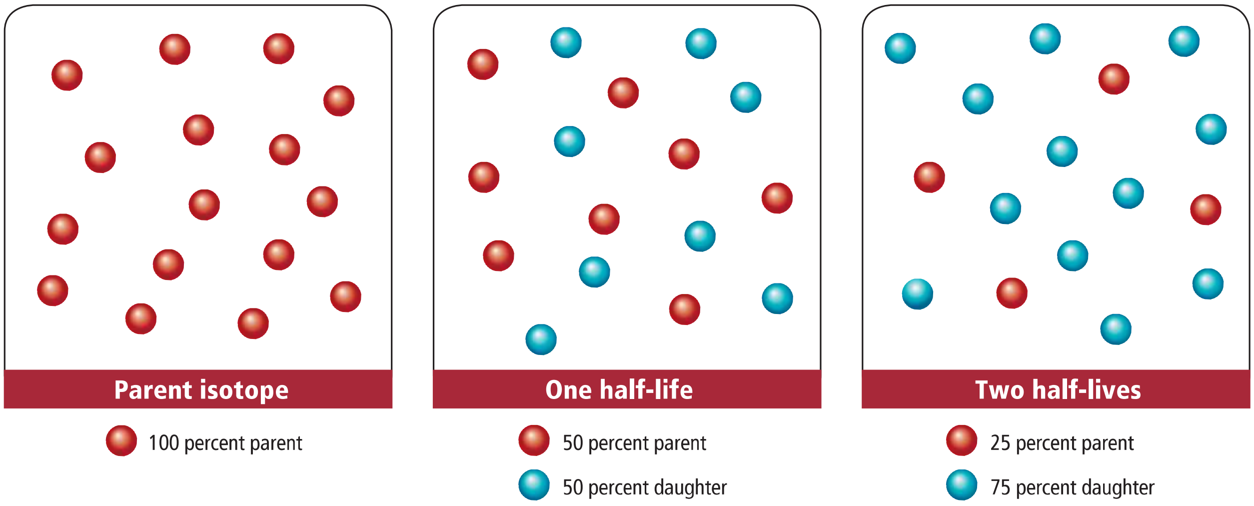


Table 21.1 **Half-Lives of Selected Radioactive Isotopes**

Concepts In Motion

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

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)

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.

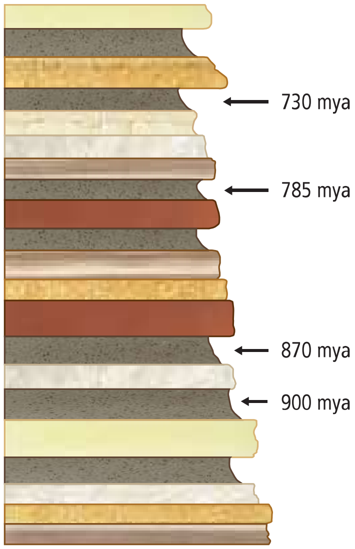
Radiometric dating is not useful for dating sedimentary rocks because, as you learned in Chapter 6, the minerals in most sedimentary rocks were formed from pre-existing rocks. **Figure 21.16** shows how geologists can learn the approximate age of sedimentary layers by dating layers of igneous rock that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