Chapter 8 The Rock Record

Chapter Outline

Why It Matters

Rocks contain clues that show how and when they formed. Scientists study these clues to learn about Earth's history. Scientists also study fossils, such as the crinoids shown here. These animals have been living in aquatic environments on Earth for almost 490 million years.

Inquiry Lab

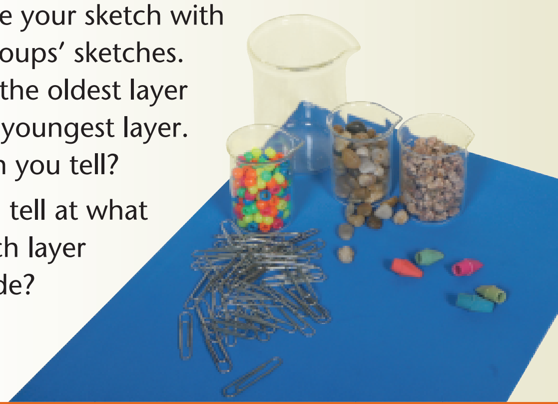
10 min

Modeling Rock Layers

Use **several types of small items** to make layers in a **beaker** or **jar.** Each layer should be made up of only one type of item. Sketch the beaker or jar and the layers it contains.

Questions to Get You Started

1. Compare your sketch with other groups' sketches. Identify the oldest layer and the youngest layer. How can you tell?
2. Can you tell at what time each layer was made? Explain.



READING TOOLBOX

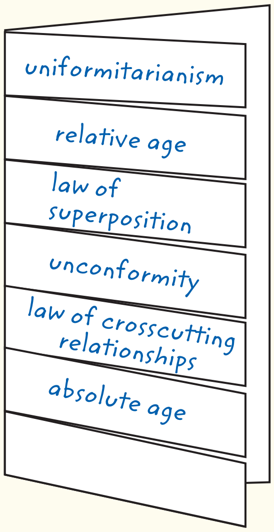
These reading tools will help you learn the material in this chapter.

FoldNotes

Key-Term Fold A key-term fold can help you learn the key terms in this chapter.

Your Turn Create a key-term fold, as described in **Appendix A.**

1. Write one key term from the Summary page on the front of each tab.
2. As you read the chapter, write the definition of each term under its tab.
3. Use this FoldNote to study the key terms.



Cause and Effect

Signal Words Certain words or phrases can signal cause-and-effect relationships. Words and phrases that signal causes include *cause, affect,* and *because*. Words and phrases that signal effects include *therefore, results in,* and *thus*. Sentences can also express cause-and-effect relationships without using explicit markers.

Your Turn In this chapter, you will read about cause-and-effect relationships that allow scientists to draw conclusions about the ages of rock layers and structures. Complete a table of cause-and-effect pairs like the table below.

CAUSE	EFFECT	MARKER(S)
movements of Earth's crust	Buried rock layers can be lifted up and exposed to erosion.	(none)

Note Taking

Outlining Taking notes in outline form can help you see how information is organized in a chapter. You can use your outline notes to review the chapter before a test.

Your Turn As you read through this chapter, make notes about the chapter in outline form. An example from Section 1 is shown on the right to help you get started.

1. DETERMINING RELATIVE AGE
   - A. Uniformitarianism
     1. The principle of uniformitarianism states that current geologic processes are the same ones that operated in the past.
        - a. Uniformitarianism was developed by James Hutton in the 18th century.
        - b. Uniformitarianism is one of the basic foundations of geology.
     2. Geologists after Hutton noted that, although geologic processes are the same through time, their rates may vary.

For more information on how to use these and other tools, see **Appendix A.**

SECTION 1

Determining Relative Age

Key Ideas

- State the principle of uniformitarianism.
- Explain how the law of superposition can be used to determine the relative ages of rocks.
- Compare three types of unconformities.
- Apply the law of crosscutting relationships to determine the relative ages of rocks.

Key Terms

uniformitarianism
relative age
law of superposition
unconformity
law of crosscutting relationships

Why It Matters

By determining the relative ages of rock layers and structures, we can better understand the processes that shape the world around us.

Geologists estimate that Earth is about 4.6 billion years old. The idea that Earth is billions of years old originated with the work of James Hutton, an 18th-century Scottish physician and farmer. Hutton, who is shown in **Figure 1**, wrote about agriculture, weather, climate, physics, and even philosophy. Hutton was also a keen observer of the geologic changes taking place on his farm. Using scientific methods, Hutton drew conclusions based on his observations. Today, he is most famous for his ideas and writings about geology.

Uniformitarianism

Hutton concluded that the same forces that changed the landscape of his farm had changed Earth's surface in the past. He thought that by studying the present, people could learn about Earth's past. Hutton's principle of **uniformitarianism** is that current geologic processes, such as volcanism and erosion, are the same processes that were at work in the past. This principle is one of the basic foundations of the science of geology. Geologists later refined Hutton's ideas by pointing out that although the processes of the past and present are the same, the rates of the processes may vary over time.

uniformitarianism a principle that geologic processes that occurred in the past can be explained by current geologic processes

Figure 1 James Hutton (left) thought that studying the present is the key to understanding the past. This modern-day geologist (right) is looking for clues to Earth's past.

Quick Lab

20 min

What's Your Relative Age?

Procedure

1. Form a group with 5 to 10 of your classmates.
2. Work together to arrange group members in order from oldest to youngest.

Analysis

1. How did you determine your classmates' relative ages?
2. How did the relative ages compare to the absolute ages of your classmates?
3. How is this process of determining relative and absolute age different from the way scientists date rocks?

Earth's Age

Before Hutton's research was undertaken, many people thought that Earth was only about 6,000 years old. They also thought that all geologic features had formed at the same time. Hutton's principle of uniformitarianism raised some serious questions about Earth's age. Hutton observed that the forces that changed the land on his farm operated very slowly. He reasoned that millions of years must be needed for those same forces to create the complicated rock structures observed in Earth's crust. He concluded that Earth must be much older than previously thought. Hutton's observations and conclusions about the age of Earth encouraged other scientists to learn more about Earth's history. One way to learn about Earth's past is to determine the order in which rock layers and other rock structures formed.

Reading Check **What evidence did Hutton propose to show that Earth is very old?** (See Appendix G for answers to Reading Checks.)

Relative Age

In the same way that a history book shows an order of events, layers of rock, called *strata,* show the sequence of events that took place in the past. Using a few basic principles, scientists can determine the order in which rock layers formed. Once they know the order, a relative age can be determined for each rock layer. **Relative age** indicates that one layer is older or younger than another layer but does not indicate the rock's age in years.

Various types of rock form layers. Igneous rocks form layers when successive lava flows stack on top of each other. Metamorphic rocks that formed from layered rocks can have layers. To determine the relative ages of rocks, however, scientists commonly study the layers in sedimentary rocks, such as those shown in **Figure 2.**

Academic Vocabulary

sequence (SEE kwuhns) the order in which things come or events happen

relative age the age of an object in relation to the ages of other objects

Figure 2 The layers of sedimentary rock that make up this butte near Caineville, Utah were deposited over millions of years.

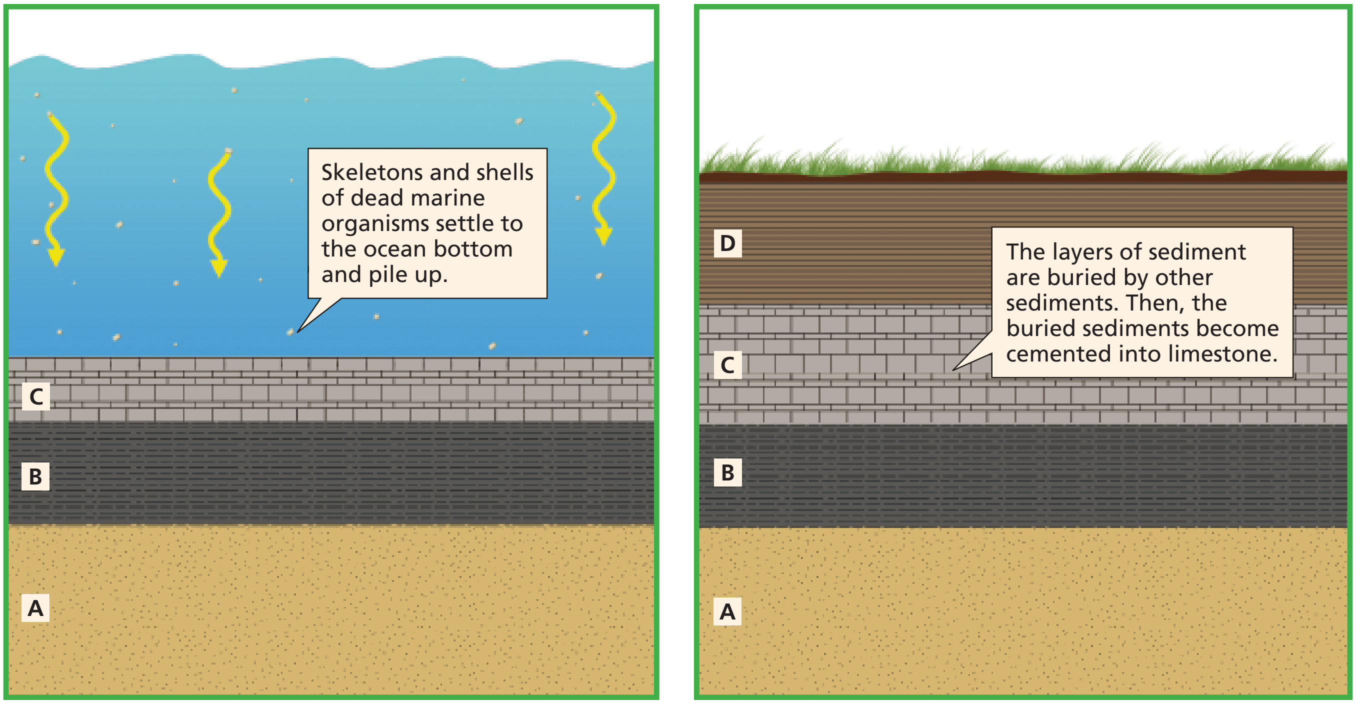


Figure 3 By applying the law of superposition, geologists are able to determine that layer D is the youngest bed in this rock section. ***According to the law of superposition, is layer B older or younger than layer C?***

Law of Superposition

Sedimentary rocks form when new sediments are deposited on top of old layers of sediment. As the sediments accumulate, they are compressed and become naturally cemented into sedimentary rock layers that are called *beds*. The boundary between two beds is called a *bedding plane*.

Scientists use a basic principle called the law of superposition to determine the relative age of a layer of sedimentary rock. The **law of superposition** states that an undeformed sedimentary rock layer is older than the layers above it and younger than the layers below it. According to the law of superposition, layer A, shown in **Figure 3,** was the first layer deposited, and thus it is the oldest layer. The last layer deposited was layer D, and thus it is the youngest layer.

law of superposition the principle that a sedimentary rock layer is older than the layers above it and younger than the layers below it if the layers are not disturbed

Principle of Original Horizontality

Scientists also know that sedimentary rock generally forms in horizontal layers. The *principle of original horizontality* states that sedimentary rocks left undisturbed will remain in horizontal layers. Therefore, scientists can assume that sedimentary rock layers that are not horizontal have been tilted or deformed by crustal movements that happened after the layers formed.

In some cases, tectonic forces push older layers on top of younger layers or overturn a group of rock layers. In such cases, the law of superposition cannot be easily applied. So, scientists must look for clues to the original position of layers and then apply the law of superposition.

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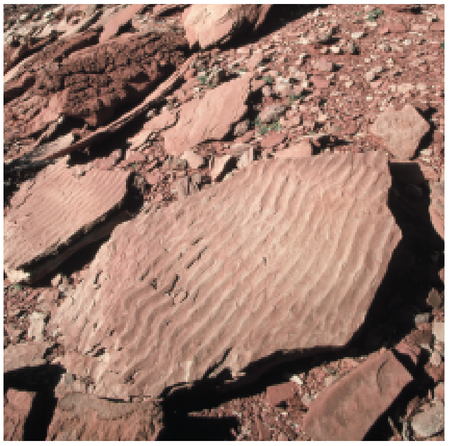
Topic: Law of Superposition
Code: **HQX0858**

Figure 4 Sedimentary Rock Structures

Graded Bedding Heavy particles settle to the bottom of a lake or river faster than smaller particles do and create graded beds like these.

Cross-Beds As sand slides down the slope of a large sand dune, the sand forms slanting layers like the ones shown here.



Ripple Marks When waves move back and forth on a beach, ripple marks like these commonly form.

READING TOOLBOX

Cause and Effect Many factors give clues about the original position of rock layers. As you read this page and the previous page, look for multiple causes and multiple effects that allow scientists to recognize which layers formed above earlier layers.

Graded Bedding

One possible clue to the original position of rock layers is the size of the particles in the layers. In some depositional environments, the largest particles of sediment are deposited in the bottom layers, as shown in **Figure 4.** The arrangement of layers in which coarse and heavy particles are located in the bottom layers is called *graded bedding*. If larger particles are located in the top layers, the layers may have been overturned by tectonic forces.

Cross-Beds

Another clue to the original position of rock layers is in the shape of the bedding planes. When sand is deposited, sandy sediment forms beds at an angle to the bedding plane. These beds are called *cross-beds* and are shown in **Figure 4.** The tops of these layers commonly erode before new layers are deposited. So, the sediment appears to be curved at the bottom of the layer and to be cut off at the top. By studying the shape of the cross-beds, scientists can determine the original position of these layers.

Ripple Marks

Ripple marks are small waves that form on the surface of sand because of the action of water or wind. When the sand becomes sandstone, the ripple marks may be preserved, as shown in **Figure 4.** In undisturbed sedimentary rock layers, the crests of the ripple marks point upward. By examining the orientation of ripple marks, scientists can establish the original arrangement of the rock layers. The relative ages of the rocks can then be determined by using the law of superposition.

Reading Check **How can ripple marks indicate the original position of rock layers?**

Unconformities

Movements of Earth's crust can lift up rock layers that were buried and expose them to erosion. Then, if sediments are deposited, new rock layers form in place of the eroded layers. The missing rock layers create a break in the geologic record in the same way that pages missing from a book create a break in a story. A break in the geologic record is called an **unconformity.** An unconformity shows that deposition either stopped for a period of time, or rock may have been removed by erosion before deposition resumed.

unconformity a break in the geologic record created when rock layers are eroded or when sediment is not deposited for a long period of time

As shown in **Table 1,** there are three types of unconformities. An unconformity in which stratified rock rests upon unstratified rock is called a *nonconformity*. The boundary between a set of tilted layers and a set of horizontal layers is called an *angular unconformity*. The boundary between horizontal layers of old sedimentary rock and younger, overlying layers that are deposited on an eroded surface is called a *disconformity*. According to the law of superposition, all rocks beneath an unconformity are older than the rocks above the unconformity.

Table 1 Types of Unconformities

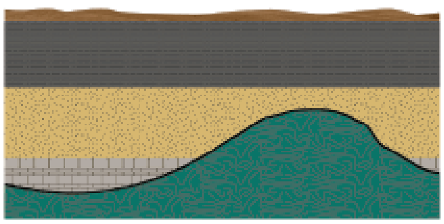
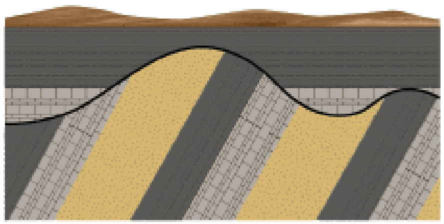
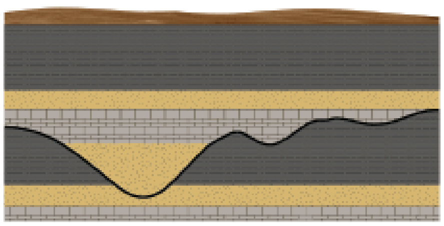
Type	Example	Description
Nonconformity		Unstratified igneous or metamorphic rock may be uplifted to Earth's surface by crustal movements. Once the rock is exposed, it erodes. Sediments may then be deposited on the eroded surface. The boundary between the new sedimentary rock and the igneous or metamorphic rock is a *nonconformity*. The boundary represents an unknown period of time during which the older rock was eroded.
Angular unconformity		An angular unconformity forms when rock deposited in horizontal layers is folded or tilted and then eroded. When erosion stops, a new horizontal layer is deposited on top of a tilted layer. When the bedding planes of the older rock layers are not parallel to those of the younger rock layers deposited above them, an angular unconformity results.
Disconformity		Sometimes, layers of sediments are uplifted without folding or tilting and are eroded. Eventually, the area subsides and deposition resumes. The layers on either side of the boundary are deposited horizontally. Although the rock layers look as if they were deposited continuously, a large time gap exists where the upper and lower layers meet. This gap is known as a *disconformity*.

Figure 5 The law of crosscutting relationships can be used to determine the relative ages of rock layers and the faults and intrusions within them.

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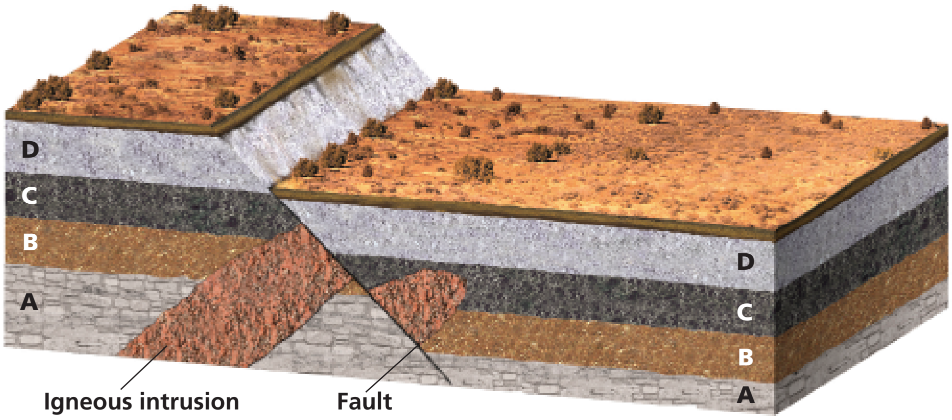

Crosscutting Relationships

When rock layers have been disturbed by faults or intrusions, determining relative age may be difficult. A *fault* is a break or crack in Earth's crust along which rocks shift their position. An *intrusion* is a mass of igneous rock that forms when magma is injected into rock and then cools and solidifies. In such cases, scientists may apply the law of crosscutting relationships. The **law of crosscutting relationships** is that a fault or igneous intrusion is always younger than the rock layers it cuts through. If a fault or intrusion cuts through an unconformity, the fault or intrusion is younger than all the rocks it cuts through above and below the unconformity.

law of crosscutting relationships the principle that a fault or body of rock is younger than any other body of rock that it cuts through

Figure 5 shows a series of rock layers that contains both a fault and an igneous intrusion. As you can see, an intrusion cuts across layers A, B, and C. According to the law of crosscutting relationships, the intrusion is younger than layers A, B, and C. The fault is younger than the intrusion and all four layers.

Section 1 Review

Key Ideas

1. **Explain** why it is important for scientists to be able to determine the relative ages of rocks.
2. **State** the principle of uniformitarianism in your own words.
3. **Explain** how the law of superposition can be used to determine the relative age of sedimentary rock.
4. **Explain** the difference between an unconformity and a nonconformity.
5. **Compare** an angular unconformity with a disconformity.
6. **Describe** how the law of crosscutting relationships helps scientists determine the relative ages of rocks.

Critical Thinking

7. **Making Comparisons** Which would be more difficult to recognize: a nonconformity or a disconformity? Explain your answer.
8. **Analyzing Relationships** Suppose that you find a series of rock layers in which a fault ends at an unconformity. Explain how you could apply the law of crosscutting relationships to determine the relative age of the fault and of the rock layers that were deposited above the unconformity.

Concept Mapping

9. Use the following terms to create a concept map: *principle of original horizontality, relative age, graded bedding, law of superposition, cross-bed,* and *ripple mark.*

SECTION 2 Determining Absolute Age

Key Ideas	Key Terms	Why It Matters
› Summarize the limitations of using the rates of erosion and deposition to determine the absolute age of rock formations. › Describe the formation of varves. › Explain how the process of radioactive decay can be used to determine the absolute ages of rocks.	**absolute age** **varve** **radiometric dating** **half-life**	The absolute age of a rock can be determined using radioactive elements. This information helps us understand how our planet formed and continues to change.

Relative age indicates only that one rock formation is younger or older than another rock formation. To learn more about Earth's history, scientists often need to determine the numeric age, or **absolute age,** of a rock formation.

Absolute Dating Methods

Scientists use a variety of methods to measure absolute age. Some methods involve geologic processes that can be observed and measured over time. Other methods involve the chemical composition of certain materials in rock.

Rates of Erosion

One way to estimate absolute age is to study rates of erosion. For example, if scientists measure the rate at which a stream erodes its bed, they can estimate the age of the stream. But determining absolute age by using the rate of erosion is practical only for geologic features that formed within the past 10,000 to 20,000 years. One example of such a feature is Niagara Falls, which is shown in **Figure 1.** For older surface features, such as the Grand Canyon, which formed over millions of years, the method is less dependable because rates of erosion may vary greatly over millions of years.

absolute age the numeric age of an object or event, often stated in years before the present, as established by an absolute-dating process, such as radiometric dating

Academic Vocabulary

estimate (ES tuh MAYT) to calculate approximately

Figure 1 The rocky ledge that forms Niagara Falls has been eroding at a rate of about 1.3 m per year for nearly 9,900 years. ***How many kilometers has the ledge been eroded in the last 9,900 years?***

Math Skills

Deposition If 30 cm of sediments are deposited every 1,000 years, how long would 10 m of sediments take to accumulate?

Rates of Deposition

Another way to estimate absolute age is to calculate the rate of sediment deposition. By using data collected over a long period of time, geologists can estimate the average rates of deposition for common sedimentary rocks such as limestone, shale, and sandstone. In general, about 30 cm of sedimentary rock are deposited over a period of 1,000 years. However, any given sedimentary layer that is being studied may not have been deposited at an average rate. For example, a flood can deposit many meters of sediment in just one day. In addition, the rate of deposition may change over time. Therefore, this method of determining absolute age is not always accurate; it merely provides an estimate.

READING TOOLBOX

Key-Term Fold
Make a FoldNote for methods that can be used to determine absolute age. List each method and give three facts about how it is used.

Varve Count

You may know that a tree's age can be estimated by counting the growth rings in its trunk. Scientists have devised a similar method for estimating the age of certain sedimentary deposits. Some sedimentary deposits show definite annual layers, called **varves,** that consist of a light-colored band of coarse particles and a dark band of fine particles.

varve a pair of sedimentary layers (one coarse, one fine) that is deposited in an annual cycle, commonly in glacial lakes, and that can be used to determine absolute age

Varves generally form in glacial lakes. During the summer, when snow and ice melt rapidly, a rush of water can carry large amounts of sediment into a lake. Most of the coarse particles settle quickly to form a layer on the bottom of the lake. With the coming of winter, the surface of the lake begins to freeze. Fine clay particles still suspended in the water settle slowly to form a thin layer on top of the coarse sediments. A coarse summer layer and the overlying, fine winter layer make up one varve. Thus, each varve represents one year of deposition. Some varves are shown in **Figure 2.** By counting the varves, scientists can estimate the age of the sediments.

Reading Check **How are varves like tree rings?**

Figure 2 Varves (below), which form in glacial lakes (right), can be counted to determine the absolute age of sediments.

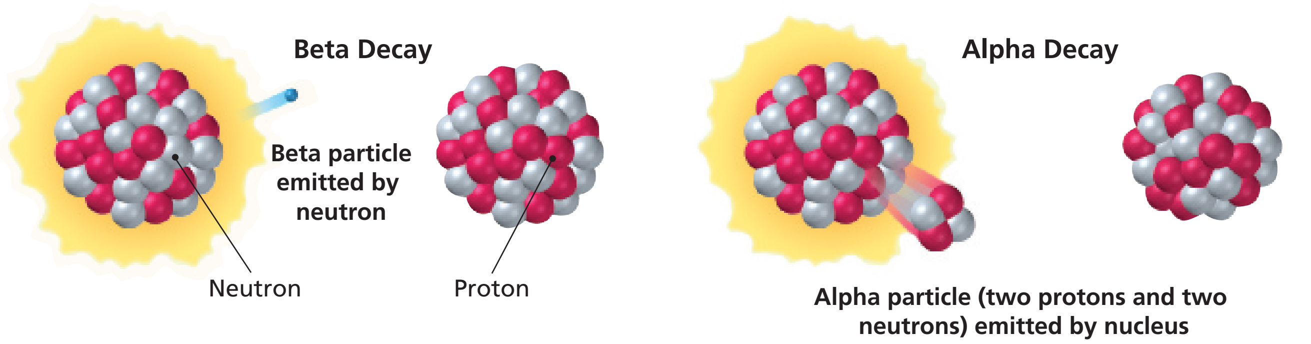

Figure 3 Beta decay and alpha decay are two forms of radioactive decay. In all forms of radioactive decay, an atom emits particles and energy.

Radiometric Dating

Rocks generally contain small amounts of radioactive material that can act as natural clocks. Atoms of the same element that have different numbers of neutrons are called *isotopes. Radioactive isotopes* have nuclei that emit particles and energy at a constant rate regardless of surrounding conditions. **Figure 3** shows two of the ways that radioactive isotopes decay. During the emission of the particles, large amounts of energy are released. Scientists use this natural breakdown of isotopes to accurately measure the absolute age of rocks. The method of using radioactive decay to measure absolute age is called **radiometric dating.**

As an atom emits particles and energy, the atom changes into a different isotope of the same element or an isotope of a different element. Scientists measure the concentrations of the original radioactive isotope, or *parent isotope,* and of the newly formed isotopes, or *daughter isotopes*. Using the known decay rate, the scientists compare the proportions of the parent and daughter isotopes to determine the absolute age of the rock.

radiometric dating a method of determining the absolute age of an object by comparing the relative percentages of a radioactive (parent) isotope and a stable (daughter) isotope

Why It Matters

Exposing a Fake Mummy

FORENSIC SCIENCE

"Genuine 2,600-year-old artifact for sale!" How could a potential buyer know whether this claim is true or false? Radiometric dating, based on carbon isotopes, can help. As well as being used to determine the age of rocks, radiometric dating is used in forensics to unmask art forgers and unethical antiquities dealers.

Preparation Steps

- Burn a tiny sample of the coffin's wood and collect the gas.
- Analyze the proportions of carbon isotopes in the gas.
- Determine the age of the wood. At only 250 years old, it is too young to be genuine.

YOUR TURN

UNDERSTANDING CONCEPTS
How is radiometric dating used to expose archaeological frauds?

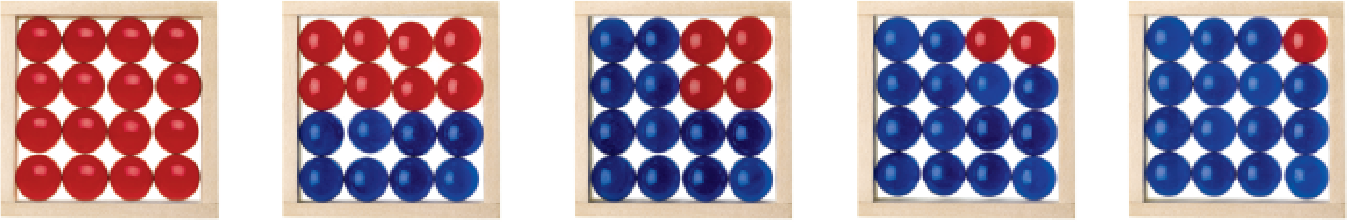

Figure 4 After each half-life, one-half of the parent isotope (shown in red) is converted into a daughter isotope (shown in blue). After four half-lives, only 1/16 of the parent isotope remains.

half-life the time required for half of a sample of a radioactive isotope to break down by radioactive decay to form a daughter isotope

Half-Life

Radioactive decay happens at a relatively constant rate that is not changed by temperature, pressure, or other environmental conditions. Scientists have determined that the time required for half of any amount of a particular radioactive isotope to decay is always the same and can be determined for any isotope. Therefore, a **half-life** is the time it takes half the mass of a given amount of a radioactive parent isotope to decay into its daughter isotopes. If you began with 10 g of a parent isotope, you would have 5 g of that isotope after one half-life of that isotope. At the end of a second half-life, one-fourth, or 2.5 g, of the original isotope would remain. Three-fourths of the sample would now be the daughter isotope. This process is shown in **Figure 4.**

By comparing the amounts of parent and daughter isotopes in a rock sample, scientists can determine the age of the sample. The greater the percentage of daughter isotopes present in the sample, the older the rock is. But comparing parent and daughter isotopes works only when the sample has not gained or lost either parent or daughter isotopes through leaking or contamination.

Quick Lab — Radioactive Decay

10 min

Procedure

1. Use a clock or watch that has a second hand to record the time.
2. Wait 20 s, and then use scissors to carefully cut a sheet of paper in half. Select one piece, and set the other piece aside.
3. Repeat step 2 until nine 20 s intervals have elapsed.

Analysis

1. What does the whole piece of paper used in this investigation represent?
2. What do the pieces of paper that you set aside in each step represent?
3. What is the half-life of your paper isotope?
4. How much of your paper isotope was left after the first three intervals? after six intervals? after nine intervals? Express your answers as percentages.
5. What two factors in your model must remain constant so that your model is accurate? Explain your answer.

Table 1 Radiometric Dating Methods

Radiometric dating methods	Parent isotope	Daughter isotope	Half-life	Effective dating range
Radiocarbon dating	carbon-14, ^{14}C	nitrogen-14, ^{14}N	5,730 years	less than 70,000 years
Argon-argon dating, $^{39}Ar/^{40}Ar$	potassium-40, ^{40}K irradiated to form argon-39, ^{39}Ar	argon-40, ^{40}Ar	1.25 billion years	10,000 to 4.6 billion years
Potassium-argon dating, $^{40}K/^{40}Ar$	potassium-40, ^{40}K	argon-40, ^{40}Ar	1.25 billion years	50,000 to 4.6 billion years
Rubidium-strontium dating, $^{87}Rb/^{87}Sr$	rubidium-87, ^{87}Rb	strontium-87, ^{87}Sr	48.1 billion years	10 million to 4.6 billion years
Uranium-lead dating, $^{235}U/^{207}Pb$	uranium-235, ^{235}U	lead-207, ^{207}Pb	704 million years	10 million to 4.6 billion years
Uranium-lead dating, $^{238}U/^{206}Pb$	uranium-238, ^{238}U	lead-206, ^{206}Pb	4.5 billion years	10 million to 4.6 billion years
Thorium-lead dating $^{232}Th/^{208}Pb$	thorium-232, ^{232}Th	lead-208, ^{208}Pb	14.0 billion years	greater than 200 million years

Radioactive Isotopes

The amount of time that has passed since a rock formed determines which radioactive element will give a more accurate age measurement. If too little time has passed since radioactive decay began, there may not be enough of the daughter isotope for accurate dating. If too much time has passed, there may not be enough of the parent isotope left for accurate dating.

Uranium-238, ^{238}U (which is read as "U two thirty-eight"), has an extremely long half-life of 4.5 billion years. ^{238}U is most useful for dating geologic samples that are more than 10 million years old, as long as they contain uranium. In addition to ^{238}U, several other radioactive isotopes are used to date rock samples. One such isotope is potassium-40, ^{40}K, which has a half-life of 1.25 billion years. ^{40}K occurs in mica, clay, and feldspar and is used to date rocks that are between 50,000 and 4.6 billion years old. Rubidium-87, ^{87}Rb, has a half-life of about 48 billion years. ^{87}Rb, which commonly occurs in minerals that contain ^{40}K, can be used to verify the age of rocks previously dated by using ^{40}K. **Table 1** provides a list of other radiometric dating methods.

Reading Check **How does the half-life of an isotope affect the accuracy of the radiometric dating method?**

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Topic: Radiometric Dating
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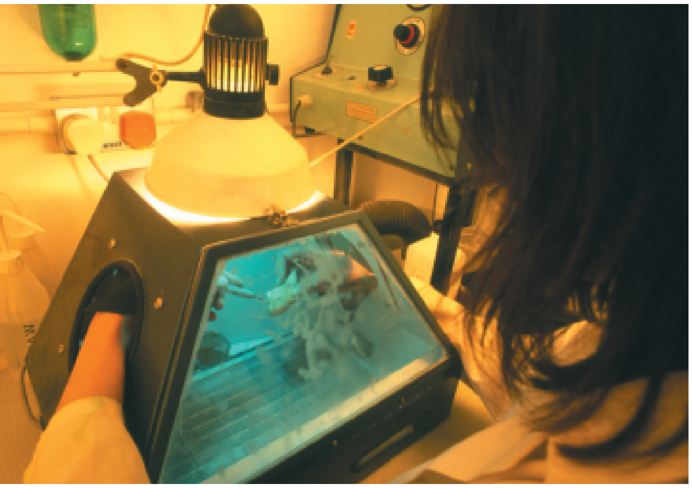


Figure 5 This scientist is preparing a mammoth's tooth for carbon-14 dating, which will determine the tooth's absolute age.

Carbon Dating

Younger rock layers may be dated indirectly by dating organic material found within the rock. The ages of wood, bones, shells, and other organic remains that are included in the layers and that are less than 70,000 years old can be determined by using a method known as *carbon-14 dating*, or *radiocarbon dating*, as shown in **Figure 5.** The isotope carbon-14, ^{14}C, combines with oxygen to form radioactive carbon dioxide, CO_2. Most CO_2 in the atmosphere contains nonradioactive carbon-12, ^{12}C. Only a small amount of CO_2 in the atmosphere contains ^{14}C.

Plants absorb CO_2, which contains either ^{12}C or ^{14}C, during photosynthesis. Then, when animals eat the plants or the plant-eating animals, the ^{12}C and ^{14}C become part of the animals' body tissues. Thus, all living organisms contain both ^{12}C and ^{14}C.

To find the age of a small amount of organic material, scientists first determine the ratio of ^{14}C to ^{12}C in the sample. Then, they compare that ratio with the ratio of ^{14}C to ^{12}C known to exist in a living organism. While organisms are alive, the ratio of ^{12}C to ^{14}C remains relatively constant. When a plant or an animal dies, however, the ratio begins to change. The half-life of ^{14}C is only about 5,730 years. Because the organism is dead, it no longer absorbs ^{12}C and ^{14}C, and the amount of ^{14}C in the organism's tissues decreases steadily as the radioactive ^{14}C decays to nonradioactive nitrogen-14, ^{14}N.

Section 2 Review

Key Ideas

1. **Differentiate** between relative and absolute age.
2. **Summarize** why calculations of absolute age based on rates of erosion and deposition can be inaccurate.
3. **Describe** varves, and describe how and where they form.
4. **Explain** how radiometric dating is used to estimate absolute age.
5. **Define** half-life, and explain how it helps determine an object's absolute age.
6. **List** three methods of radiometric dating, and explain the age range for which they are most effective.

Critical Thinking

7. **Demonstrating Reasoned Judgment** Suppose you have a shark's tooth that you suspect is about 15,000 years old. Would you use ^{238}U or ^{14}C to date the tooth? Explain your answer.
8. **Making Inferences** You see an advertisement for an atomic clock. You also know that radioactive decay emits harmful radiation. Do you think the atomic clock contains decaying isotopes? Explain.

Concept Mapping

9. Use the following terms to create a concept map: *absolute age, varve, radiometric dating, parent isotope, daughter isotope,* and *carbon dating.*

SECTION 3 The Fossil Record

Key Ideas	Key Terms	Why It Matters
❯ Describe four ways in which entire organisms can be preserved as fossils. ❯ List five examples of fossilized traces of organisms. ❯ Describe how index fossils can be used to determine the age of rocks.	**fossil** **paleontology** **trace fossil** **index fossil**	Fossils give information about the ages of rocks. They also give information about changes in life forms and the environment throughout time.

The remains or traces of animals or plants that lived in a previous geologic time are called **fossils.** Fossils, such as the one shown in **Figure 1,** are an important source of information for finding the relative and absolute ages of rocks. Fossils also provide clues to past geologic events, climates, and the evolution of living things over time. The study of fossils is called **paleontology.**

Almost all fossils are discovered in sedimentary rock. The sediments that cover the fossils slow or stop the process of decay and protect the body of the dead organism from damage. Fossils are rare in igneous rock or highly metamorphosed rock because intense heat, pressure, and chemical reactions that occur during the formation of these rock types destroy all organic structures.

Interpreting the Fossil Record

The fossil record provides information about the geologic history of Earth. By revealing how organisms have changed throughout the geologic past, fossils provide important clues to the environmental changes that occurred in Earth's past. For example, fossils of marine animals and plants have been discovered in areas far from any ocean. These fossils tell us that such areas were covered by an ocean in the past. Scientists can use this information to learn about how environmental changes have affected living organisms.

fossil the trace or remains of an organism that lived long ago, most commonly preserved in sedimentary rock

paleontology the scientific study of fossils

Figure 1 Paleontologists are unearthing the remains of rhinoceroses that are 10 million years old at this site in Orchard, Nebraska.

Fossilization

Normally, dead plants and animals are eaten by other animals or decomposed by bacteria. If left unprotected, even hard parts such as bones decay and leave no record of the organism. Only dead organisms that are buried quickly or protected from decay can become fossils. Generally, only the hard parts of organisms, such as wood, bones, shells, and teeth, become fossils. In rare cases, an entire organism may be preserved. In some types of fossils, only a replica of the original organism remains. Other fossils merely provide evidence that life once existed. **Table 1** describes different ways that fossils can form.

Academic Vocabulary

evidence (EV uh duhns) information showing whether an idea is true or valid

READING TOOLBOX

Outlining

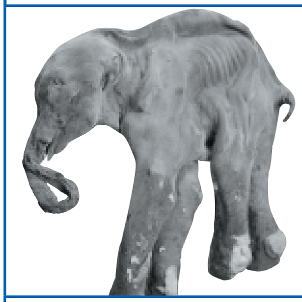
Create an outline using the main ideas from this section. Include all key ideas, key terms, and red topic headings. Use your outline to review the material.

Table 1 How Fossils Form

Mummification Mummified remains are often found in very dry places, because most bacteria, which cause decay, cannot survive in these places. Some ancient civilizations mummified their dead by carefully extracting the body's internal organs and then wrapping the body in carefully prepared strips of cloth.

Amber Hardened tree sap is called *amber*. Insects become trapped in the sticky sap and are preserved when the sap hardens. In many cases, delicate features such as legs and antennae have been preserved. In rare cases, DNA has been recovered from amber.

Tar Seeps When thick petroleum oozes to Earth's surface, the petroleum forms a tar seep. Tar seeps are commonly covered by water. Animals that come to drink the water can become trapped in the sticky tar. Other animals prey on the trapped animals and can also become trapped. The remains of the trapped animals are covered by the tar and preserved.



Freezing The low temperatures of frozen soil and ice can protect and preserve organisms. Because most bacteria cannot survive freezing temperatures, organisms that are buried in frozen soil or ice do not decay.

Petrification Minerals that precipitate from groundwater solutions replace original organic materials that have been buried under layers of sediment. Some common petrifying minerals are silica, calcite, and pyrite. The substitution of minerals for organic material often results in the formation of a nearly perfect mineral replica of the original organism.

Table 2 Types of Fossils

	**Carbon films** Carbonized residue of leaves, stems, flowers, and fish have been found preserved in sedimentary rock made of soft mud or clay. When original organic material partially decays, it leaves behind a carbon-rich film that displays the surface features of the organism.
Molds and Casts Shells often leave empty spaces called *molds* within hardened sediment. When a shell is buried, its remains eventually dissolve and leave an empty space. When sand or mud fills a mold and turns into rock, a natural cast forms. A cast is a replica of the original organism.	
	**Coprolites** Fossilized dung or waste materials from ancient animals are called *coprolites*. They can be cut into thin sections and observed through a microscope. The materials identified in these sections reveal the feeding habits of ancient animals, such as dinosaurs.
Gastroliths Some dinosaurs had stones in their digestive systems to help grind their food. In many cases, these stones, which are called *gastroliths,* survive as fossils. Gastroliths can often be recognized by their smooth, polished surfaces and by their close proximity to dinosaur remains.	

Types of Fossils

Fossils can show a remarkable amount of detail about ancient organisms. **Table 2** describes some of these fossils. In some cases, no part of the original organism survives in fossil form. But **trace fossils,** or fossilized evidence of past animal movement such as tracks, footprints, borings, and burrows, can still provide information about prehistoric life.

trace fossil a fossilized mark that formed in sedimentary rock by the movement of an animal on or within soft sediment

A trace fossil, such as the footprint of an animal, is an important clue to the animal's appearance and activities. Suppose that a giant dinosaur left deep footprints in soft mud. Sand or silt may have blown or washed into the footprint so gently that the footprints remained intact. Then, more sediment may have been deposited over the prints. As time passed, the mud containing the footprints turned into sedimentary rock and preserved the footprints. Scientists have discovered ancient footprints of reptiles, amphibians, birds, and mammals.

Reading Check **What is a trace fossil?**

Figure 2 If you discovered fossils such as these ammonites, you would know that the surrounding rock formed between 180 million and 206 million years ago.

Index Fossils

Paleontologists can use fossils to determine the relative ages of the rock layers in which the fossils are located. Fossils that occur only in rock layers of a particular geologic age are called **index fossils.** To be an index fossil, a fossil must meet certain requirements. First, it must be present in rocks scattered over a large region. Second, it must have features that clearly distinguish it from other fossils. Third, the organisms from which the fossil formed must have lived during a short span of geologic time. Fourth, the fossil must occur in fairly large numbers within the rock layers.

index fossil a fossil that is used to establish the age of rock layers because it is distinct, abundant, and widespread and existed for only a short span of geologic time

Index Fossils and Absolute Age

Scientists can use index fossils to estimate absolute ages of specific rock layers. Because organisms that formed index fossils lived during short spans of geologic time, the rock layer in which an index fossil was discovered can be dated accurately. The ammonite fossils in **Figure 2** show that the rock in which the fossils were observed formed between 180 million and 206 million years ago.

Scientists can also use index fossils to date rock layers in separate areas. So, an index fossil discovered in rock layers in different areas of the world indicates that the rock layers in these areas formed during the same time period.

Geologists also use index fossils to help locate rock layers that are likely to contain oil and natural gas deposits. These deposits form from plant and animal remains that change by chemical processes over millions of years.

Section 3 Review

Key Ideas

1. **Describe** four ways in which an entire organism can be preserved as a fossil.
2. **List** four types of fossils that can be used to provide indirect evidence of organisms.
3. **Explain** how geologists use fossils to date sedimentary rock layers.
4. **Compare** the process of mummification with the process of petrification.
5. **Describe** how index fossils can be used to determine the ages of rocks.

Critical Thinking

6. **Applying Ideas** What characteristic do all good sources of animal fossils have in common?
7. **Identifying Relationships** If a rock layer in Mexico and a rock layer in Australia contain the same index fossil, what do you know about the absolute ages of the layers in both places? Explain your answer.

Concept Mapping

8. Use the following terms to create a concept map: *fossils, mummification, amber, tar seep, freezing,* and *petrification.*

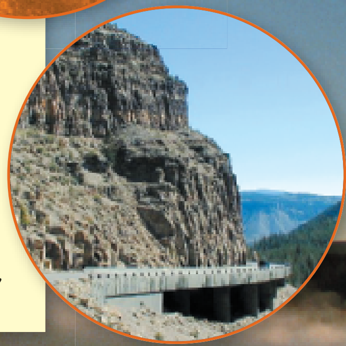
Why It Matters

SCIENCE & SOCIETY

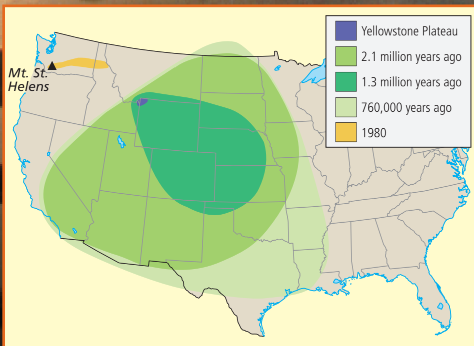
A Record of Yellowstone's Explosive Past

Would you feel safe camping on top of an active volcano with a destructive past? At Yellowstone National Park, people do, every day! Yellowstone's geysers are perched on one of Earth's largest active volcanoes. The rock record shows that three giant eruptions took place at Yellowstone, throwing massive amounts of volcanic ash into the air between 2.1 million and 640,000 years ago.

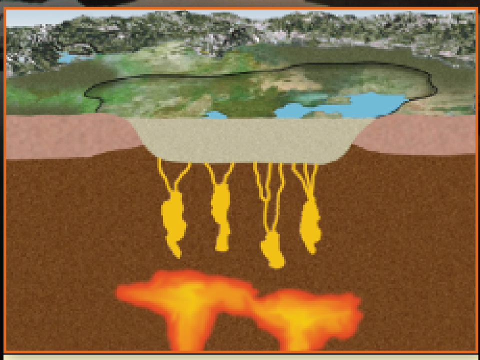
As a geyser's water heats up, pressure mounts underground, eventually forcing water high into the air.



Yellowstone's largest eruption created the Huckleberry Ridge ash bed, which formed this hillside.



Ash deposits from a Yellowstone eruption have been identified more than 2,000 km away from the eruption site!



Yellowstone is shaped like a basin. Its giant eruptions expelled so much material that the ground collapsed into the magma chamber below.

YOUR TURN

CRITICAL THINKING

How do you think scientists made the map that shows the extent of the volcanic deposits from Yellowstone's giant eruptions?

Making Models **Lab**

45 min

Types of Fossils

Paleontologists study fossils to find evidence of the kinds of life and conditions that existed on Earth in the past. Fossils are the remains of ancient plants and animals or evidence of their presence. In this lab, you will use various methods to make models of fossils.

What You'll Do

- **Model** how different types of fossils form.
- **Demonstrate** how certain types of fossils form.

What You'll Need

clay, modeling
container, plastic
hard objects such as a shell, key, paper clip, or coin
leaf
newspaper
paper, carbon, soft
paper, white (1 sheet)
pencil (or wood dowel)
plaster of Paris
spoon, plastic
tweezers
water
wax paper

Safety

Procedure

1. Place a ball of modeling clay on a flat surface that is covered with wax paper.
2. Press the clay down to form a flat disk about 8 cm in diameter. Turn the clay over so that the smooth, flat surface is facing up.
3. Choose a small, hard object. Press the object onto the clay carefully so that you do not disturb the indentation. Is the indentation left by the object a mold or a cast? What features of the object are best shown in the indentation? Sketch the indentation.
4. On a second piece of smooth, flat clay, make a shallow imprint to represent the burrow or footprint of an animal. Sketch your fossil imprint.
5. Fill the plastic container with water to a depth of 1 to 2 cm. Stir in enough plaster of Paris to make a paste that has the consistency of whipped cream.
6. Using the plastic spoon, fill both indentations with plaster. Allow excess plaster to run over the edges of the imprints. Let the plaster set for about 15 min, until it hardens.

Step 3

7. After the plaster has hardened, remove both pieces of plaster from the clay. Do the pieces of hardened plaster represent molds or casts?
8. Place the carbon paper on a flat surface with the carbon facing up. Gently place the leaf on the carbon paper, and cover it with several sheets of newspaper. Roll the pencil or wooden dowel back and forth across the surface of the newspaper several times, and press firmly to bring the leaf into full contact with the carbon paper.
9. Remove the newspaper. Lift the leaf by using the tweezers, and place it on a clean sheet of paper with the carbon-coated side facing down. Cover the leaf with clean wax paper, and roll your pencil across the surface of the wax paper.
10. Remove the wax paper and leaf. Observe and describe the carbon film left by the leaf.

Step 6

Step 9

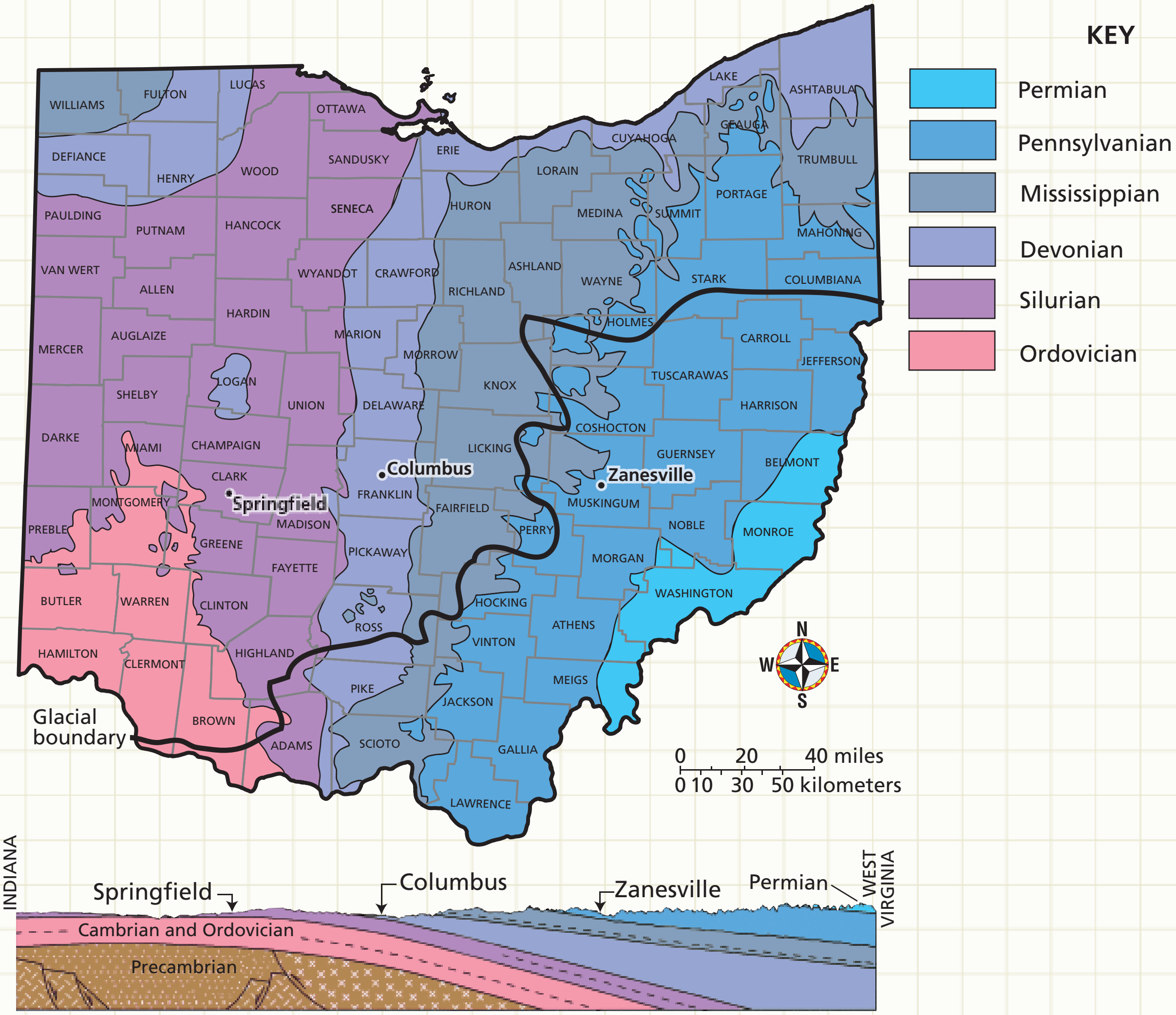
Analysis

1. **Analyzing Results** Look at the molds and casts made by others in your class. Identify as many of the objects used to make the molds and casts as you can.
2. **Making Comparisons** How does the carbon film you made differ from an actual carbonized film fossil?
3. **Applying Ideas** Trace fossils are evidence of the movement of an animal on or within soft sediment. Why are carbon films, molds, and casts not considered trace fossils?

Extension

Making Predictions Which organism—a rabbit, a housefly, an earthworm, or a snail—would be most likely to form fossils? Which of these organisms would leave trace fossils? Explain.

Geologic Map of Bedrock in Ohio



Map Skills Activity

This map shows the ages of the bedrock in Ohio. Bedrock is the solid rock that lies underneath all surface soil and other loose material. Use the map to answer the questions below.

1. **Using a Key** What geologic periods are represented by the bedrock in Ohio?
2. **Analyzing Data** Where is the youngest bedrock in Ohio? Where is the oldest bedrock in Ohio?
3. **Identifying Trends** If you traveled from east to west across Ohio, how would the ages of the rock beneath you change?
4. **Analyzing Relationships** Based on the geologic cross section, how does the shape of the rock beds cause rocks of different ages to be exposed at different places in Ohio?
5. **Identifying Relationships** Why is Mississippian rock likely to be located next to Devonian rock?
6. **Using a Key** The first reptiles appeared in the fossil record during the Pennsylvanian Period. If you wanted to look for fossils of these reptiles in Ohio, in what part of the state would you look? Explain your answer.

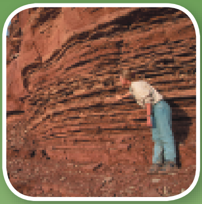
Chapter 8

Summary

THINK central
SUPER SUMMARY
Keyword: HQXRECS

Key Ideas | **Key Terms**

Section 1



Determining Relative Age

- According to the principle of uniformitarianism, the forces that are changing Earth's surface today are the same forces that changed Earth's surface in the past.
- In undeformed rock layers, the youngest layer is on the top and the oldest layer is on the bottom, according to the law of superposition.
- Nonconformities, angular unconformities, and disconformities are interruptions in the sequence of rock layers and are collectively known as unconformities.
- According to the law of crosscutting relationships, a geologic feature is always younger than the rock it cuts through.

Key Terms

uniformitarianism, p. 201
relative age, p. 202
law of superposition, p. 203
unconformity, p. 205
law of crosscutting relationships, p. 206

Section 2

Determining Absolute Age

- Because rates of erosion and deposition can change over time, they are imprecise methods for determining absolute ages of rocks.
- Varves are layers of sediment that form in glacial lakes as a result of the annual cycle of freezing and thawing of the glacier.
- Radioactive elements decay at constant and measurable rates and can be used to determine absolute age.

Key Terms

absolute age, p. 207
varve, p. 208
radiometric dating, p. 209
half-life, p. 210

Section 3

The Fossil Record

- Entire organisms may be preserved in amber, in tar seeps, or through freezing or mummification.
- Fossilized evidence of organisms includes trace fossils, carbon films, molds, casts, coprolites, and gastroliths.
- Index fossils occur only in rock layers of a particular geologic age, and they can help geologists estimate the age of rock formations.

Key Terms

fossil, p. 213
paleontology, p. 213
trace fossil, p. 215
index fossil, p. 216

Chapter 8 Review

1. Key-Term Fold Use the FoldNote that you made at the beginning of the chapter to study the key terms for this chapter. See if you know all of the definitions. When you have reviewed the terms, use each term in a sentence.

READING TOOLBOX

USING KEY TERMS

Use each of the following terms in a separate sentence.

2. *uniformitarianism*

3. *varve*

4. *radiometric dating*

5. *half-life*

For each pair of terms, explain how the meanings of the terms differ.

6. *relative age* and *absolute age*

7. *law of superposition* and *law of crosscutting relationships*

8. *trace fossil* and *index fossil*

UNDERSTANDING KEY IDEAS

9. Varves are layers of
a. limestone mixed with coarse sediments.
b. alternating coarse and fine sediments.
c. fossils.
d. sediments that have gaps that represent missing time in the rock sequence.

10. An unconformity that results when new sediments are deposited on eroded horizontal layers is a(n)
a. angular unconformity.
b. disconformity.
c. crosscut unconformity.
d. nonconformity.

11. A fault or intrusion is younger than the rock it cuts through, according to the
a. type of unconformity.
b. law of superposition.
c. law of crosscutting relationships.
d. principle of uniformitarianism.

12. The age of a rock in years is the rock's numerical age, or
a. index age.
b. relative age.
c. half-life age.
d. absolute age.

13. A gap in the sequence of rock layers is a(n)
a. bedding plane.
b. varve.
c. unconformity.
d. uniformity.

14. The process by which the remains of an organism are preserved by drying is called
a. petrification.
b. mummification.
c. erosion.
d. superposition.

15. Molds that fill with sediment sometimes produce
a. casts.
b. gastroliths.
c. coprolites.
d. carbon films.

SHORT ANSWER

16. What prompted James Hutton to formulate the principle of uniformitarianism?

17. Describe how the law of superposition helps scientists determine relative age.

18. Compare and contrast the three types of unconformities.

19. How do scientists use radioactive decay to determine absolute age?

20. Besides radiometric dating, what are three other methods of estimating absolute age?

21. List and describe five ways that organisms can be preserved.

22. List the four characteristics that define an index fossil.

CRITICAL THINKING

23. Making Inferences James Hutton developed the principle of uniformitarianism by observing geologic changes on his farm. What changes might he have observed?

24. Applying Ideas How might a scientist determine the original positions of the sedimentary layers beneath an angular unconformity?

25. **Analyzing Relationships** One intrusion cuts through all the rock layers. Another intrusion is eroded and lies beneath several layers of sedimentary rock. Which intrusion is younger? Explain your answer.

26. **Analyzing Concepts** A fossil that has unusual features is found in many areas on Earth. It represents a brief period of geologic time but occurs in small numbers. Would this fossil make a good index fossil? Explain.

27. **Making Comparisons** Compare the processes of mummification and freezing.

CONCEPT MAPPING

28. Use the following terms to create a concept map: *relative age, law of superposition, unconformity, law of crosscutting relationships, absolute age, radiometric dating, carbon dating,* and *index fossil.*

MATH SKILLS

Math Skills

29. **Making Calculations** Scientists know that 1 million grams of ^{238}U will undergo radioactive decay to produce 1/7,600 g of ^{206}Pb per year. How many grams of ^{238}U would be left after 1 million years?

30. **Applying Quantities** A sample contains 1,000 g of an isotope that has a half-life of 500 years. How many half-lives will have to pass before the sample contains less than 10 g of the parent isotope?

31. **Making Calculations** The half-life of ^{238}U is 4.5 billion years. How many years would 16 g of ^{238}U take to decay into 0.5 g of ^{238}U and 15.5 g of daughter products?

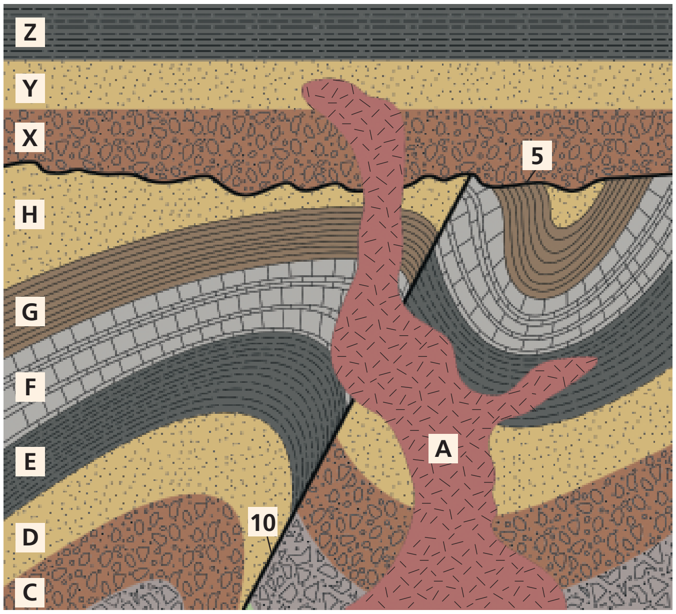
WRITING SKILLS

32. **Writing Persuasively** Imagine that you are James Hutton. Write a letter to a fellow scientist to convince him or her of the validity of the principle of uniformitarianism.

33. **Outlining Topics** Describe what happens to the amount of an isotope as it undergoes radioactive decay through three half-lives.

INTERPRETING GRAPHICS

The illustration below shows crosscutting relationships in an outcrop of rock. Use this illustration to answer the questions that follow.



34. Is intrusion A older or younger than fault 10? Explain your answer.

35. What type of unconformity does feature 5 represent? Explain your answer.

36. Which rock formation is older: layer X or layer Y? Explain your answer.

Chapter 8

Standardized Test Prep

Understanding Concepts

Directions (1–5): For each question, write on a separate sheet of paper the letter of the correct answer.

1. A scientist used radiometric dating during an investigation. The scientist used this method because she wanted to determine the
   A. relative ages of rocks.
   B. absolute ages of rocks.
   C. climate of a past era.
   D. fossil types in a rock.

2. Fossils that provide direct evidence of the feeding habits of ancient animals are known as
   F. coprolites.
   G. molds and casts.
   H. carbon films.
   I. trace fossils.

3. One way to estimate the absolute age of rock is
   A. nonconformity.
   B. varve count.
   C. the law of superposition.
   D. the law of crosscutting relationships.

4. To be an index fossil, a fossil must
   F. be present in rocks that are scattered over a small geographic area.
   G. contain remains of organisms that lived for a long period of geologic time.
   H. occur in small numbers within the rock layers.
   I. have features that clearly distinguish it from other fossils.

5. Which of the following statements best describes the relationship between the law of superposition and the principle of original horizontality?
   A. Both describe the deposition of sediments in horizontal layers.
   B. Both conclude that Earth is more than 100,000 years old.
   C. Both indicate the absolute ages of layers of rock.
   D. Both recognize that the geologic processes in the past are the same as those at work now.

Directions (6): Write a short response to this question.

6. What is the name of a type of fossil that can be used to establish the age of rock?

Reading Skills

Directions (7–10): Read the passage below. Then, answer the questions on a separate sheet of paper.

Illinois Nodules

Around 300 million years ago, the region that is now Illinois had a very different climate. Swamps and marshes covered much of the area. Scientists estimate that no fewer than 500 species lived in this ancient environment. Today, the remains of these organisms are found preserved within structures known as nodules. Nodules are round or oblong structures that are usually composed of cemented sediments. Sometimes, these nodules contain the fossilized hard parts of plants and animals. The Illinois nodules are extremely unusual because many contain finely detailed impressions of the soft parts of the organisms together with the hard parts. Because they are rare, these nodules are desired for their incredible scientific value and may be found in fossil collections around the world.

7. According to the passage above, which of the following statements about nodules is correct?
   F. Nodules are rarely round or oblong.
   G. Nodules are usually composed of cemented sediments.
   H. Nodules are rarely found outside of Illinois.
   I. Nodules always contain fossils.

8. What is the most unusual feature of the nodules found in modern-day Illinois?
   A. their bright coloration
   B. the fact that they come in many more unusual shapes that other nodules
   C. the fact that they contain both the soft and hard parts of animals
   D. their extremely heavy weight

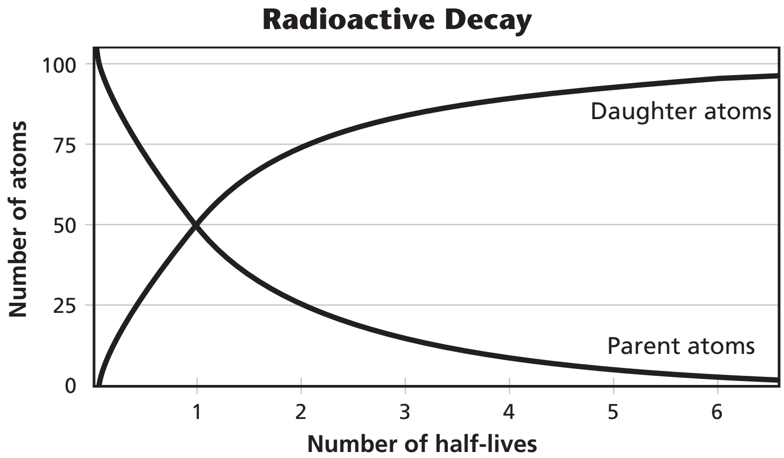
9. Which of the following statements can be inferred from the information in the passage?
   F. Illinois nodules are sought by scientists.
   G. Nodules can be purchased from the state.
   H. Similar nodules can be found in nearby Iowa.
   I. Nodules contain dinosaur fossils.

10. What might scientists learn from a nodule that contains the soft and hard parts of an animal?

Interpreting Graphics

Directions (11–13): For each question below, record the correct answer on a separate sheet of paper.

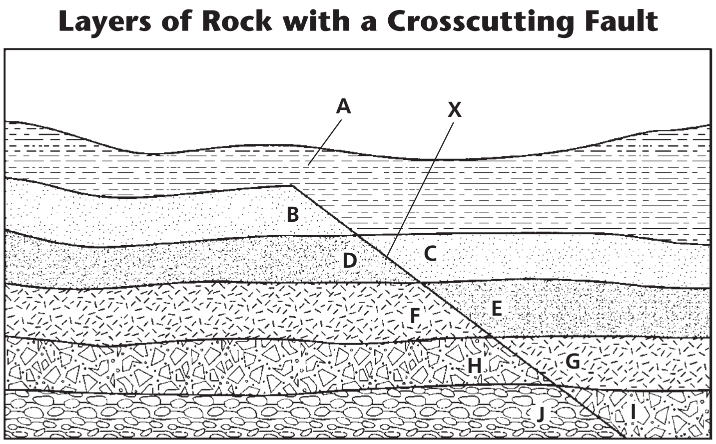
The graph below shows the rate of radioactive decay. Use this graph to answer question 11.



11. How many half-lives have passed when the number of daughter atoms is approximately three times the number of parent atoms?

A. one
B. two
C. three
D. four

The diagram below shows crosscutting taking place in layers of rock. Use this diagram to answer questions 12 and 13.



12. Which two layers belonged to the same layer of rock before the fault disrupted the layer?

F. C and D
G. C and F
H. G and I
I. G and F

13. Which is older, structure B or structure X? Explain your answer. What structure shown on the diagram is the youngest?

Test Tip

If time permits, take short mental breaks to improve your concentration during a test.