

3

The Rock and Fossil Record

SECTION 1 Earth's Story and Those Who First Listened 60

SECTION 2 Relative Dating: Which Came First? 64

SECTION 3 Absolute Dating: A Measure of Time 70

SECTION 4 Looking at Fossils 74

SECTION 5 Time Marches On 80

Chapter Lab 86

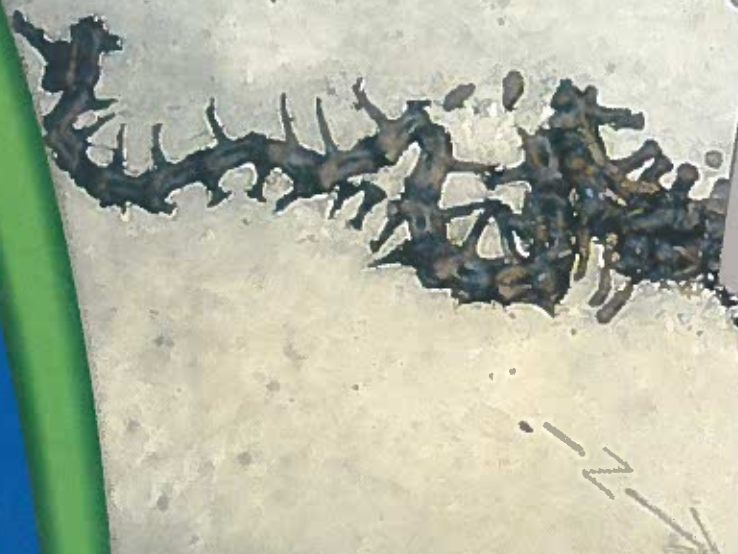
Chapter Review 88

Standardized Test Preparation 90

Science in Action 92

About the **PHOTO**

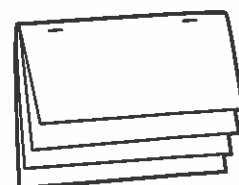
This extremely well preserved crocodile fossil has been out of water for 49 million years. Its skeleton was collected in an abandoned mine pit in Messel, Germany.



PRE-READING **Activity**



Layered Book Before you read the chapter, create the FoldNote entitled "Layered Book" described in the **Study Skills** section of the Appendix. Label the tabs of the layered book with "Earth's history," "Relative dating," "Absolute dating," "Fossils," and "Geologic time." As you read the chapter, write information you learn about each category under the appropriate tab.



Careers

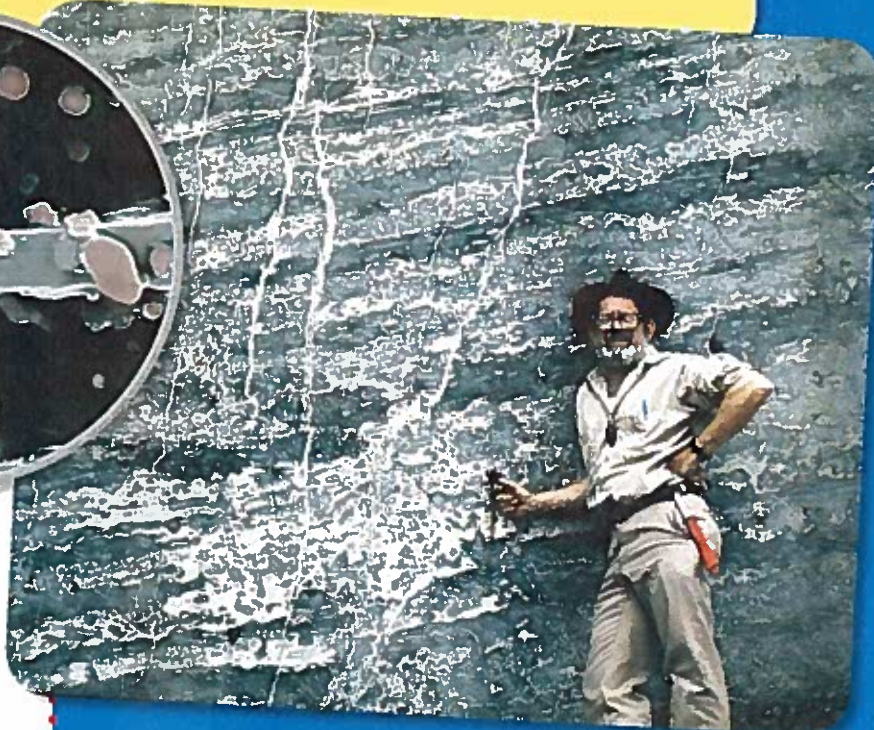
Robert L. Folk

Petrologist For Dr. Robert Folk, the study of rock takes place on the microscopic level. Dr. Folk is searching for tiny life-forms he has named nannobacteria, or dwarf bacteria, in rock. *Nannobacteria* may also be spelled *nanobacteria*. Because nannobacteria are so incredibly small, only 0.05 to 0.2 μm in diameter, Folk must use an extremely powerful 100,000 \times microscope, called a *scanning electron microscope*, to see the shape of the bacteria in rock. Folk's research had already led him to discover that a certain type of Italian limestone is produced by bacteria. The bacteria were consuming the minerals, and the waste of the bacteria was forming the limestone. Further research led Folk to the discovery of the tiny nannobacteria. The spherical or oval-shaped nannobacteria appeared as chains and grapelike clusters. From his research, Folk hypothesized that nannobacteria are responsible for many inorganic reactions that occur in rock. Many scientists are skeptical of Folk's nannobacteria. Some skeptics believe that the tiny size of nannobacteria makes the bacteria simply too small to contain the chemistry of life. Others believe that nannobacteria actually represent structures that do not come from living things.



Math ACTiViTy

If a nannobacterium is $\frac{1}{10}$ the length, $\frac{1}{10}$ the width, and $\frac{1}{10}$ the height of an ordinary bacterium, how many nannobacteria can fit within an ordinary bacterium? (Hint: Draw block diagrams of both a nannobacterium and an ordinary bacterium.)

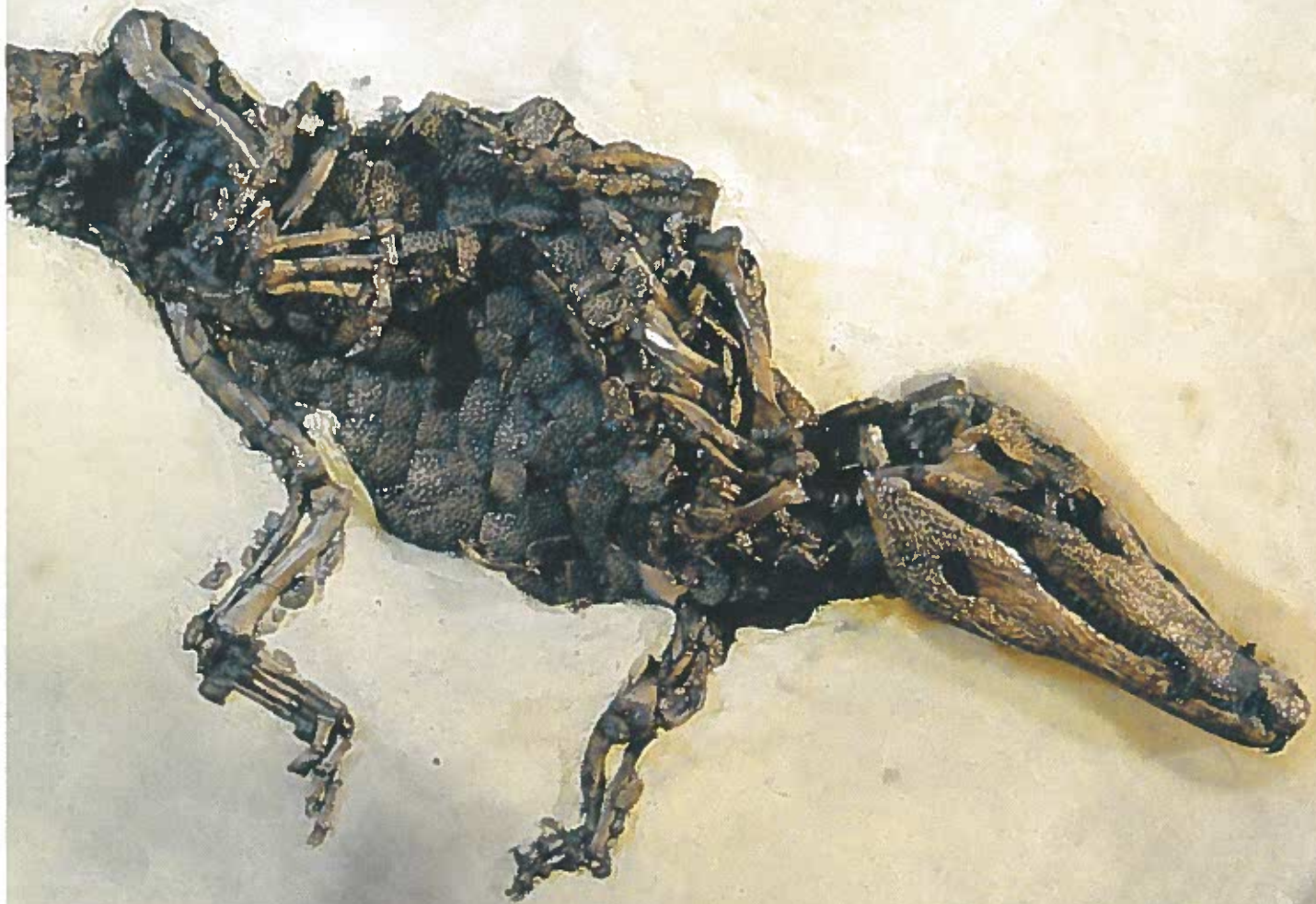


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START-UP ACTIVITY

Making Fossils

How do scientists learn from fossils? In this activity, you will study "fossils" and identify the object that made each.

Procedure

1. You and three or four of your classmates will be given **several pieces of modeling clay** and a **paper sack** containing a few **small objects**.
2. Press each object firmly into a piece of clay. Try to leave a "fossil" imprint showing as much detail as possible.
3. After you have made an imprint of each object, exchange your model fossils with another group.

4. On a **sheet of paper**, describe the fossils you have received. List as many details as possible. What patterns and textures do you observe?
5. Work as a group to identify each fossil, and check your results. Were you right?

Analysis

1. What kinds of details were important in identifying your fossils? What kinds of details were not preserved in the imprints? For example, can you tell the materials from which the objects are made or their color?
2. Explain how scientists follow similar methods when studying fossils.

SECTION

1

READING WARM-UP

Objectives

- Compare uniformitarianism and catastrophism.
- Describe how the science of geology has changed over the past 200 years.
- Explain the role of paleontology in the study of Earth's history.

Terms to Learn

uniformitarianism
catastrophism
paleontology

READING STRATEGY

Reading Organizer As you read this section, make a table comparing uniformitarianism and catastrophism.

Earth's Story and Those Who First Listened

How do mountains form? How is new rock created? How old is the Earth? Have you ever asked these questions? Nearly 250 years ago, a Scottish farmer and scientist named James Hutton did.

Searching for answers to his questions, Hutton spent more than 30 years studying rock formations in Scotland and England. His observations led to the foundation of modern geology.

The Principle of Uniformitarianism

In 1788, James Hutton collected his notes and wrote *Theory of the Earth*. In *Theory of the Earth*, he stated that the key to understanding Earth's history was all around us. In other words, processes that we observe today—such as erosion and deposition—remain uniform, or do not change, over time. This assumption is now called uniformitarianism. **Uniformitarianism** is the idea that the same geologic processes shaping the Earth today have been at work throughout Earth's history. **Figure 1** shows how Hutton developed the idea of uniformitarianism.

Figure 1 Hutton observed gradual, uniform geologic change.

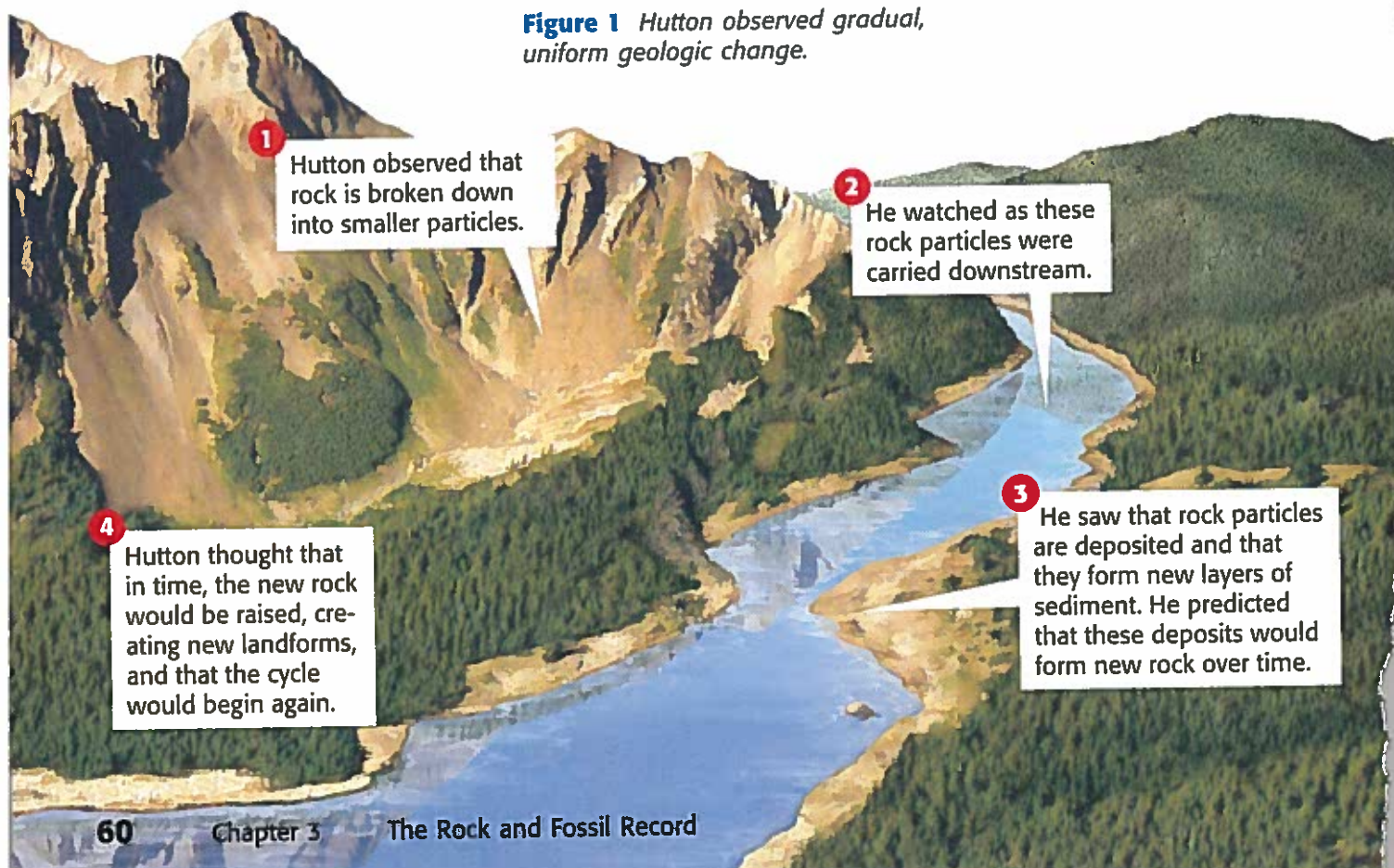




Figure 2 This photograph shows Siccar Point on the coast of Scotland. Siccar Point is one of the places where Hutton observed results of geologic processes that would lead him to form his principle of uniformitarianism.

Uniformitarianism Versus Catastrophism

Hutton's theories sparked a scientific debate by suggesting that Earth was much older than previously thought. In Hutton's time, most people thought that Earth was only a few thousand years old. A few thousand years was not nearly enough time for the gradual geologic processes that Hutton described to have shaped our planet. The rocks that he observed at Siccar Point, shown in **Figure 2**, were deposited and folded, indicating a long geological history. To explain Earth's history, most scientists supported catastrophism. **Catastrophism** is the principle that states that all geologic change occurs suddenly. Supporters of catastrophism thought that Earth's features, such as its mountains, canyons, and seas, formed during rare, sudden events called *catastrophes*. These unpredictable events caused rapid geologic change over large areas—sometimes even globally.

✓ Reading Check According to catastrophists, what was the rate of geologic change? (See the Appendix for answers to Reading Checks.)

A Victory for Uniformitarianism

Despite Hutton's work, catastrophism remained geology's guiding principle for decades. Only after the work of British geologist Charles Lyell did people seriously consider uniformitarianism as geology's guiding principle.

From 1830 to 1833, Lyell published three volumes, collectively titled *Principles of Geology*, in which he reintroduced uniformitarianism. Armed with Hutton's notes and new evidence of his own, Lyell successfully challenged the principle of catastrophism. Lyell saw no reason to doubt that major geologic change happened at the same rate in the past as it happens in the present—gradually.

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

catastrophism a principle that states that geologic change occurs suddenly

CONNECTION TO Biology

WRITING SKILL

Darwin and Lyell

The theory of evolution was developed soon after Lyell introduced his ideas, which was no coincidence. Lyell and Charles Darwin were good friends, and their talks greatly influenced Darwin's theories. Similar to uniformitarianism, Darwin's theory of evolution proposes that changes in species occur gradually over long periods of time. Write a short essay comparing uniformitarianism and evolution.

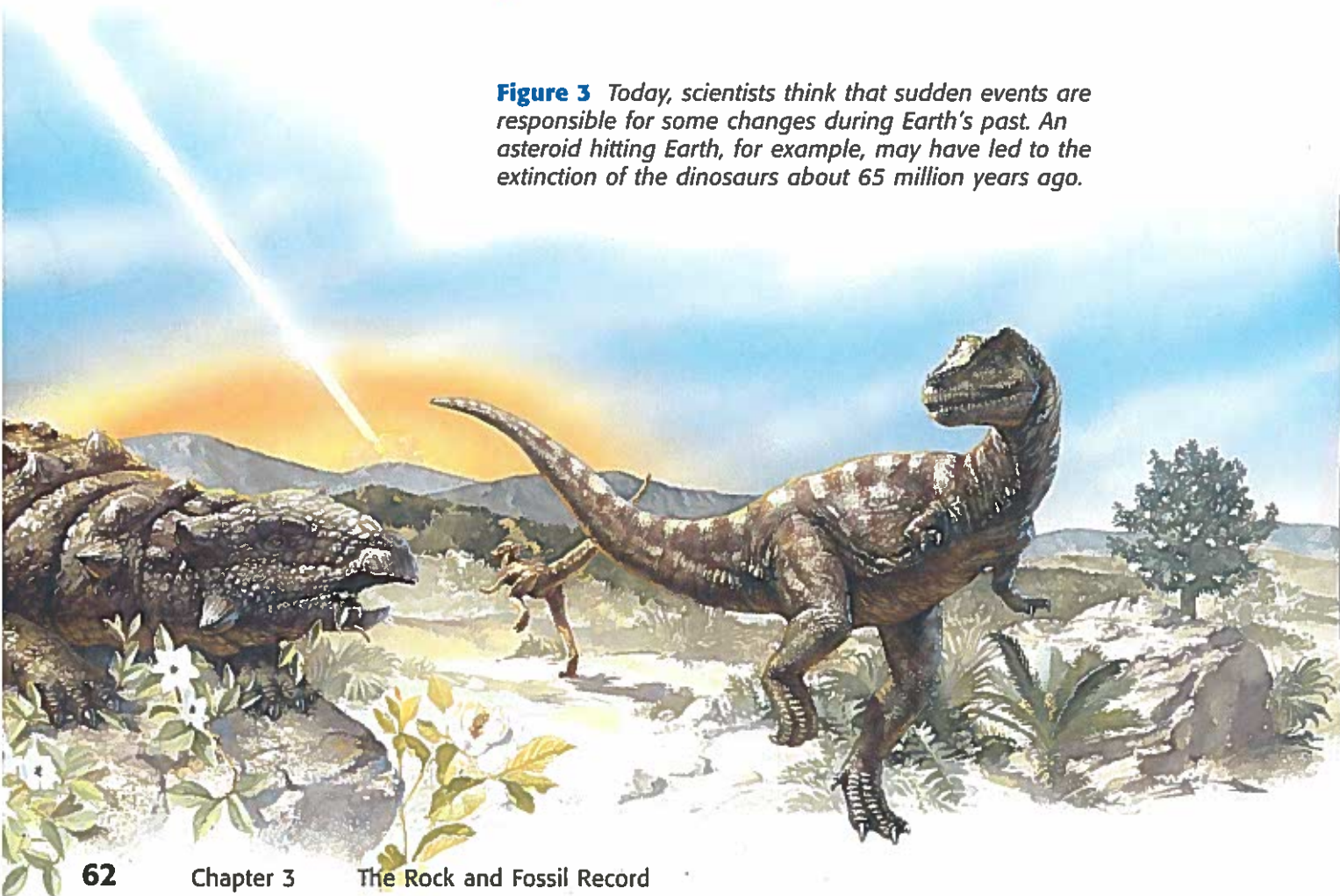
Modern Geology—A Happy Medium

During the late 20th century, scientists such as Stephen J. Gould challenged Lyell's uniformitarianism. They believed that catastrophes do, at times, play an important role in shaping Earth's history.

Today, scientists realize that neither uniformitarianism nor catastrophism accounts for all geologic change throughout Earth's history. Although most geologic change is gradual and uniform, catastrophes that cause geologic change have occurred during Earth's long history. For example, huge craters have been found where asteroids and comets are thought to have struck Earth in the past. Some scientists think one such asteroid strike, approximately 65 million years ago, may have caused the dinosaurs to become extinct. **Figure 3** is an imaginary re-creation of the asteroid strike that is thought to have caused the extinction of the dinosaurs. The impact of this asteroid is thought to have thrown debris into the atmosphere. The debris spread around the entire planet and rained down on Earth for decades. This global debris cloud may have blocked the sun's rays, causing major changes in the global climate that doomed the dinosaurs.

 **Reading Check** How can a catastrophe affect life on Earth?

Figure 3 Today, scientists think that sudden events are responsible for some changes during Earth's past. An asteroid hitting Earth, for example, may have led to the extinction of the dinosaurs about 65 million years ago.



Paleontology—The Study of Past Life

The history of the Earth would be incomplete without a knowledge of the organisms that have inhabited our planet and the conditions under which they lived. The science involved with the study of past life is called **paleontology**. Scientists who study this life are called *paleontologists*. The data paleontologists use are fossils. Fossils are the remains of organisms preserved by geologic processes. Some paleontologists specialize in the study of particular organisms. Invertebrate paleontologists study animals without backbones, whereas vertebrate paleontologists, such as the scientist in **Figure 4**, study animals with backbones. Paleobotanists study fossils of plants. Other paleontologists reconstruct past ecosystems, study the traces left behind by animals, and piece together the conditions under which fossils were formed. As you see, the study of past life is as varied and complex as Earth's history itself.



Figure 4 Edwin Colbert was a 20th-century vertebrate paleontologist who made important contributions to the study of dinosaurs.

paleontology the scientific study of fossils

SECTION Review

Summary

- Uniformitarianism assumes that geologic change is gradual. Catastrophism is based on the idea that geologic change is sudden.
- Modern geology is based on the idea that gradual geologic change is interrupted by catastrophes.
- Using fossils to study past life is called *paleontology*.

Using Key Terms

1. Use each of the following terms in a separate sentence: *uniformitarianism*, *catastrophism*, and *paleontology*.

Understanding Key Ideas

2. Which of the following words describes change according to the principle of uniformitarianism?
 - a. sudden
 - b. rare
 - c. global
 - d. gradual
3. What is the difference between uniformitarianism and catastrophism?
4. Describe how the science of geology has changed.
5. Give one example of catastrophic global change.
6. Describe the work of three types of paleontologists.

Math Skills

7. An impact crater left by an asteroid strike has a radius of 85 km. What is the area of the crater? (Hint: The area of a circle is πr^2 .)

Critical Thinking

8. **Analyzing Ideas** Why is uniformitarianism considered to be the foundation of modern geology?
9. **Applying Concepts** Give an example of a type of recent catastrophe.

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SECTION

2

READING WARM-UP

Objectives

- Explain how relative dating is used in geology.
- Explain the principle of superposition.
- Describe how the geologic column is used in relative dating.
- Identify two events and two features that disrupt rock layers.
- Explain how physical features are used to determine relative ages.

Terms to Learn

relative dating
superposition
geologic column
unconformity

READING STRATEGY

Reading Organizer As you read this section, create an outline of the section. Use the headings from the section in your outline.

Relative Dating: Which Came First?

Imagine that you are a detective investigating a crime scene. What is the first thing you would do?

You might begin by dusting the scene for fingerprints or by searching for witnesses. As a detective, you must figure out the sequence of events that took place before you reached the crime scene.

Geologists have a similar goal when investigating the Earth. They try to determine the order in which events have happened during Earth's history. But instead of relying on fingerprints and witnesses, geologists rely on rocks and fossils to help them in their investigation. Determining whether an object or event is older or younger than other objects or events is called **relative dating**.

The Principle of Superposition

Suppose that you have an older brother who takes a lot of photographs of your family and piles them in a box. Over the years, he keeps adding new photographs to the top of the stack. Think about the family history recorded in those photos. Where are the oldest photographs—the ones taken when you were a baby? Where are the most recent photographs—those taken last week?

Layers of sedimentary rock, such as the ones shown in **Figure 1**, are like stacked photographs. As you move from top to bottom, the layers are older. The principle that states that younger rocks lie above older rocks in undisturbed sequences is called **superposition**.

Figure 1 Rock layers are like photos stacked over time—the younger ones lie above the older ones.



Disturbing Forces

Not all rock sequences are arranged with the oldest layers on the bottom and the youngest layers on top. Some rock sequences are disturbed by forces within the Earth. These forces can push other rocks into a sequence, tilt or fold rock layers, and break sequences into movable parts. Sometimes, geologists even find rock sequences that are upside down! The disruptions of rock sequences pose a challenge to geologists trying to determine the relative ages of rocks. Fortunately, geologists can get help from a very valuable tool—the geologic column.

The Geologic Column

To make their job easier, geologists combine data from all the known undisturbed rock sequences around the world. From this information, geologists create the geologic column, as illustrated in **Figure 2**. The **geologic column** is an ideal sequence of rock layers that contains all the known fossils and rock formations on Earth, arranged from oldest to youngest.

Geologists rely on the geologic column to interpret rock sequences. Geologists also use the geologic column to identify the layers in puzzling rock sequences.

Reading Check List two ways in which geologists use the geologic column. (See the Appendix for answers to Reading Checks.)

relative dating any method of determining whether an event or object is older or younger than other events or objects

superposition a principle that states that younger rocks lie above older rocks if the layers have not been disturbed

geologic column an arrangement of rock layers in which the oldest rocks are at the bottom

Figure 2 Constructing the Geologic Column

Here, you can see three rock sequences (A, B, and C) from three different locations. Some rock layers appear in more than one sequence. Geologists construct the geologic column by piecing together different rock sequences from all over the world.

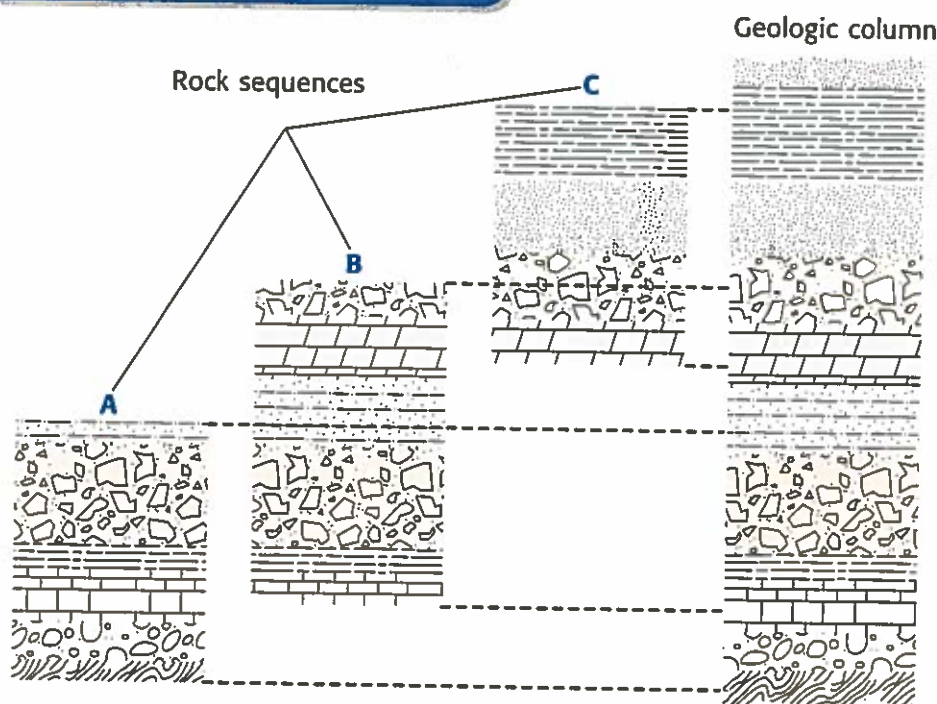
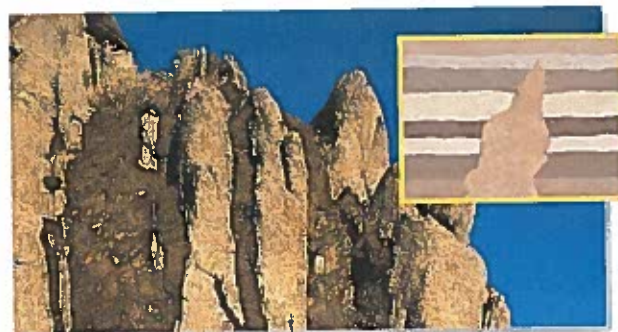


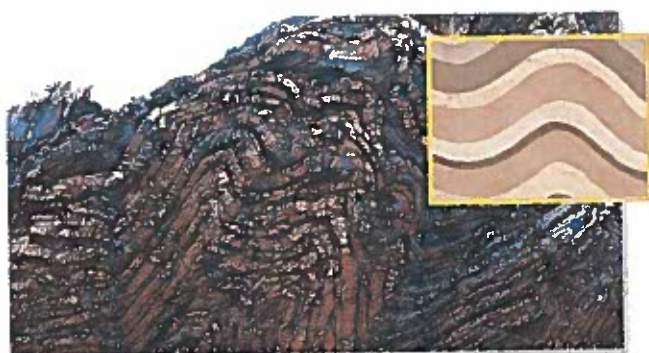
Figure 3 How Rock Layers Become Disturbed



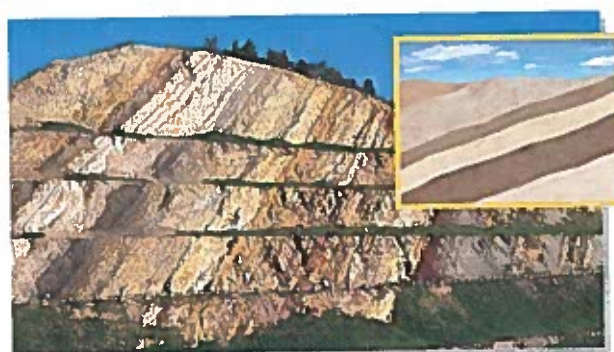
Fault A *fault* is a break in the Earth's crust along which blocks of the crust slide relative to one another.



Intrusion An *intrusion* is molten rock from the Earth's interior that squeezes into existing rock and cools.



Folding Folding occurs when rock layers bend and buckle from Earth's internal forces.



Tilting Tilting occurs when internal forces in the Earth slant rock layers.

Disturbed Rock Layers

Geologists often find features that cut across existing layers of rock. Geologists use the relationships between rock layers and the features that cut across them to assign relative ages to the features and the layers. They know that the features are younger than the rock layers because the rock layers had to be present before the features could cut across them. Faults and intrusions are examples of features that cut across rock layers. A fault and an intrusion are illustrated in **Figure 3**.

Events That Disturb Rock Layers

Geologists assume that the way sediment is deposited to form rock layers—in horizontal layers—has not changed over time. According to this principle, if rock layers are not horizontal, something must have disturbed them after they formed. This principle allows geologists to determine the relative ages of rock layers and the events that disturbed them.

Folding and tilting are two types of events that disturb rock layers. These events are always younger than the rock layers they affect. The results of folding and tilting are shown in **Figure 3**.

Gaps in the Record—Unconformities

Faults, intrusions, and the effects of folding and tilting can make dating rock layers a challenge. Sometimes, layers of rock are missing altogether, creating a gap in the geologic record. To think of this another way, let's say that you stack your newspapers every day after reading them. Now, let's suppose you want to look at a paper you read 10 days ago. You know that the paper should be 10 papers deep in the stack. But when you look, the paper is not there. What happened? Perhaps you forgot to put the paper in the stack. Now, imagine a missing rock layer instead of a missing newspaper.

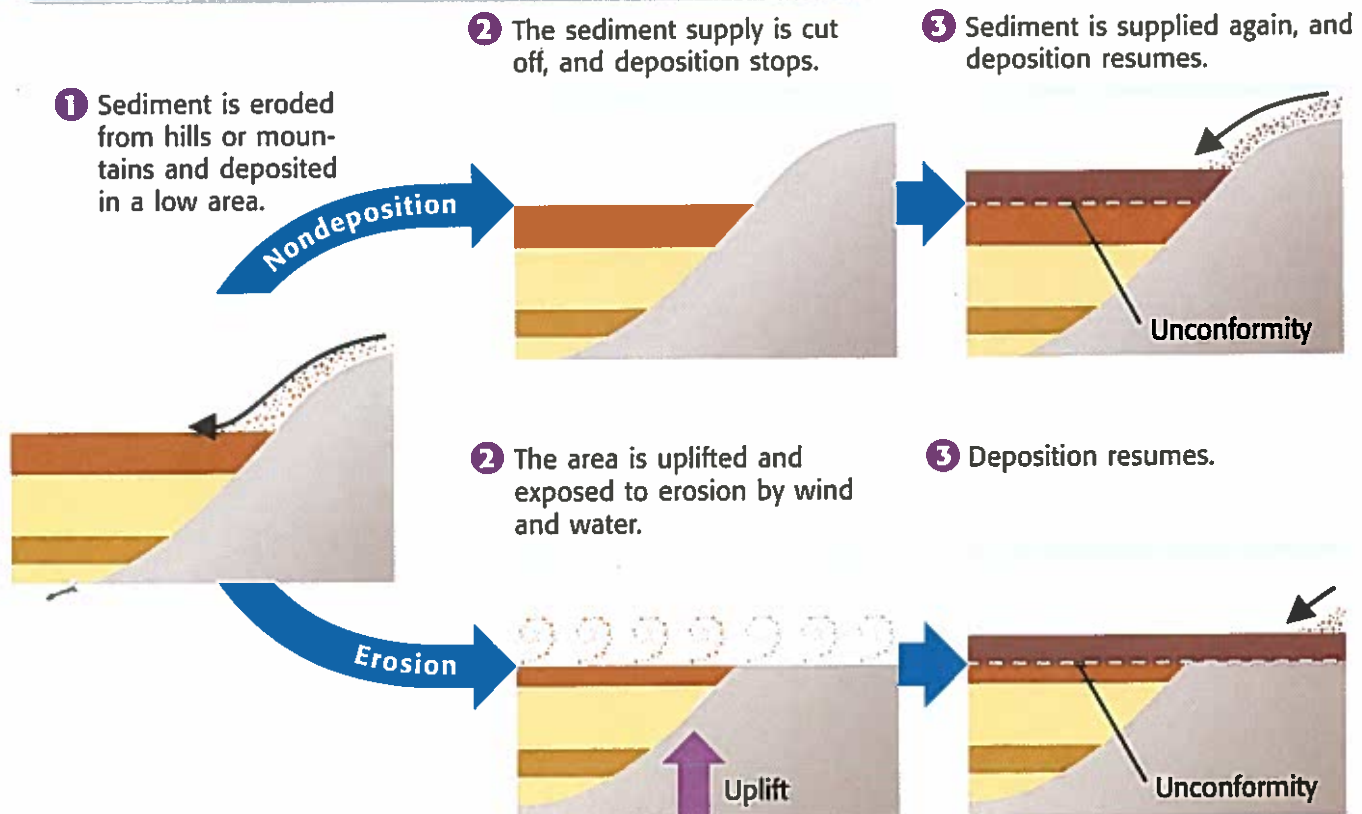
Missing Evidence

Missing rock layers create breaks in rock-layer sequences called unconformities. An **unconformity** is a surface that represents a missing part of the geologic column. Unconformities also represent missing time—time that was not recorded in layers of rock. When geologists find an unconformity, they must question whether the “missing layer” was never present or whether it was somehow removed. **Figure 4** shows how *nondeposition*, or the stoppage of deposition when a supply of sediment is cut off, and *erosion* create unconformities.

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

 **Reading Check** Define the term unconformity.

Figure 4 How Unconformities Are Created



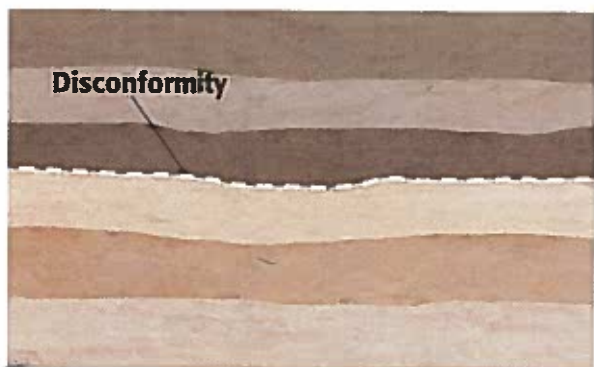


Figure 5 A disconformity exists where part of a sequence of parallel rock layers is missing.

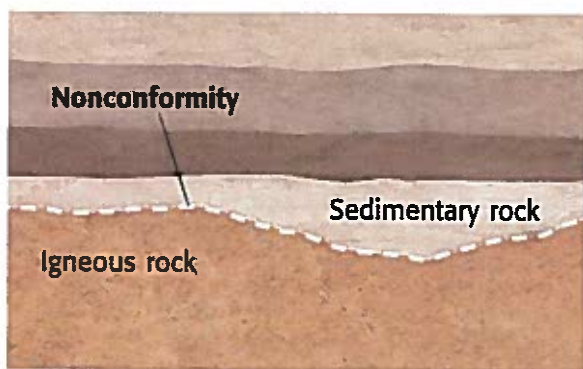


Figure 6 A nonconformity exists where sedimentary rock layers lie on top of an eroded surface of nonlayered igneous or metamorphic rock.

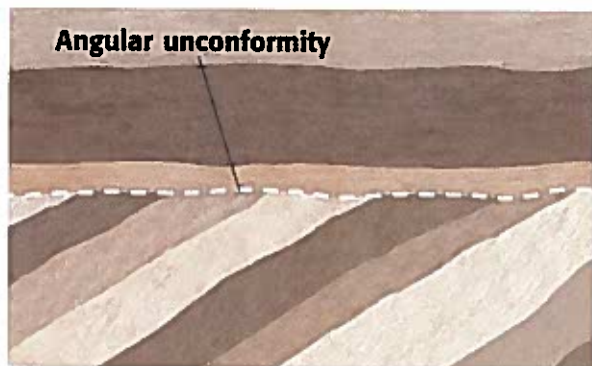


Figure 7 An angular unconformity exists between horizontal rock layers and rock layers that are tilted or folded.

Types of Unconformities

Most unconformities form by both erosion and nondeposition. But other factors can complicate matters. To simplify the study of unconformities, geologists place them into three major categories: disconformities, nonconformities, and angular unconformities. The three diagrams at left illustrate these three categories.

Disconformities

The most common type of unconformity is a disconformity, which is illustrated in **Figure 5**. Disconformities are found where part of a sequence of parallel rock layers is missing. A disconformity can form in the following way. A sequence of rock layers is uplifted. Younger layers at the top of the sequence are removed by erosion, and the eroded material is deposited elsewhere. At some future time, deposition resumes, and sediment buries the old erosion surface. The disconformity that results shows where erosion has taken place and rock layers are missing. A disconformity represents thousands to many millions of years of missing time.

Nonconformities

A nonconformity is illustrated in **Figure 6**. Nonconformities are found where horizontal sedimentary rock layers lie on top of an eroded surface of older intrusive igneous or metamorphic rock. Intrusive igneous and metamorphic rocks form deep within the Earth. When these rocks are raised to Earth's surface, they are eroded. Deposition causes the erosion surface to be buried. Nonconformities represent millions of years of missing time.

Angular Unconformities

An angular unconformity is shown in **Figure 7**. Angular unconformities are found between horizontal layers of sedimentary rock and layers of rock that have been tilted or folded. The tilted or folded layers were eroded before horizontal layers formed above them. Angular unconformities represent millions of years of missing time.

 **Reading Check** Describe each of the three major categories of unconformities.

Rock-Layer Puzzles

Geologists often find rock-layer sequences that have been affected by more than one of the events and features mentioned in this section. For example, as shown in **Figure 8**, intrusions may squeeze into rock layers that contain an unconformity. Determining the order of events that led to such a sequence is like piecing together a jigsaw puzzle. Geologists must use their knowledge of the events that disturb or remove rock-layer sequences to help piece together the history of Earth as told by the rock record.



Figure 8 Rock-layer sequences are often disturbed by more than one rock-disturbing feature.

SECTION Review

Summary

- Geologists use relative dating to determine the order in which events happen.
- The principle of superposition states that in undisturbed rock sequences, younger layers lie above older layers.
- Folding and tilting are two events that disturb rock layers. Faults and intrusions are two features that disturb rock layers.
- The known rock and fossil record is indicated by the geologic column.
- Geologists examine the relationships between rock layers and the structures that cut across them in order to determine relative ages.

Using Key Terms

1. In your own words, write a definition for each of the following terms: *relative dating*, *superposition*, and *geologic column*.

Understanding Key Ideas

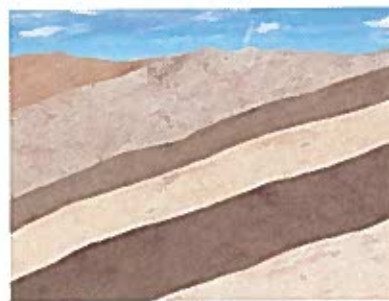
2. Molten rock that squeezes into existing rock and cools is called a(n)
 - a. fold.
 - b. fault.
 - c. intrusion.
 - d. unconformity.
3. List two events and two features that can disturb rock-layer sequences.
4. Explain how physical features are used to determine relative ages.

Critical Thinking

5. **Analyzing Concepts** Is there a place on Earth that has all the layers of the geologic column? Explain.
6. **Analyzing Ideas** Disconformities are hard to recognize because all of the layers are horizontal. How does a geologist know when he or she is looking at a disconformity?

Interpreting Graphics

Use the illustration below to answer the question that follows.



7. If the top rock layer were eroded and deposition later resumed, what type of unconformity would mark the boundary between older rock layers and the newly deposited rock layers?

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Topic: Relative Dating

SciLinks code: HSM1288

SECTION

3

READING WARM-UP

Objectives

- Describe how radioactive decay occurs.
- Explain how radioactive decay relates to radiometric dating.
- Identify four types of radiometric dating.
- Determine the best type of radiometric dating to use to date an object.

Terms to Learn

absolute dating
isotope
radioactive decay
radiometric dating
half-life

READING STRATEGY

Reading Organizer As you read this section, make a concept map by using the terms above.

Absolute Dating: A Measure of Time

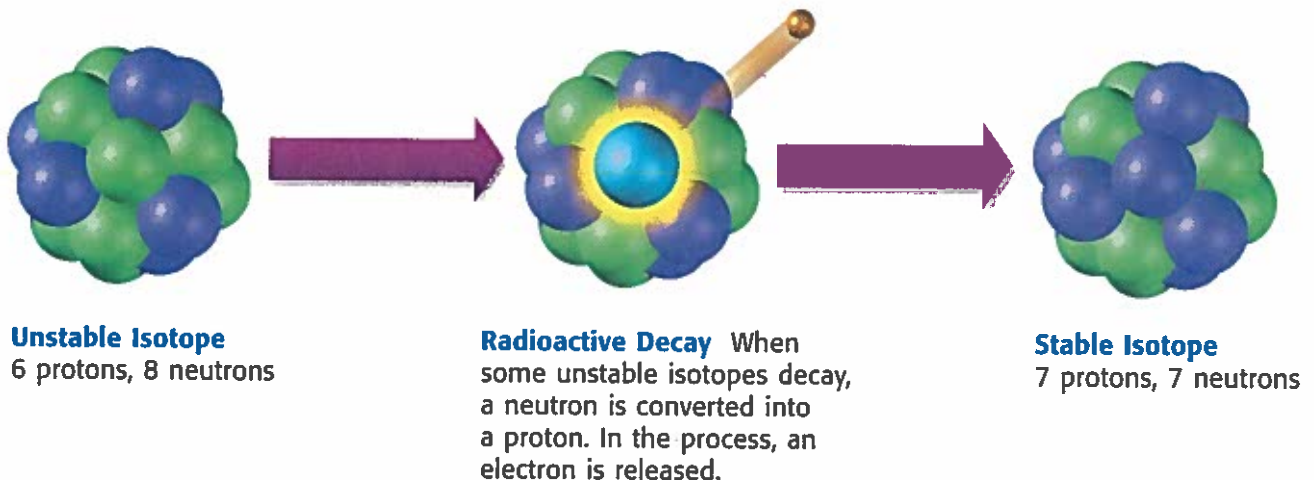
Have you ever heard the expression “turning back the clock”? With the discovery of the natural decay of uranium in 1896, French physicist Henri Becquerel provided a means of doing just that. Scientists could use radioactive elements as clocks to measure geologic time.

The process of establishing the age of an object by determining the number of years it has existed is called **absolute dating**. In this section, you will learn about radiometric dating, which is the most common method of absolute dating.

Radioactive Decay

To determine the absolute ages of fossils and rocks, scientists analyze isotopes of radioactive elements. Atoms of the same element that have the same number of protons but have different numbers of neutrons are called **isotopes**. Most isotopes are stable, meaning that they stay in their original form. But some isotopes are unstable. Scientists call unstable isotopes **radioactive**. Radioactive isotopes tend to break down into stable isotopes of the same or other elements in a process called **radioactive decay**. **Figure 1** shows an example of how radioactive decay occurs. Because radioactive decay occurs at a steady rate, scientists can use the relative amounts of stable and unstable isotopes present in an object to determine the object's age.

Figure 1 Radioactive Decay



Dating Rocks—How Does It Work?

In the process of radioactive decay, an unstable radioactive isotope of one element breaks down into a stable isotope. The stable isotope may be of the same element or, more commonly, a different element. The unstable radioactive isotope is called the *parent isotope*. The stable isotope produced by the radioactive decay of the parent isotope is called the *daughter isotope*. The radioactive decay of a parent isotope into a stable daughter isotope can occur in a single step or a series of steps. In either case, the rate of decay is constant. Therefore, to date rock, scientists compare the amount of parent material with the amount of daughter material. The more daughter material there is, the older the rock is.

Radiometric Dating

If you know the rate of decay for a radioactive element in a rock, you can figure out the absolute age of the rock. Determining the absolute age of a sample, based on the ratio of parent material to daughter material, is called **radiometric dating**. For example, let's say that a rock sample contains an isotope with a half-life of 10,000 years. A **half-life** is the time that it takes one-half of a radioactive sample to decay. So, for this rock sample, in 10,000 years, half the parent material will have decayed and become daughter material. You analyze the sample and find equal amounts of parent material and daughter material. This means that half the original radioactive isotope has decayed and that the sample must be about 10,000 years old.

What if one-fourth of your sample is parent material and three-fourths is daughter material? You would know that it took 10,000 years for half the original sample to decay and another 10,000 years for half of what remained to decay. The age of your sample would be $2 \times 10,000$, or 20,000, years. **Figure 2** shows how this steady decay happens.

 **Reading Check** What is a half-life? (See the Appendix for answers to Reading Checks.)

absolute dating any method of measuring the age of an event or object in years

isotope an atom that has the same number of protons (or the same atomic number) as other atoms of the same element do but that has a different number of neutrons (and thus a different atomic mass)

radioactive decay the process in which a radioactive isotope tends to break down into a stable isotope of the same element or another element

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

half-life the time needed for half of a sample of a radioactive substance to undergo radioactive decay

Figure 2 After every half-life, the amount of parent material decreases by one-half.

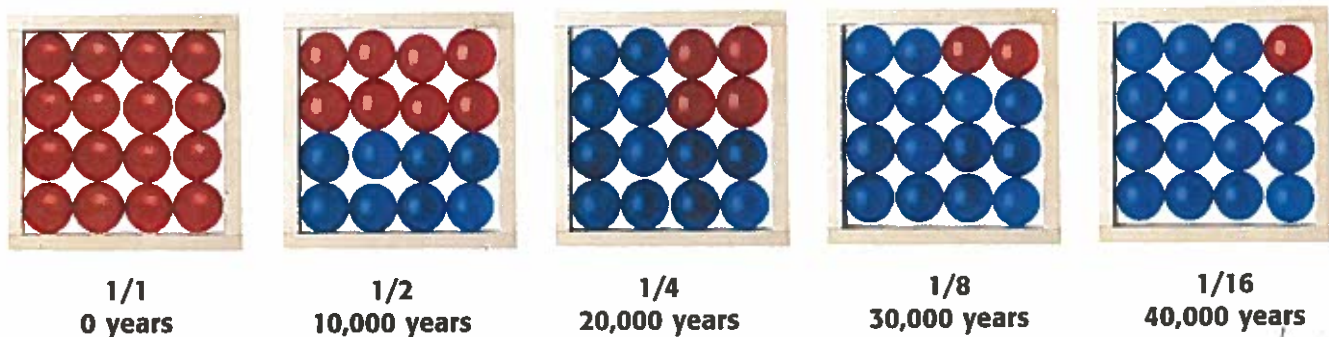




Figure 3 This burial mound at Effigy Mounds resembles a snake.

Types of Radiometric Dating

Imagine traveling back through the centuries to a time before Columbus arrived in America. You are standing along the bluffs of what will one day be called the Mississippi River. You see dozens of people building large mounds. Who are these people, and what are they building?

The people you saw in your time travel were Native Americans, and the structures they were building were burial mounds. The area you imagined is now an archaeological site called Effigy Mounds National Monument. **Figure 3** shows one of these mounds.

According to archaeologists, people lived at Effigy Mounds from 2,500 years ago to 600 years ago. How do archaeologists know these dates? They have dated bones and other objects in the mounds by using radiometric dating. Scientists use different radiometric-dating techniques based on the estimated age of an object. As you read on, think about how the half-life of an isotope relates to the age of the object being dated. Which technique would you use to date the burial mounds?

Potassium-Argon Method

One isotope that is used for radiometric dating is potassium-40. Potassium-40 has a half-life of 1.3 billion years, and it decays to argon and calcium. Geologists measure argon as the daughter material. This method is used mainly to date rocks older than 100,000 years.

Uranium-Lead Method

Uranium-238 is a radioactive isotope that decays in a series of steps to lead-206. The half-life of uranium-238 is 4.5 billion years. The older the rock is, the more daughter material (lead-206) there will be in the rock. Uranium-lead dating can be used for rocks more than 10 million years old. Younger rocks do not contain enough daughter material to be accurately measured by this method.

Rubidium-Strontium Method

Through radioactive decay, the unstable parent isotope rubidium-87 forms the stable daughter isotope strontium-87. The half-life of rubidium-87 is 49 billion years. This method is used to date rocks older than 10 million years.

 **Reading Check** What is the daughter isotope of rubidium-87?

Carbon-14 Method

The element carbon is normally found in three forms, the stable isotopes carbon-12 and carbon-13 and the radioactive isotope carbon-14. These carbon isotopes combine with oxygen to form the gas carbon dioxide, which is taken in by plants during photosynthesis. As long as a plant is alive, new carbon dioxide with a constant carbon-14 to carbon-12 ratio is continually taken in. Animals that eat plants contain the same ratio of carbon isotopes.

Once a plant or an animal dies, however, no new carbon is taken in. The amount of carbon-14 begins to decrease as the plant or animal decays, and the ratio of carbon-14 to carbon-12 decreases. This decrease can be measured in a laboratory, such as the one shown in **Figure 4**. Because the half-life of carbon-14 is only 5,730 years, this dating method is used mainly for dating things that lived within the last 50,000 years.



Figure 4 Some samples containing carbon must be cleaned and burned before their age can be determined.

SECTION Review

Summary

- During radioactive decay, an unstable isotope decays at a constant rate and becomes a stable isotope of the same or a different element.
- Radiometric dating, based on the ratio of parent to daughter material, is used to determine the absolute age of a sample.
- Methods of radiometric dating include potassium-argon, uranium-lead, rubidium-strontium, and carbon-14 dating.

Using Key Terms

- Use each of the following terms in a separate sentence: *absolute dating*, *isotope*, and *half-life*.

Understanding Key Ideas

- Rubidium-87 has a half-life of
 - 5,730 years.
 - 4.5 billion years.
 - 49 billion years.
 - 1.3 billion years.
- Explain how radioactive decay occurs.
- How does radioactive decay relate to radiometric dating?
- List four types of radiometric dating.

Math Skills

- A radioactive isotope has a half-life of 1.3 billion years. After 3.9 billion years, how much of the parent material will be left?

Critical Thinking

- Analyzing Methods** Explain why radioactive decay must be constant in order for radiometric dating to be accurate.
- Applying Concepts** Which radiometric-dating method would be most appropriate for dating artifacts found at Effigy Mounds? Explain.

SCILINKS.

NSTA

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For a variety of links related to this chapter, go to www.scilinks.org

Topic: **Absolute Dating**
SciLinks code: **HSM0003**

SECTION

4

READING WARM-UP

Objectives

- Describe five ways that different types of fossils form.
- List three types of fossils that are not part of organisms.
- Explain how fossils can be used to determine the history of changes in environments and organisms.
- Explain how index fossils can be used to date rock layers.

Terms to Learn

fossil
trace fossil
mold
cast
index fossil

READING STRATEGY

Reading Organizer As you read this section, create an outline of the section. Use the headings from this section in your outline.

Looking at Fossils

Descending from the top of a ridge in the badlands of Argentina, your expedition team suddenly stops. You look down and realize that you are walking on eggshells—dinosaur eggshells!

A paleontologist named Luis Chiappe had this experience. He had found an enormous dinosaur nesting ground.

Fossilized Organisms

The remains or physical evidence of an organism preserved by geologic processes is called a **fossil**. Fossils are most often preserved in sedimentary rock. But as you will see, other materials can also preserve evidence of past life.

Fossils in Rocks

When an organism dies, it either immediately begins to decay or is consumed by other organisms. Sometimes, however, organisms are quickly buried by sediment when they die. The sediment slows down decay. Hard parts of organisms, such as shells and bones, are more resistant to decay than soft tissues are. So, when sediments become rock, the hard parts of animals are much more commonly preserved than are soft tissues.

Fossils in Amber

Imagine that an insect is caught in soft, sticky tree sap. Suppose that the insect gets covered by more sap, which quickly hardens and preserves the insect inside. Hardened tree sap is called **amber**. Some of our best insect fossils are found in amber, as shown in **Figure 1**. Frogs and lizards have also been found in amber.

✓ Reading Check Describe how organisms are preserved in amber. (See the Appendix for answers to Reading Checks.)

Figure 1 These insects are preserved in amber.





Figure 2 Scientist Vladimir Eisner studies the upper molars of a 20,000-year-old woolly mammoth found in Siberia, Russia. The almost perfectly preserved male mammoth was excavated from a block of ice in October 1999.

Petrifaction

Another way that organisms are preserved is by petrification. *Petrification* is a process in which minerals replace an organism's tissues. One form of petrification is called *permineralization*. *Permineralization* is a process in which the pore space in an organism's hard tissue—for example, bone or wood—is filled up with mineral. Another form of petrification is called *replacement*, a process in which the organism's tissues are completely replaced by minerals. For example, in some specimens of petrified wood, all of the wood has been replaced by minerals.

Fossils in Asphalt

There are places where asphalt wells up at the Earth's surface in thick, sticky pools. The La Brea asphalt deposits in Los Angeles, California, for example, are at least 38,000 years old. These pools of thick, sticky asphalt have trapped and preserved many kinds of organisms for the past 38,000 years. From these fossils, scientists have learned about the past environment in southern California.

Frozen Fossils

In October 1999, scientists removed a 20,000-year-old woolly mammoth frozen in the Siberian tundra. The remains of this mammoth are shown in **Figure 2**. Woolly mammoths, relatives of modern elephants, became extinct approximately 10,000 years ago. Because cold temperatures slow down decay, many types of frozen fossils are preserved from the last ice age. Scientists hope to find out more about the mammoth and the environment in which it lived.

fossil the remains or physical evidence of an organism preserved by geological processes

CONNECTION TO Environmental Science

WRITING SKILL

Preservation in Ice

Subfreezing climates contain almost no decomposing bacteria. The well-preserved body of John Torrington, a member of an expedition that explored the Northwest Passage in Canada in the 1840s, was uncovered in 1984. His body appeared much as it did at the time he died, more than 160 years earlier. Research another well-preserved discovery, and write a report for your class.

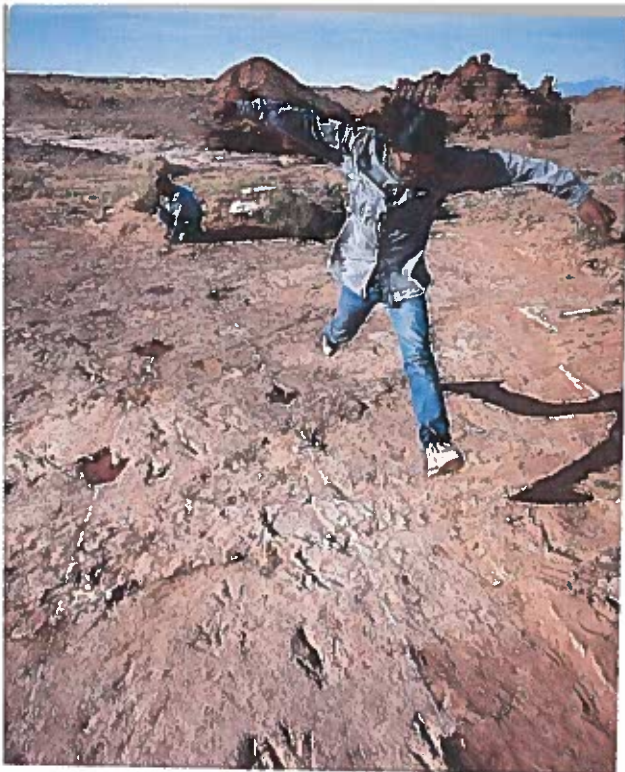


Figure 3 These dinosaur tracks are located in Arizona. They leave a trace of a dinosaur that had longer legs than humans do.

trace fossil a fossilized mark that is formed in soft sediment by the movement of an animal

mold a mark or cavity made in a sedimentary surface by a shell or other body

cast a type of fossil that forms when sediments fill in the cavity left by a decomposed organism

Other Types of Fossils

Besides their hard parts—and in rare cases their soft parts—do organisms leave behind any other clues about their existence? What other evidence of past life do paleontologists look for?

Trace Fossils

Any naturally preserved evidence of animal activity is called a **trace fossil**. Tracks like the ones shown in **Figure 3** are a fascinating example of a trace fossil. These fossils form when animal footprints fill with sediment and are preserved in rock. Tracks reveal a lot about the animal that made them, including how big it was and how fast it was moving. Parallel trackways showing dinosaurs moving in the same direction have led paleontologists to hypothesize that dinosaurs moved in herds.

Burrows are another trace fossil. Burrows are shelters made by animals, such as clams, that bury in sediment. Like tracks, burrows are preserved when they are filled in with sediment and buried quickly. A *coprolite* (KAHP roh LIET), a third type of trace fossil, is preserved animal dung.

Molds and Casts

Molds and casts are two more examples of fossils. A cavity in rock where a plant or animal was buried is called a **mold**. A **cast** is an object created when sediment fills a mold and becomes rock. A cast shows what the outside of the organism looked like. **Figure 4** shows two types of molds from the same organism—and internal mold and an external mold.

Reading Check How are a cast and a mold different?

Figure 4 This photograph shows two molds from an ammonite. The image on the left is the internal mold of the ammonite, which formed when sediment filled the ammonite's shell, which later dissolved away. The image on the right is the external mold of the ammonite, which preserves the external features of the shell.



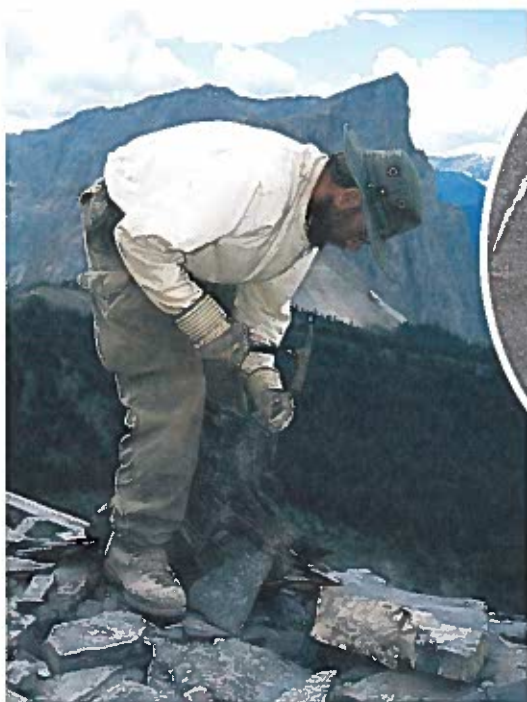


Figure 5 This scientist has found marine fossils on mountaintops in the Yoho National Park in Canada. The fossil of *Marrella*, shown above, tells the scientist that these rocks were pushed up from below sea level millions of years ago.

Using Fossils to Interpret the Past

Think about your favorite outdoor place. Now, imagine that you are a paleontologist at the same site 65 million years from now. What types of fossils would you dig up? Based on the fossils you found, how would you reconstruct this place?

The Information in the Fossil Record

The fossil record offers only a rough sketch of the history of life on Earth. Some parts of this history are more complete than others. For example, scientists know more about organisms that had hard body parts than about organisms that had soft body parts. Scientists also know more about organisms that lived in environments that favored fossilization. The fossil record is incomplete because most organisms never became fossils. And of course, many fossils have yet to be discovered.

History of Environmental Changes

Would you expect to find marine fossils on the mountaintop shown in **Figure 5**? The presence of marine fossils means that the rocks of these mountaintops in Canada formed in a totally different environment—at the bottom of an ocean.

The fossil record reveals a history of environmental change. For example, marine fossils help scientists reconstruct ancient coastlines and the deepening and shallowing of ancient seas. Using the fossils of plants and land animals, scientists can reconstruct past climates. They can tell whether the climate in an area was cooler or wetter than it is at present.

QUICK LAB

Make a Fossil

1. Find a **common object**, such as a shell, a button, or a pencil, to use to make a mold. Keep the object hidden from your classmates.
2. To create a mold, press the item down into **modeling clay** in a shallow pan or tray.
3. Trade your tray with a classmate's tray, and try to identify the item that made the mold.
4. Describe how a cast could be formed from your mold.

SCHOOL to HOME

Fossil Hunt

Go on a fossil hunt with your family. Find out what kinds of rocks in your local area might contain fossils. Take pictures or draw sketches of your trip and any fossils that you find.

ACTIVITY

index fossil a fossil that is found in the rock layers of only one geologic age and that is used to establish the age of the rock layers

History of Changing Organisms

By studying the relationships between fossils, scientists can interpret how life has changed over time. For example, older rock layers contain organisms that often differ from the organisms found in younger rock layers.

Only a small fraction of the organisms that have existed in Earth's history have been fossilized. Because the fossil record is incomplete, it does not provide paleontologists with a continuous record of change. Instead, they look for similarities between fossils, or between fossilized organisms and their closest living relatives, and try to fill in the blanks in the fossil record.

✓ Reading Check How do paleontologists fill in missing information about changes in organisms in the fossil record?

Using Fossils to Date Rocks

Scientists have found that particular types of fossils appear only in certain layers of rock. By dating the rock layers above and below these fossils, scientists can determine the time span in which the organisms that formed the fossils lived. If a type of organism existed for only a short period of time, its fossils would show up in a limited range of rock layers. These types of fossils are called index fossils. **Index fossils** are fossils of organisms that lived during a relatively short, well-defined geologic time span.

Ammonites

To be considered an index fossil, a fossil must be found in rock layers throughout the world. One example of an index fossil is the fossil of a genus of ammonites (AM uh NIETS) called *Tropites*, shown in **Figure 6**. *Tropites* was a marine mollusk similar to a modern squid. It lived in a coiled shell. *Tropites* lived between 230 million and 208 million years ago and is an index fossil for that period of time.



Figure 6 *Tropites* is a genus of coiled ammonites. *Tropites* existed for only about 20 million years, which makes this genus a good index fossil.

Trilobites

Fossils of a genus of trilobites (TRIE loh BIETS) called *Phacops* are another example of an index fossil. Trilobites are extinct. Their closest living relative is the horseshoe crab. Through the dating of rock, paleontologists have determined that *Phacops* lived approximately 400 million years ago. So, when scientists find *Phacops* in rock layers anywhere on Earth, they assume that these rock layers are also approximately 400 million years old. An example of a *Phacops* fossil is shown in **Figure 7**.

✓ Reading Check Explain how fossils of *Phacops* can be used to establish the age of rock layers.



Figure 7 Paleontologists assume that any rock layer containing a fossil of the trilobite *Phacops* is about 400 million years old.

SECTION Review

Summary

- Fossils are the remains or physical evidence of an organism preserved by geologic processes.
- Fossils can be preserved in rock, amber, asphalt, and ice and by petrification.
- Trace fossils are any naturally preserved evidence of animal activity. Tracks, burrows, and coprolites are examples of trace fossils.
- Scientists study fossils to determine how environments and organisms have changed over time.
- An index fossil is a fossil of an organism that lived during a relatively short, well-defined time span. Index fossils can be used to establish the age of rock layers.

Using Key Terms

Complete each of the following sentences by choosing the correct term from the word bank.

cast index fossils
mold trace fossils

1. A ___ is a cavity in rock where a plant or animal was buried.
2. ___ can be used to establish the age of rock layers.

Understanding Key Ideas

3. Fossils are most often preserved in
 - a. ice.
 - b. amber.
 - c. asphalt.
 - d. rock.
4. Describe three types of trace fossils.
5. Explain how an index fossil can be used to date rock.
6. Explain why the fossil record contains an incomplete record of the history of life on Earth.
7. Explain how fossils can be used to determine the history of changes in environments and organisms.

Math Skills

8. If a scientist finds the remains of a plant between a rock layer that contains 400 million-year-old *Phacops* fossils and a rock layer that contains 230 million-year-old *Tropites* fossils, how old could the plant fossil be?

Critical Thinking

9. **Making Inferences** If you find rock layers containing fish fossils in a desert, what can you infer about the history of the desert?
10. **Identifying Bias** Because information in the fossil record is incomplete, scientists are left with certain biases concerning fossil preservation. Explain two of these biases.

SCI LINKS.

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chapter, go to www.scilinks.org

Topic: Looking at Fossils

SciLinks code: HSM0886

SECTION

5

READING WARM-UP

Objectives

- Explain how geologic time is recorded in rock layers.
- Identify important dates on the geologic time scale.
- Explain how environmental changes resulted in the extinction of some species.

Terms to Learn

geologic time scale	period
eon	epoch
era	extinction

READING STRATEGY

Brainstorming The key idea of this section is the geologic time scale. Brainstorm words and phrases related to the geologic time scale.

Figure 1 Bones of dinosaurs that lived about 150 million years ago are exposed in the quarry wall at Dinosaur National Monument in Utah.

Time Marches On

How old is the Earth? Well, if the Earth celebrated its birthday every million years, there would be 4,600 candles on its birthday cake! Humans have been around only long enough to light the last candle on the cake.

Try to think of the Earth's history in "fast-forward." If you could watch the Earth change from this perspective, you would see mountains rise up like wrinkles in fabric and quickly wear away. You would see life-forms appear and then go extinct. In this section, you will learn that geologists must "fast-forward" the Earth's history when they write or talk about it. You will also learn about some incredible events in the history of life on Earth.

Geologic Time

Shown in **Figure 1** is the rock wall at the Dinosaur Quarry Visitor Center in Dinosaur National Monument, Utah. Contained within this wall are approximately 1,500 fossil bones that have been excavated by paleontologists. These are the remains of dinosaurs that inhabited the area about 150 million years ago. Granted, 150 million years seems to be an incredibly long period of time. However, in terms of the Earth's history, 150 million years is little more than 3% of the time our planet has existed. It is a little less than 4% of the time represented by the Earth's oldest known rocks.





Figure 2 Well-preserved plant and animal fossils are common in the Green River formation. Clockwise from the upper right are a fossil leaf, a dragonfly, a fish, and a turtle.

The Rock Record and Geologic Time

One of the best places in North America to see the Earth's history recorded in rock layers is in Grand Canyon National Park. The Colorado River has cut the canyon nearly 2 km deep in some places. Over the course of 6 million years, the river has eroded countless layers of rock. These layers represent almost half, or nearly 2 billion years, of Earth's history.

Reading Check How much geologic time is represented by the rock layers in the Grand Canyon? (See the Appendix for answers to Reading Checks.)

The Fossil Record and Geologic Time

Figure 2 shows sedimentary rocks that belong to the Green River formation. These rocks, which are found in parts of Wyoming, Utah, and Colorado, are thousands of meters thick. These rocks were once part of a system of ancient lakes that existed for a period of millions of years. Fossils of plants and animals are common in these rocks and are very well preserved. Burial in the fine-grained lake-bed sediments preserved even the most delicate structures.

INTERNET ACTIVITY

For another activity related to this chapter, go to go.hrw.com and type in the keyword HZ5FOSW.

Phanerozoic Eon

(543 million years ago to the present)

The rock and fossil record mainly represents the Phanerozoic eon, which is the eon in which we live.

Proterozoic Eon

(2.5 billion years ago to 543 million years ago)

The first organisms with well-developed cells appeared during this eon.

Archean Eon

(3.8 billion years ago to 2.5 billion years ago)

The earliest known rocks on Earth formed during this eon.

Hadean Eon

(4.6 billion years ago to 3.8 billion years ago)

The only rocks that scientists have found from this eon are meteorites and rocks from the moon.

Geologic Time Scale				
PHANEROZOIC EON	Era	Period	Epoch	Millions of years ago
	Cenozoic	Quaternary	Holocene	0.01
			Pleistocene	1.8
		Tertiary	Pliocene	5.3
			Miocene	23.8
			Oligocene	33.7
			Eocene	54.8
			Paleocene	65
	Mesozoic	Cretaceous		144
		Jurassic		206
		Triassic		248
	Paleozoic	Permian		290
		Pennsylvanian		323
		Mississippian		354
		Devonian		417
		Silurian		443
		Ordovician		490
		Cambrian		543
PROTEROZOIC EON				2,500
ARCHEAN EON				3,800
HADEAN EON				4,600

Figure 3 The geologic time scale accounts for Earth's entire history. It is divided into four major parts called eons. Dates given for intervals on the geologic time scale are estimates.

The Geologic Time Scale

The geologic column represents the billions of years that have passed since the first rocks formed on Earth. Altogether, geologists study 4.6 billion years of Earth's history! To make their job easier, geologists have created the geologic time scale. The **geologic time scale**, which is shown in **Figure 3**, is a scale that divides Earth's 4.6 billion-year history into distinct intervals of time.

 **Reading Check** Define the term *geologic time scale*.

Divisions of Time

Geologists have divided Earth's history into sections of time, as shown on the geologic time scale in **Figure 3**. The largest divisions of geologic time are **eons** (EE ahnz). There are four eons—the Hadean eon, the Archean eon, the Proterozoic eon, and the Phanerozoic eon. The Phanerozoic eon is divided into three **eras**, which are the second-largest divisions of geologic time. The three eras are further divided into **periods**, which are the third-largest divisions of geologic time. Periods are divided into **epochs** (EP uhks), which are the fourth-largest divisions of geologic time.

The boundaries between geologic time intervals represent shorter intervals in which visible changes took place on Earth. Some changes are marked by the disappearance of index fossil species, while others are recognized only by detailed paleontological studies.

The Appearance and Disappearance of Species

At certain times during Earth's history, the number of species has increased or decreased dramatically. An increase in the number of species often comes as a result of either a relatively sudden increase or decrease in competition among species. *Hallucigenia*, shown in **Figure 4**, appeared during the Cambrian period, when the number of marine species greatly increased. On the other hand, the number of species decreases dramatically over a relatively short period of time during a mass extinction event. **Extinction** is the death of every member of a species. Gradual events, such as global climate change and changes in ocean currents, can cause mass extinctions. A combination of these events can also cause mass extinctions.

geologic time scale the standard method used to divide the Earth's long natural history into manageable parts

eon the largest division of geologic time

era a unit of geologic time that includes two or more periods

period a unit of geologic time into which eras are divided

epoch a subdivision of a geologic period

extinction the death of every member of a species

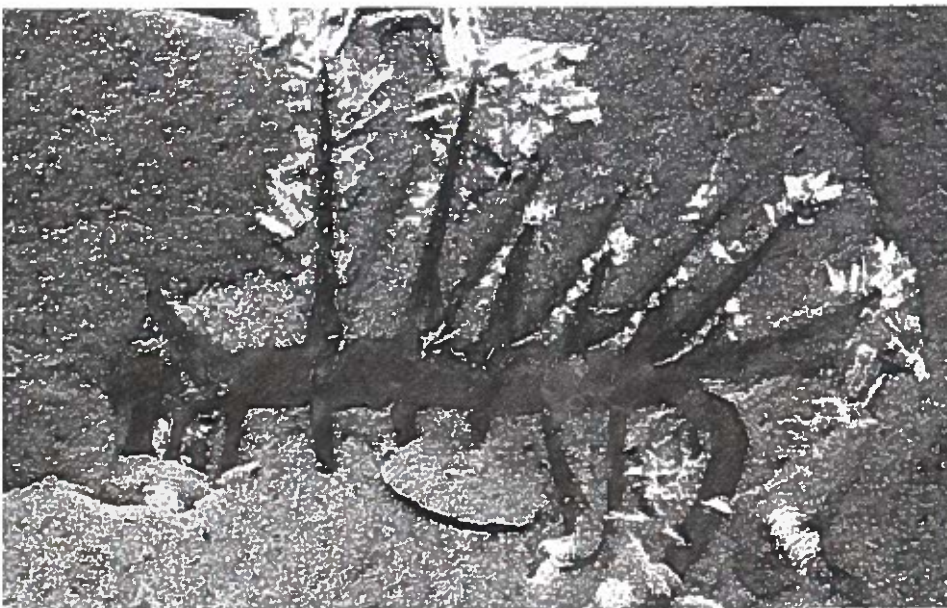


Figure 4 *Hallucigenia*, named for its "bizarre and dreamlike quality," was one of numerous marine organisms to make its appearance during the early Cambrian period.

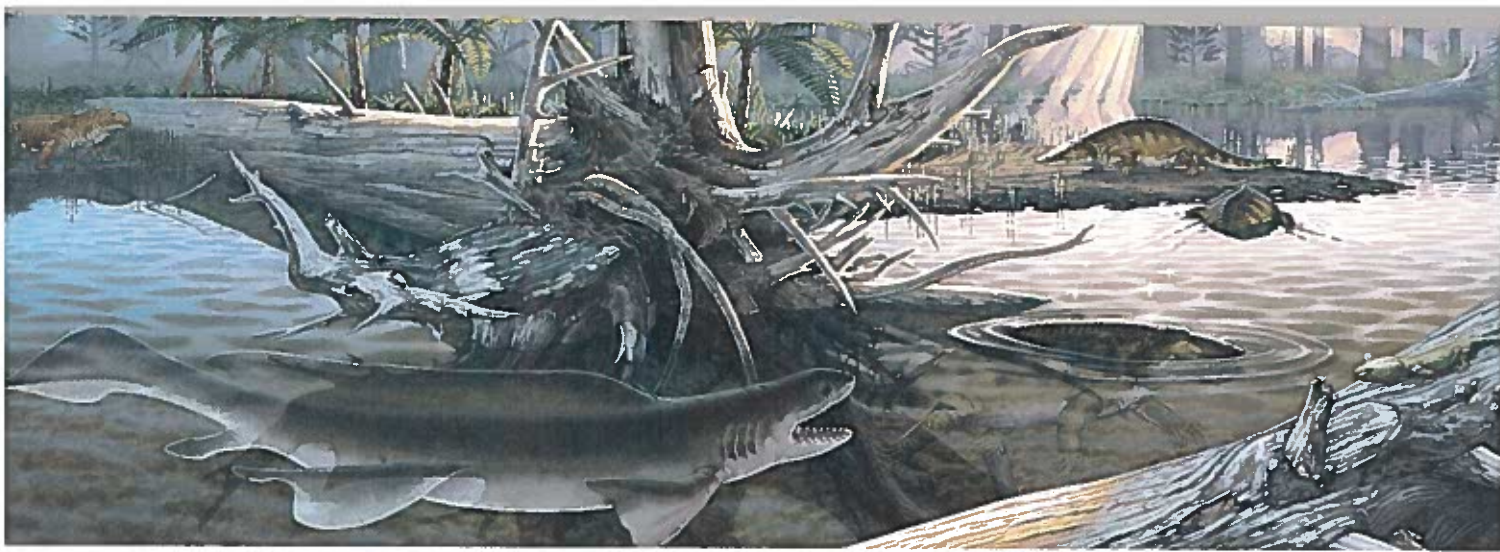


Figure 5 Jungles were present during the Paleozoic era, but there were no birds singing in the trees and no monkeys swinging from the branches. Birds and mammals didn't evolve until much later.

The Paleozoic Era—Old Life

The Paleozoic era lasted from about 543 million to 248 million years ago. It is the first era well represented by fossils.

Marine life flourished at the beginning of the Paleozoic era. The oceans became home to a diversity of life. However, there were few land organisms. By the middle of the Paleozoic, all modern groups of land plants had appeared. By the end of the era, amphibians and reptiles lived on the land, and insects were abundant. **Figure 5** shows what the Earth might have looked like late in the Paleozoic era. The Paleozoic era came to an end with the largest mass extinction in Earth's history. Some scientists believe that ocean changes were a likely cause of this extinction, which killed nearly 90% of all species.

The Mesozoic Era—The Age of Reptiles

The Mesozoic era began about 248 million years ago. The Mesozoic is known as the *Age of Reptiles* because reptiles, such as the dinosaurs shown in **Figure 6**, inhabited the land.

During this time, reptiles dominated. Small mammals appeared about the same time as dinosaurs, and birds appeared late in the Mesozoic era. Many scientists think that birds evolved directly from a type of dinosaur. At the end of the Mesozoic era, about 15% to 20% of all species on Earth, including the dinosaurs, became extinct. Global climate change may have been the cause.

 **Reading Check** Why is the Mesozoic known as the Age of Reptiles?

Figure 6 Imagine walking in the desert and bumping into these fierce creatures! It's a good thing humans didn't evolve in the Mesozoic era, which was dominated by dinosaurs.



The Cenozoic Era—The Age of Mammals

The Cenozoic era, as shown in **Figure 7**, began about 65 million years ago and continues to the present. This era is known as the *Age of Mammals*. During the Mesozoic era, mammals had to compete with dinosaurs and other animals for food and habitat. After the mass extinction at the end of the Mesozoic era, mammals flourished. Unique traits, such as regulating body temperature internally and bearing young that develop inside the mother, may have helped mammals survive the environmental changes that probably caused the extinction of the dinosaurs.



Figure 7 Thousands of species of mammals evolved during the Cenozoic era. This scene shows species from the early Cenozoic era that are now extinct.

SECTION Review

Summary

- The geologic time scale divides Earth's 4.6 billion-year history into distinct intervals of time. Divisions of geologic time include eons, eras, periods, and epochs.
- The boundaries between geologic time intervals represent visible changes that have taken place on Earth.
- The rock and fossil record represents mainly the Phanerozoic eon, which is the eon in which we live.
- At certain times in Earth's history, the number of life-forms has increased or decreased dramatically.

Using Key Terms

1. Use each of the following terms in the same sentence: *era*, *period*, and *epoch*.

Understanding Key Ideas

2. The unit of geologic time that began 65 million years ago and continues to the present is the
 - a. Holocene epoch.
 - b. Cenozoic era.
 - c. Phanerozoic eon.
 - d. Quaternary period.
3. What are the major time intervals represented by the geologic time scale?
4. Explain how geologic time is recorded in rock layers.
5. What kinds of environmental changes cause mass extinctions?

Critical Thinking

6. **Making Inferences** What future event might mark the end of the Cenozoic era?
7. **Identifying Relationships** How might a decrease in competition between species lead to the sudden appearance of many new species?

Interpreting Graphics

8. Look at the illustration below. On the Earth-history clock shown, 1 h equals 383 million years, and 1 min equals 6.4 million years. In millions of years, how much more time is represented by the Proterozoic eon than by the Phanerozoic eon?



SCILINKS.

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For a variety of links related to this
chapter, go to www.scilinks.org

Topic: **Geologic Time**
SciLinks code: **HSM0668**



Model-Making Lab

OBJECTIVES

Make a model of a geologic column.

Interpret the geologic history represented by the geologic column you have made.

MATERIALS

- paper, white
- pencil
- pencils or crayons, assorted colors
- ruler, metric
- scissors
- tape, transparent

SAFETY



How Do You Stack Up?

According to the principle of superposition, in undisturbed sequences of sedimentary rock, the oldest layers are on the bottom. Geologists use this principle to determine the relative age of the rocks in a small area. In this activity, you will model what geologists do by drawing sections of different rock outcrops. Then, you will create a part of the geologic column, showing the geologic history of the area that contains all of the outcrops.

Procedure

- 1 Use a metric ruler and a pencil to draw four boxes on a blank piece of paper. Each box should be 3 cm wide and at least 6 cm tall. (You can trace the boxes shown on the next page.)
- 2 With colored pencils, copy the illustrations of the four outcrops on the next page. Copy one illustration in each of the four boxes. Use colors and patterns similar to those shown.
- 3 Pay close attention to the contact between layers—straight or wavy. Straight lines represent bedding planes, where deposition was continuous. Wavy lines represent unconformities, where rock layers may be missing. The top of each outcrop is incomplete, so it should be a jagged line. (Assume that the bottom of the lowest layer is a bedding plane.)
- 4 Use a black crayon or pencil to add the symbols representing fossils to the layers in your drawings. Pay attention to the shapes of the fossils and the layers that they are in.
- 5 Write the outcrop number on the back of each section.
- 6 Carefully cut the outcrops out of the paper, and lay the individual outcrops next to each other on your desk or table.
- 7 Find layers that have the same rocks and contain the same fossils. Move each outcrop up or down to line up similar layers next to each other.
- 8 If unconformities appear in any of the outcrops, there may be rock layers missing. You may need to examine other sections to find out what fits between the layers above and below the unconformities. Leave room for these layers by cutting the outcrops along the unconformities (wavy lines).



- 9 Eventually, you should be able to make a geologic column that represents all four of the outcrops. It will show rock types and fossils for all the known layers in the area.
- 10 Tape the pieces of paper together in a pattern that represents the complete geologic column.

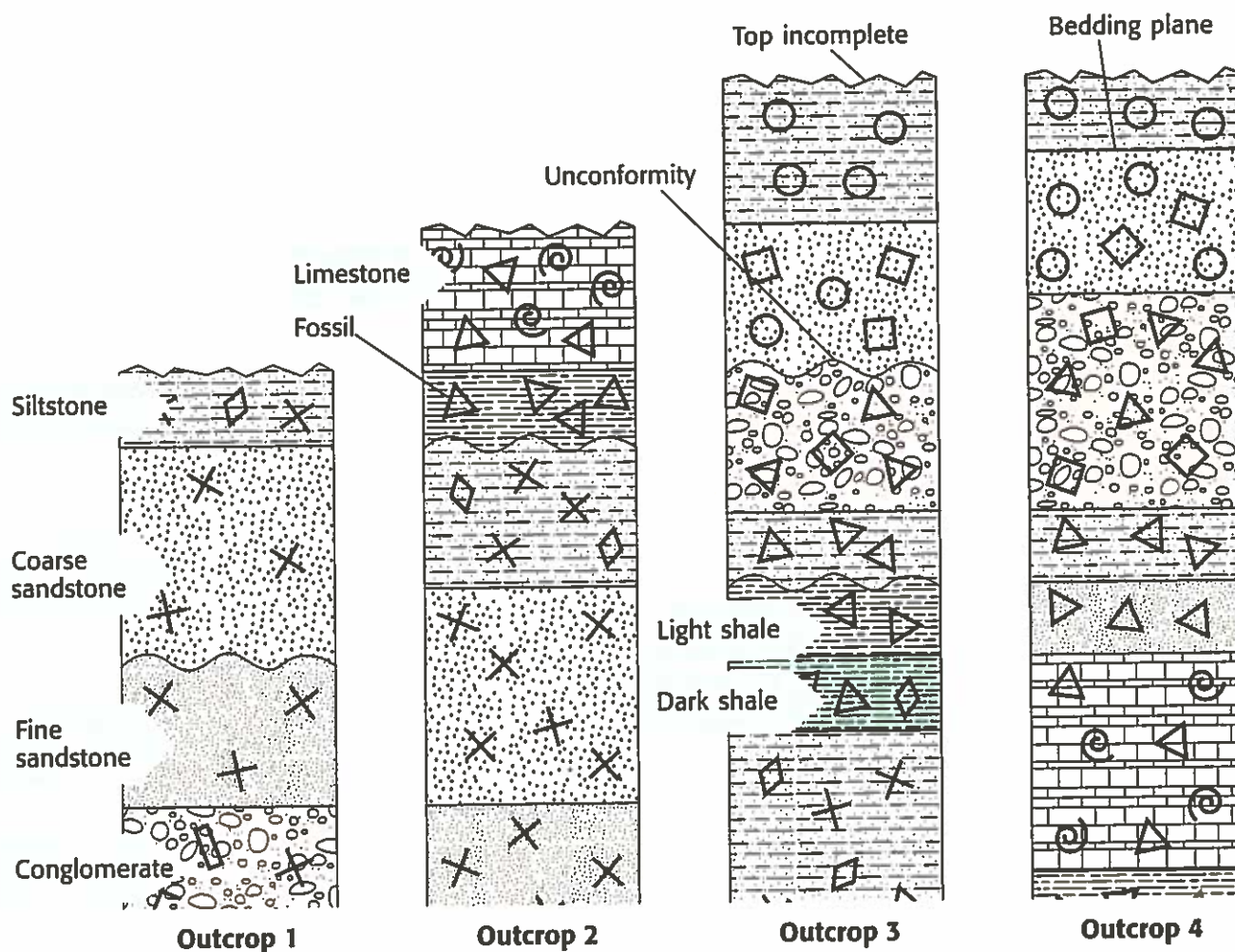
Analyze the Results

- 1 **Examining Data** How many layers are in the part of the geologic column that you modeled?
- 2 **Examining Data** Which is the oldest layer in your column? Which rock layer is the youngest? How do you know? Describe these layers in terms of rock type or the fossils they contain.

- 3 **Classifying** List the fossils in your column from oldest to youngest. Label the youngest and oldest fossils.
- 4 **Analyzing Data** Look at the unconformity in outcrop 2. Which rock layers are partially or completely missing? How do you know?

Draw Conclusions

- 5 **Drawing Conclusions** Which (if any) fossils can be used as index fossils for a single layer? Why are these fossils considered index fossils? What method(s) would be required to determine the absolute age of these fossils?





Chapter Review

USING KEY TERMS

- 1 In your own words, write a definition for each of the following terms: *superposition*, *geologic column*, and *geologic time scale*.

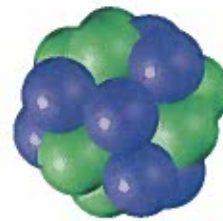
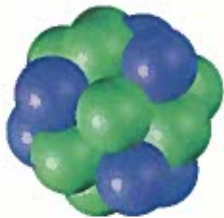
For each pair of terms, explain how the meanings of the terms differ.

- 2 *uniformitarianism* and *catastrophism*
3 *relative dating* and *absolute dating*
4 *trace fossil* and *index fossil*

UNDERSTANDING KEY IDEAS

Multiple Choice

- 5 Which of the following does not describe catastrophic change?
a. widespread
b. sudden
c. rare
d. gradual
- 6 Scientists assign relative ages by using
a. absolute dating.
b. the principle of superposition.
c. radioactive half-lives.
d. carbon-14 dating.
- 7 Which of the following is a trace fossil?
a. an insect preserved in amber
b. a mammoth frozen in ice
c. wood replaced by minerals
d. a dinosaur trackway
- 8 The largest divisions of geologic time are called
a. periods.
b. eras.
c. eons.
d. epochs.
- 9 Rock layers cut by a fault formed
a. after the fault.
b. before the fault.
c. at the same time as the fault.
d. There is not enough information to determine the answer.
- 10 Of the following isotopes, which is stable?
a. uranium-238
b. potassium-40
c. carbon-12
d. carbon-14
- 11 A surface that represents a missing part of the geologic column is called a(n)
a. intrusion.
b. fault.
c. unconformity.
d. fold.
- 12 Which method of radiometric dating is used mainly to date the remains of organisms that lived within the last 50,000 years?
a. carbon-14 dating
b. potassium-argon dating
c. uranium-lead dating
d. rubidium-strontium dating



Short Answer

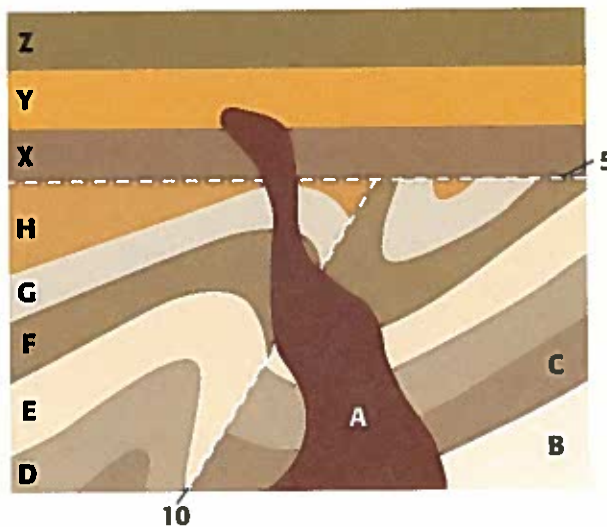
- 13 Describe three processes by which fossils form.
- 14 Identify the role of uniformitarianism in Earth science.
- 15 Explain how radioactive decay occurs.
- 16 Describe two ways in which scientists use fossils to determine environmental change.
- 17 Explain the role of paleontology in the study of Earth's history.

CRITICAL THINKING

- 18 **Concept Mapping** Use the following terms to create a concept map: *age, half-life, absolute dating, radioactive decay, radiometric dating, relative dating, superposition, geologic column, and isotopes.*
- 19 **Applying Concepts** Identify how changes in environmental conditions can affect the survival of a species. Give two examples.
- 20 **Identifying Relationships** Why do paleontologists know more about hard-bodied organisms than about soft-bodied organisms?
- 21 **Analyzing Processes** Why isn't a 100 million-year-old fossilized tree made of wood?

INTERPRETING GRAPHICS

Use the diagram below to answer the questions that follow.



- 22 Is intrusion A younger or older than layer X? Explain.
- 23 What feature is marked by 5?
- 24 Is intrusion A younger or older than fault 10? Explain.
- 25 Other than the intrusion and faulting, what event happened in layers B, C, D, E, F, G, and H? Number this event, the intrusion, and the faulting in the order that they happened.





Standardized Test Preparation

READING

Read each of the passages below. Then, answer the questions that follow each passage.

Passage 1 Three hundred million years ago, the region that is now Illinois had a different climate than it does today. Swamps and shallow bays covered much of the area. No fewer than 500 species of plants and animals lived in this environment. Today, the remains of these organisms are found beautifully preserved within nodules. Nodules are round or oblong structures usually composed of cemented sediments that sometimes contain the fossilized hard parts of plants and animals. The Illinois nodules are exceptional because the soft parts of organisms are found together with hard parts. For this reason, these nodules are found in fossil collections around the world.

1. In the passage, what is the meaning of the word *exceptional*?
A beautiful
B extraordinary
C average
D large
2. According to the passage, which of the following statements about nodules is correct?
F Nodules are rarely round or oblong.
G Nodules are usually composed of cemented sediment.
H Nodules are not found in present-day Illinois.
I Nodules always contain fossils.
3. Which of the following is a fact in the passage?
A The Illinois nodules are not well known outside of Illinois.
B Illinois has had the same climate throughout Earth's history.
C Both the hard and soft parts of organisms are preserved in the Illinois nodules.
D Fewer than 500 species of plants and animals have been found in Illinois nodules.

Passage 2 In 1995, paleontologist Paul Sereno and his team were working in an unexplored region of Morocco when they made an astounding find—an enormous dinosaur skull! The skull measured approximately 1.6 m in length, which is about the height of a refrigerator. Given the size of the skull, Sereno concluded that the skeleton of the animal it came from must have been about 14 m long—about as big as a school bus. The dinosaur was even larger than *Tyrannosaurus rex*! The newly discovered 90 million-year-old predator most likely chased other dinosaurs by running on large, powerful hind legs, and its bladelike teeth meant certain death for its prey.

1. In the passage, what does the word *astounding* mean?
A important
B new
C incredible
D one of a kind
2. Which of the following is evidence that the dinosaur described in the passage was a predator?
F It had bladelike teeth.
G It had a large skeleton.
H It was found with the bones of a smaller animal nearby.
I It is 90 million years old.
3. What types of information do you think that fossil teeth provide about an organism?
A the color of its skin
B the types of food it ate
C the speed that it ran
D the mating habits it had