Sealed in darkness for 49 million years, this beetle still shimmers with the same metallic hues that once helped it hide among ancient plants. This rare fossil was found in Messel, Germany. In the same rock formation, scientists have found fossilized crocodiles, bats, birds, and frogs. A living stag beetle (above) has a similar form and color. Do you think that these two beetles would live in similar environments? What do you think Messel, Germany, was like 49 million years ago? In this chapter, you will learn how scientists answer these kinds of questions.
MAKING FOSSILS

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 an 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. In your ScienceLog, 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

6. What kinds of details were important in identifying your fossil? What kinds of details were not preserved in the imprints? For example, can you tell the colors of the objects?

7. Explain how Earth scientists follow similar methods when studying fossils.
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 amateur scientist named James Hutton did.

Searching for answers to his questions, Hutton spent more than 30 years studying rock formations in Scotland and Great Britain. As you can see, geology, the scientific study of the Earth’s history, got a pretty late start. It wasn’t until the nineteenth century that we began to understand the incredible history of the planet right beneath our feet.

The Present Is the Key to the Past

In 1795, two years before he died, James Hutton collected his notes and wrote *Theory of the Earth*. In that series of books, 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.

1. Hutton observed that rock is broken down into smaller particles.
2. He watched as rivers carried these particles downstream.
3. He knew that rock particles formed layers of sediment. He predicted that these deposits would form new rock over time.
4. Hutton thought that in time the new rock would be raised, forming new landforms, and that the cycle would begin again.

**Figure 1** Hutton observed gradual, uniform geologic change. Judging by the rate of change, he concluded that the Earth must be incredibly old.
**Uniformitarianism Versus Catastrophism**

Hutton’s theories sparked a scientific debate because he suggested that the Earth was much older than previously thought. In Hutton’s time, most people thought that the Earth was only a few thousand years old. To explain the Earth’s history, most scientists supported **catastrophism**, the idea that all geologic change happens suddenly. Supporters of this idea claimed that all of the Earth’s features, such as mountains, canyons, and oceans, formed during rare, sudden events called **catastrophes**. These unpredictable events caused rapid geologic change over large areas—even across the entire Earth.

**Slow and Steady Wins the Race!**

Despite Hutton’s work, people still thought that the Earth’s history could be explained by catastrophism. It took the work of Charles Lyell, another Scottish scientist, for people to seriously consider uniformitarianism.

Armed with Hutton’s notes and new evidence of his own, Lyell successfully challenged catastrophism in the 1830s. Lyell’s victory inspired generations of geologists to interpret rock formations and unlock the Earth’s long and sometimes bizarre history. For example, fossil evidence showed that there were once great oceans where deserts now exist. Geologists learned that rocks formed by the gradual deposition of sediment on the ocean floor could be twisted and deformed by incredible pressures and temperatures inside the Earth. Scientists began to see layers of rock as if they were pages in the book of Earth’s history. Every stone told a tale.

**Biology CONNECTION**

It’s no coincidence that the theory of evolution was developed soon after Lyell introduced his ideas. 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 happen gradually over long periods of time.

---

**APPLY**

**Making Assumptions**

Examine these photographs. List them in the order you think they were taken. Now write down all of the assumptions that you made to infer that order. Were your assumptions similar to those of your classmates? Briefly explain the importance of making assumptions in science. How does this apply to uniformitarianism?
Modern Geology—Rethinking the Past

Today geologists understand that sudden catastrophes are also a part of Earth’s history. Although most geologic change is slow and uniform, rare catastrophes have left their mark in the rock and fossil record. For example, enormous craters have been found where asteroids and comets struck the Earth in the past. Some of these impacts may have been catastrophic. Such an asteroid impact, illustrated in Figure 2, may have led to the extinction of the dinosaurs. The impact would have spread dust and smoke into the Earth’s atmosphere, blocking the sun’s rays and causing major changes in the global climate. Unable to adapt to the changes, the dinosaurs died out.

Figure 2  Today scientists think that sudden events are responsible for some changes in Earth’s past. For example, an asteroid impact may have led to the extinction of the dinosaurs 65 million years ago.

SECTION REVIEW

1. Why did Hutton’s theories suggest that the Earth is much older than previously thought?  
2. How has the role of catastrophism in Earth science changed?  
3. Making Predictions  Apply the principle of uniformitarianism to predict how land features such as river channels, rock layers, and mountains form.
When on Earth?

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

You might begin by dusting for fingerprints or by searching for witnesses. As a detective, your goal is to figure out the order of events that happened before you reached the crime scene.

You could think of the Earth as an enormous geologic crime scene. Like detectives, geologists try to figure out the order of events in the Earth’s history. But instead of fingerprints and witnesses, geologists study rocks and fossils, and they use a method called relative dating. Relative dating is the process of determining the order in which events happened. Relative dating also compares the ages of objects such as rocks or fossils.

Relative Dating: Which Came First?

Suppose 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 pictures to the top of the stack. Think about the family history recorded in those pictures. Where are the oldest pictures—the ones taken when you were a baby? Where are the most recent pictures—those taken last week?

Rock layers, such as those shown in Figure 3, are like stacked pictures. As you move from top to bottom, the layers are older. The principle of superposition states that younger rocks lie above older rocks unless the layers have been disturbed. “Younger over older” is a phrase you can use to remember this principle.
Disturbing Forces

Not all rock layers are neatly arranged with the oldest layer on the bottom and the youngest on the top. Some rock-layer sequences are disturbed by tectonic forces. These forces can push other rocks into a sequence, tilt or fold rock layers, and break sequences into movable parts. Sometimes geologists find rock-layer sequences that are upside down! These disruptions are a challenge for geologists when they try to determine the relative age of rocks. Fortunately, they can get help from a very valuable tool—the geologic column.

The Geologic Column

Geologists combine data from all of the undisturbed rock sequences around the world to make the geologic column. The geologic column is an ideal sequence of rock layers that contains all known rock formations and fossils on Earth. The geologic column is arranged from oldest to youngest, as shown in Figure 4.

Geologists rely on the geologic column to interpret rock sequences. When they are not sure about the age of a rock sequence, they compare it to the geologic column. Geologists also use the geologic column to identify the layers in puzzling rock sequences, such as those that have been folded.
Finding Clues in Rock Layers

Here’s a simple question: When you slice a birthday cake into pieces, which is older—the layers of the cake or the cut you just made? Of course, the layers of the cake are older than the cut you made. Congratulations—you have just used another relative-dating method!

Geologists also assume that the layers of sediment that form rock were originally horizontal and undisturbed. This means that if rock layers are not horizontal or if they are disturbed, an event must have altered them after they formed. Geologists study the relationships between the rock layers and the events that altered them and assign relative ages to both. Figure 5 shows how four of these events have disrupted rock layers.

**Figure 5  Four Events That Alter Rock Layers**

- **Faulting** A *fault* is a break in the Earth’s crust along which blocks of the crust slide against each other.
- **Intrusion** An *intrusion* is molten rock from the Earth’s interior that squeezes into existing rock and cools.
- **Folding** *Folding* happens when rock layers bend and buckle from Earth’s internal forces.
- **Tilting** *Tilting* happens when rock layers slant without folding.
Faults, intrusions, and the effects of folding and tilting can make dating rock layers a challenge. But sometimes layers of rock are missing altogether, and a gap is left in the geologic record. This gap is called an unconformity. 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 unconformities, they must question whether the missing layers were weathered away or if they were ever present in the first place. **Figure 6** shows how erosion can cause an unconformity.
Absolute Dating: A Measure of Time

As you have learned, relative dating is used to compare the ages of objects or events. But how do you tell the actual age (in years) of a rock layer or a fossil? **Absolute dating** is the process of dating an object by determining the number of years it has existed.

**Isotopes**

As you may know, atoms are made of neutrons, protons, and electrons. The number of protons in an atom determines what element it is. For example, carbon always has 6 protons, and nitrogen has 7 protons. But did you know that elements have different forms called isotopes? **Isotopes** are atoms that have the same number of protons but different numbers of neutrons. For example, carbon has 6 protons, but it could have 6, 7, or 8 neutrons. All of these atoms are still carbon because they have 6 protons, but they are isotopes because they have different numbers of neutrons.

**Radioactive Decay**

Most naturally occurring isotopes are stable, which means that they do not change over time. Some isotopes are unstable, however. Unstable isotopes are called **radioactive**.

Radioactive isotopes tend to break down into stable isotopes of other elements. This is called radioactive decay. **Figure 7** shows how an unstable parent isotope decays into a stable daughter isotope. Because unstable isotopes decay at a steady rate, scientists can analyze the ratio of parent and daughter material in a sample to determine the sample's age. This method is called **radiometric dating**.

**Figure 7** Radioactive Decay

<table>
<thead>
<tr>
<th>Unstable isotope</th>
<th>Radioactive decay</th>
<th>Stable isotope</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 protons, 8 neutrons</td>
<td>When the unstable isotope decays, an electron is released. In the process, a neutron is converted to a proton.</td>
<td>7 protons, 7 neutrons</td>
</tr>
</tbody>
</table>
Radiometric Dating and Half-lives

Because the rate that a radioactive isotope decays is constant, radiometric dating can accurately determine an object’s age. To date an object, you need to know the half-life of the radioactive isotope you are measuring. A half-life is simply the amount of time it takes for one-half of a radioactive sample to decay. For example, carbon-14 decays into nitrogen-14. If you have a sample containing carbon-14, it would take 5,730 years for half of that isotope to decay. Thus, the half-life of carbon-14 is 5,730 years.

Counting Half-lives

Let’s say that a rock sample contains an isotope with a half-life of 10,000 years. In 10,000 years, half of the parent material in the sample 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 of 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 of the original sample to decay and another 10,000 years for half of what remained to decay. Your sample would be $2 \times 10,000$, or 20,000, years old. Figure 8 shows how this decay happens.

Types of Radiometric Dating

Every radioactive isotope has a half-life. Some half-lives last a fraction of a second; others last billions of years. This is one reason why scientists must choose the correct method to date the sample they are studying.
**Carbon-14 Method**

Carbon-14 decays into nitrogen-14, but because nitrogen-14 also occurs naturally, this method measures the ratio of unstable carbon-14 to stable carbon-12. The half-life of carbon-14 is only 5,730 years. For this reason, the carbon-14 method is used mainly for dating things that lived within the last 70,000 years. Human remains such as those shown in Figure 9 can be dated using the carbon-14 method.

**Potassium-Argon Method**

Potassium-40 has a half-life of 1.3 billion years, and it decays to argon and calcium. Argon is measured as the daughter material. This method is mainly used to date rocks older than 100,000 years.

**Uranium-Lead Method**

Uranium-238 decays to lead-206 in a series of steps. The half-life of uranium-238 is 4.5 billion years. The older a rock is, the more daughter material (lead-206) will be present. Uranium-lead dating is used for rocks more than 10 million years old.

<table>
<thead>
<tr>
<th>Common Radiometric Dating Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
</tr>
<tr>
<td>Carbon-14</td>
</tr>
<tr>
<td>Potassium-Argon</td>
</tr>
<tr>
<td>Uranium-Lead</td>
</tr>
</tbody>
</table>

**SECTION REVIEW**

1. List the three parts of an atom, and explain what an isotope is.
2. Explain how radioactive decay happens and how it relates to radiometric dating.
3. Describe three types of radiometric dating.
4. **Applying Concepts** Explain why radioactive decay must be constant in order for radiometric dating to be accurate.
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!

You are standing in the middle of an enormous dinosaur nest-ground. There are hundreds of eggs, and some still have unhatched babies inside! This is what happened to a scientist named Luis Chiappe. Of course he couldn’t make a dino-sized omelet out of these eggs because they are fossils.

Fossilized Organisms

A fossil is the remains or physical evidence of an organism preserved by geologic processes. Fossils are most often preserved in sedimentary rock. But as you will see, other materials can also preserve evidence of life. Scientists who study fossils are called paleontologists (PAY lee uhn TAHL uh jists).

Fossils in Rocks

When organisms die, they immediately begin to decay. Over time, even teeth and bones become part of the Earth’s soil. Occasionally, however, organisms are quickly buried by sediments when they die. The sediments slow down decay. If the sediments become rock, they can trap a fossil inside. Hard parts such as shells and bones decay slowly, so most fossils are evidence of these parts. Rare fossils reveal the details of soft parts.

Fossils in Amber

Imagine that a mosquito is caught in sticky tree sap millions of years ago. The mosquito is covered by more sap, which hardens, preserving the insect inside. Hardened tree sap is called amber. Some of the most amazing fossils are found in amber, as shown in Figure 10. Amber preserves fossils so well that some scientists have claimed to have grown bacteria taken from the stomach of a bee preserved in 40-million-year-old amber!

Figure 10 These insects are preserved in amber.
Mineral Replacement
Organisms can also be preserved when minerals replace an organism's tissues. The trees in Figure 11 became petrified when their cells were completely replaced by minerals.

Frozen Fossils
In October 1999, scientists made an amazing discovery—a 20,000-year-old woolly mammoth frozen in the Siberian tundra. Woolly mammoths, relatives of modern elephants, became extinct 12,000 years ago at the end of the last ice age. Because cold temperatures slow down decay, there are many types of frozen fossils preserved from the last ice age. Scientists plan to thaw the mammoth out very slowly using hair dryers. They hope to find out more about this animal and the environment it lived in. Some scientists are even trying to clone the mammoth!

Fossils in Tar
There are places where tar collects at the Earth’s surface in thick, sticky pools. The La Brea tar pits in Southern California, for example, are at least 40,000 years old. This area, illustrated in Figure 12, became a world-famous fossil site when fossils of saber-toothed cats were found there.

Much of what we know about the extinct saber-toothed cats comes from fossils found in the La Brea tar pits. The tar pits have preserved fossils of many other mammals as well as snails, birds, salamanders, insects, and plants. From these fossils, scientists can reconstruct what the environment in Southern California was like 40,000 years ago.
Other Types of Fossils

Do organisms leave behind any other clues about their past existence besides their remains? What other evidence of life do paleontologists look for?

**Trace Fossils**

Any naturally preserved evidence of animal activity is called a **trace fossil**. **Tracks** such as those shown in Figure 13 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 its size and weight. Tracks can even provide clues to an animal’s behavior. **Burrows** are another type of trace fossil. **Burrows** are shelters made by animals that dig into the ground. Like tracks, burrows are preserved when they are filled in with sediment and are buried quickly. A **coprolite** (KAHP roh LIET), a third type of trace fossil, is preserved animal dung. A coprolite can reveal a lot about the habits and diet of the animal that left it. **Figure 14** shows an example of a coprolite.

**Molds and Casts**

A **mold** is a cavity in rock where a plant or animal was buried. Often these cavities are filled in with sediment, leaving a cast of the original organism. A **cast** is an object made when sediment fills a mold and becomes rock. A cast shows what the outside of the organism looked like. **Figure 15** on the next page shows a mold and a cast of the same organism.

---

**QuickLab**

**Happy Trails**

1. Find an area of soft ground or a sandbox. Have your partner walk across it.
2. Observe each print closely. Is the toe print deeper than the heel print? Using a meterstick, measure the distance between each print. Do taller people have longer strides?
3. With a protractor, measure the step angle using the diagram shown at right as a reference.
4. Repeat steps 2 and 3 with different people and different walking styles. What does each set of prints tell you about the organism that left them? Try this activity with your family or even your pets!
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 Nature of the Fossil Record

The fossil record offers a rough sketch of the history of life on Earth. Some parts of this history are more detailed than others. For example, we know much more about organisms with hard body parts because these parts are more likely to become fossils than soft ones. We also know more about organisms that lived in environments that encouraged fossilization. For example, lakes, rivers, and oceans have regular cycles of sedimentation that help preserve fossils of the organisms that lived in and around them. The fossil record is also incomplete because most organisms never became fossils. And of course, there are many fossils yet to be discovered that may change our current understanding of the fossil record.

Environmental Changes

The fossil record reveals environmental change. As you know, organisms are adapted to the environment that they live in. If environmental change is dramatic, it can threaten the survival of a species. For example, would you expect to find marine fossils on the mountaintop in Figure 16? The presence of marine fossils means that these rocks were once below sea level.

You live in Texas, so you are probably familiar with limestone, a chalky, white rock. But did you know that much of the limestone in Texas is made of the skeletons of tiny sea animals that lived more than 75 million years ago? At that time, North America was divided by a shallow sea that stretched from the Gulf of Mexico to the Arctic Ocean!

Because the fossil record is incomplete, paleontologists must interpret fossil evidence to form hypotheses about past environments. Often these interpretations are based on environments that exist today.

For example, imagine you are digging in rock that was once ancient sediment. You uncover fossils of several freshwater fish and bones similar to a modern horse’s bones.
In the lab you find pollen grains similar to those produced by modern grasses. Interpreting this evidence, you might conclude that the area was once a lake located in a grassland where horses lived. Can you think of a present-day environment like that?

**Changes in Life**

The fossil record gives scientists insight into the history of life over the past 3.5 billion years. By studying the relationships between fossils, scientists can interpret how life has changed in the past. Only a small fraction of the organisms that have existed in Earth’s history have been fossilized. Because the fossil record is not complete, paleontologists rarely find a continuous record of change. Instead they look for similarities between fossils and try to fill in the blanks.

**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 these organisms lived. If a type of organism existed only for a short period of time, its fossils would show up in a limited range of rock layers. These fossils are called **index fossils**.

In order to be considered an index fossil, the fossil must be found in rock layers throughout the world. **Figure 17** shows an index fossil of a genus of trilobite called *Phacops*. Through the dating of rock, *Phacops* has been determined to have lived about 400 million years ago. So, when scientists find *Phacops* in rock layers anywhere on Earth, they assume that these rock layers are also about 400 million years old. Using index fossils, scientists can assign layers of rock to positions in the geologic column without dating the rock directly.
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.

It’s hard to imagine the Earth being billions of years old. Year after year nothing seems to change. Mountains remain mountains; rivers flow their course. But try to think of the Earth’s history in “fast forward.” If you could watch the Earth change from this perspective, you’d see mountains rise up like wrinkles in fabric and then quickly wear away. Sea levels would rise and fall as glaciers spread over the Earth and melted. You’d see life-forms appear and then become extinct. In this section, you will learn that geologists must also “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.

Rock Layers and Geologic Time

One of the best places in North America to see the Earth’s history recorded in rock layers is Grand Canyon National Park, shown in Figure 18. 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 of the Earth’s history. In other words, the Colorado River is flowing across rock that is nearly 2 billion years old!
The Geologic Time Scale

As you know, the geologic column begins with the oldest rocks that have been found on Earth. But the oldest rocks that exist today are much younger than the Earth because rocks are constantly renewed by the rock cycle. In all, geologists study 4.6 billion years of Earth’s history! To make their job easier, geologists have created the **geologic time scale**, which divides Earth’s history into intervals of time. As you can see in Figure 19, the geologic time scale is divided into four major parts called **eons**. Eons are divided into **eras**. Eras are divided into **periods**.

![Figure 19](image-url) The geologic time scale divides Earth’s 4.6-billion-year history into time intervals. We live in the Quaternary period of the Cenozoic era.

<table>
<thead>
<tr>
<th>Era</th>
<th>Period</th>
<th>Began millions of years ago</th>
<th>Important events based on fossil remains and the geologic record.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cenozoic</strong></td>
<td>Quaternary</td>
<td>1.8</td>
<td>Thick glaciers advance across the Earth and then retreat. Complex human societies develop.</td>
</tr>
<tr>
<td><strong>Mesozoic</strong></td>
<td>Cretaceous</td>
<td>144</td>
<td>Flowering plants appear. Large-scale volcanic activity occurs. Dinosaurs become extinct.</td>
</tr>
<tr>
<td></td>
<td>Jurassic</td>
<td>206</td>
<td>Large dinosaurs and feathered birds present.</td>
</tr>
<tr>
<td></td>
<td>Triassic</td>
<td>248</td>
<td>Pangaea begins to break up. First dinosaurs, turtles, crocodiles, and early mammals appear.</td>
</tr>
<tr>
<td><strong>Paleozoic</strong></td>
<td>Permian</td>
<td>290</td>
<td>Continents join to form the supercontinent Pangaea. Major mass extinction occurs.</td>
</tr>
<tr>
<td></td>
<td>Pennsylvanian</td>
<td>323</td>
<td>Early reptiles appear. Giant cockroaches and dragonflies are common.</td>
</tr>
<tr>
<td></td>
<td>Mississippian</td>
<td>354</td>
<td>Appalachian Mountains begin to form. Flying insects appear.</td>
</tr>
<tr>
<td></td>
<td>Devonian</td>
<td>417</td>
<td>Amphibians and seed-bearing plants appear.</td>
</tr>
<tr>
<td></td>
<td>Silurian</td>
<td>443</td>
<td>Armored fish, insects, and land plants appear.</td>
</tr>
<tr>
<td></td>
<td>Ordovician</td>
<td>490</td>
<td>The first vertebrates, jawless fishes, appear.</td>
</tr>
<tr>
<td></td>
<td>Cambrian</td>
<td>540</td>
<td>Shallow seas cover much of the land. Invertebrate life flourishes.</td>
</tr>
<tr>
<td><strong>Proterozoic Eon</strong></td>
<td></td>
<td>2,500</td>
<td>Marine invertebrates appear.</td>
</tr>
<tr>
<td><strong>Archean Eon</strong></td>
<td></td>
<td>3,800</td>
<td>The earliest forms of life arise.</td>
</tr>
<tr>
<td><strong>Hadean Eon</strong></td>
<td></td>
<td>4,600</td>
<td>The Earth forms. The oceans and atmosphere develop.</td>
</tr>
</tbody>
</table>
Can You Imagine 4.6 Billion Years?

If you look closely at the geologic time scale, you might notice something interesting—for more than 4 billion years, complex life-forms did not exist on Earth! Figure 20 shows the geologic time scale on the face of a clock. The Earth formed at noon and the present moment is midnight. On the Earth-history clock, all life more complex than algae appeared within the last two hours. Human civilizations appeared within the last second! Compared with the age of the Earth, human existence is incredibly brief.

The Eon We Live In

The divisions of time on the geologic time scale represent major changes on Earth. These changes include the appearance or extinction of different life-forms, changes in the global climate, and changes in rock types. Let’s look closer at what the rock and fossil record suggests about the events of the three most recent eras of the Phanerozoic eon.

The Paleozoic Era—“Old Life”

The Paleozoic era began about 540 million years ago after an episode of mountain building at the end of an ice age. At that time, tectonic forces raised the land and glaciers stored much of the Earth’s water. As a result, the oceans shrank and competition among the primitive marine organisms increased. This competition led to an explosion of life-forms. The oceans became home to a diversity of life including sponges, coral, clams, trilobites, sea scorpions, primitive fish, and even sharks. But nothing lived on the land. Imagine how empty the landscape must have looked!

QuickLab

Make a Time Scale

1. Start with a length of adding-machine tape 46 cm long.
2. Starting at one end of the tape, use a black marker and a meterstick to draw a line across the tape at the following lengths: 5.4 cm, 25 cm, and 38 cm.
3. Using colored markers, color the sections of tape in this order: green, blue, red, and purple.
4. Your tape models the geologic time scale, and the present moment is at 46 cm. What is the name of each time interval on your scale?
By the middle of the Paleozoic, however, forests of giant ferns and primitive trees covered the land. All known plant groups except flowering plants were present. Insects such as cockroaches and giant dragonflies buzzed through the air. By the end of this era, primitive reptiles and amphibians the size of small dogs lived on the land. Figure 21 shows a scene from late in this era. The Paleozoic era came to an end with the largest extinction in Earth’s history—when nearly 90 percent of all species died off. There are many theories about the cause of this mass extinction. However, most scientists agree that severe climatic changes at the end of the Paleozoic contributed to the extinction.

The Mesozoic Era—The Age of Reptiles

The Mesozoic era began about 248 million years ago. After the mass extinction at the end of the Paleozoic, the surviving reptiles flourished. Thus, the Mesozoic era is known as the Age of Reptiles. Dinosaurs, such as those shown in Figure 22, inhabited the land and the water. Although reptiles dominated the Mesozoic, birds and small mammals appeared late in the era.

Like the Paleozoic era, the Mesozoic era also ended with a mass extinction. Current studies suggest that this extinction was caused by an asteroid that struck Earth in what is now the Gulf of Mexico. The impact triggered worldwide
fires and threw dust into the atmosphere. This debris blocked much of the sun’s energy, and the planet cooled. Plants died, triggering a collapse in the food chain, which caused the extinction of 50 percent of all species on Earth, including the dinosaurs.

The Cenozoic Era—The Age of Mammals

We live in the Cenozoic era, or the Age of Mammals, which began about 65 million years ago. In the previous era, the Mesozoic, mammals competed with dinosaurs and other animals for food and habitat. But the mammals flourished after the mass extinction at the end of the Mesozoic. Mammals have several unique traits that probably helped them thrive after the extinction. All mammals have fur, they can regulate their body temperature internally, and they bear young that develop inside the mother. All of these traits may have helped mammals survive the climate changes that probably caused the extinction of the dinosaurs. Figure 23 shows what a scene from the early Cenozoic might have looked like. Woolly mammoths, saber-toothed cats, and giant sloths are among the many types of mammals from the early Cenozoic that are now extinct. Camels, horses, elephants, whales, and primates are a few Cenozoic mammals that still exist today.

SECTION REVIEW

1. Describe the three most recent eras.

2. How did the extinction at the end of the Mesozoic era set the stage for the Age of Mammals?

3. **Making Predictions** What future event might mark the end of the Cenozoic era?
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. 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 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 similar layers up next to each other.

**Materials**

- metric ruler
- pencil
- white paper
- colored pencils or crayons
- scissors
- transparent tape

Chapter 16

Copyright © by Holt, Rinehart and Winston. All rights reserved.
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.

Analysis

11 How many layers are in this part of the geologic column you modeled?

12 Which is the oldest layer in your column? Which rock layer is the youngest? Describe these layers in terms of rock type and the fossils they contain.

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

14 List the fossils in your column from oldest to youngest. Label the oldest and youngest fossils.

15 Look at the unconformity in Outcrop 2. Which rock layers are partially or completely missing? Explain how you know this.
### Section 1

**Vocabulary**
- uniformitarianism (p. 426)
- catastrophism (p. 427)

**Section Notes**
- Geologists use the principle of uniformitarianism to interpret the Earth’s past and to make predictions.
- Uniformitarianism assumes that geologic change is gradual. Catastrophism is based on the idea that geologic change is sudden.
- Most land features are the result of gradual geologic changes.
- Before Hutton and Lyell, most scientists supported catastrophism. After Lyell, most scientists rejected this idea. Modern geology is based on the idea that gradual geologic change can be interrupted by occasional catastrophes.

### Section 2

**Vocabulary**
- relative dating (p. 429)
- superposition (p. 429)
- geologic column (p. 430)
- unconformity (p. 432)
- absolute dating (p. 433)
- isotopes (p. 433)
- radiometric dating (p. 433)
- half-life (p. 434)

**Section Notes**
- Geologists use relative dating to determine the order in which events happened. Relative dating can also be used to compare the age of objects.
- The principle of superposition states that, in undisturbed rock-layer sequences, younger layers lie above older layers.
- The entire rock and fossil record is represented by the geologic column.
- Geologists examine the relationships between rock layers and the events that alter them in order to determine relative ages.
- During radioactive decay, an unstable isotope decays at a constant rate and becomes a stable isotope of a different element.
- The absolute age of some rocks and fossils can be determined by analyzing the ratio of parent material to daughter material in a sample. This is called radiometric dating.

### Section 3

**Vocabulary**
- fossil (p. 436)
- paleontologist (p. 436)
- trace fossil (p. 438)
- mold (p. 438)
- cast (p. 438)
- index fossil (p. 440)

**Section Notes**
- Fossils are the remains or physical evidence of an organism preserved by geologic processes.
- Fossils can be studied to determine how environments and organisms have changed over time.
- The fossil record indicates that changes in environmental conditions can affect the survival of a species.
- The age of an index fossil is determined by radiometrically dating the rock layers above and below where the fossil is found. If the index fossil is found in other rock layers, scientists assume that those layers are of a similar age.

### Section 4

**Vocabulary**
- geologic time scale (p. 442)

**Section Notes**
- The 4.6 billion years of Earth’s history are represented on the geologic time scale. Much of geologic time is not represented in the rock and fossil record.
- The rock and fossil record primarily represents the last eon of Earth’s history.
- Environmental changes caused by natural events such as asteroid impacts have resulted in mass extinctions.
USING VOCABULARY

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

1. uniformitarianism/catastrophism
2. relative dating/absolute dating
3. neutron/proton
4. mold/cast
5. geologic time scale/geologic column

**Multiple Choice**

6. Which of the following words does not describe catastrophic change?
   a. sudden
   b. widespread
   c. gradual
   d. rare

7. Scientists assign relative ages by using
   a. potassium-argon dating.
   b. the principle of superposition.
   c. radioactive half-lives.
   d. isotope ratios.

8. Rock layers cut by a fault formed
   a. after the fault.
   b. before the fault.
   c. at the same time as the fault.
   d. Cannot be determined

9. If the half-life of an unstable element is 5,000 years, what percentage of the parent material will be left after 10,000 years?
   a. 100 percent
   b. 75 percent
   c. 50 percent
   d. 25 percent

10. Of the following isotopes, which is stable?
    a. uranium-238
    b. potassium-40
    c. carbon-12
    d. carbon-14

11. If Earth’s history is put on a scale of 24 hours, human civilizations would have been around for
    a. days.
    b. hours.
    c. minutes.
    d. seconds.

**Short Answer**

12. What is the principle of superposition? How is it used by geologists?

13. Describe how plant and animal remains become petrified.

14. List some reasons why the fossil record is incomplete.

15. Describe the event that scientists think caused the mass extinction at the end of the Mesozoic era.

**CONCEPT MAPPING**

16. 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.
CRITICAL THINKING AND PROBLEM SOLVING

Write one or two sentences to answer the following questions:

17. Describe the contributions that James Hutton made to the science of geology.

18. You may have heard the term *petrified wood*. Why isn’t a petrified tree made of wood?

19. If the amount of solar energy that reaches the Earth decreased, how would plants be affected? Explain how this change could have affected the survival of meat-eating dinosaurs.

20. Why do we know more about organisms that lived in or near bodies of water than we do about those that lived on mountains or in deserts?

21. Identify how change in environmental conditions can affect the survival of a species. Give two examples.

MATH IN SCIENCE

22. Copy the graph below on a separate sheet of paper. Place a dot on the y-axis at 100 percent. Then place a dot on the graph at each half-life to show how much of the parent material is left. Connect the points with a curved line. Will the percentage of parent material ever reach zero? Explain.

INTERPRETING GRAPHICS

Examine the drawing below, and answer the following questions:

23. Is intrusion A younger or older than layer X?

24. What feature is marked by 5?

25. Is intrusion A younger or older than fault 10? Explain.

26. 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.

Take a minute to review your answers to the Pre-Reading Questions found at the bottom of page 424. Have your answers changed? If necessary, revise your answers based on what you have learned since you began this chapter.
Chapter 16

1. What event probably caused the mass extinctions at the end of the Mesozoic era?
   A. An epidemic of disease
   B. An asteroid impact
   C. The appearance of humans
   D. A variation in the Earth’s orbit

2. A paleontologist made this graph of the types of teeth she found in a rock formation. Which statement best describes the information presented in the graph?
   F. Over time, the number of carnivores decreased and the number of herbivores increased.
   G. Over time, the number of carnivores increased and the number of herbivores increased.
   H. Over time, the number of carnivores and herbivores remained the same.
   J. Over time, the number of carnivores increased and the number of herbivores decreased.

3. Modern geology combines the ideas of uniformitarianism and catastrophism. What statement best summarizes this combination?
   A. Geologic change always happens gradually.
   B. Geologic change happened only in the past.
   C. Change in geologic history is gradual, but sometimes it is interrupted by sudden catastrophes.
   D. Catastrophes are much more common than gradual change.

4. The landform shown below is the result of what process?
   F. Faulting
   G. Intrusion
   H. Erosion
   J. Folding
Chapter 16

Math

1 Carbon-14 is a radioactive isotope with a half-life of 5730 years. How much carbon-14 would remain in a sample that is 11,460 years old?
   A 100%
   B 50%
   C 25%
   D 12.5%

2 If a sample contains an isotope with a half-life of 10,000 years, how old would the sample be if \( \frac{1}{8} \) of the original isotope remained in the sample?
   F 5000 years
   G 10,000 years
   H 20,000 years
   J 30,000 years

Reading

Read the passage. Then read each question that follows the passage. Decide which is the best answer to each question.

In 1995, paleontologist Paul Sereno and his team were working in an unexplored region of Morocco when they made an incredible find—an enormous dinosaur skull! The skull measured about 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. That’s even larger than Tyrannosaurus rex! This 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 Which of the following is evidence that the dinosaur described in the passage was a predator?
   A It had bladelike teeth.
   B It had a large skeleton.
   C It was found with the bones of a smaller animal nearby.
   D It is 90 million years old.

2 What types of information do you think that fossil teeth provide about an organism?
   F The color of its skin
   G The types of food it ate
   H The speed that it ran
   J Its mating habits
A mother nuzzles her babies in a nest. Nearby, another mother lets out a worried yelp; one of her babies has crawled out of its nest and is scampering away. The mother quickly captures her baby and returns it to safety. Are they puppies? birds? No—they are dinosaurs! Or so Jack Horner believes.

Horner has come to this conclusion by comparing dinosaur fossils with modern alligators and birds. “I am studying how dinosaur bones developed, and I’m comparing them with the development of bones of alligators and birds so that we can learn more about dinosaur growth and nesting behaviors.”

Meeting the Challenge

As a child, Horner had difficulties in school because he had a learning disability called dyslexia. But no learning disability could dampen Horner’s enthusiasm for science, especially the study of dinosaurs. “I like dinosaurs and figuring out what the world looked like at different times in the past. I’ve always liked the detective work that’s involved in paleontology. You can’t study a living dinosaur, so you have to figure out everything using clues from the past.”

Boning Up on the Latest . . .

One of Horner’s current projects is analyzing whether *Tyrannosaurus rex* was a vicious predator, as it is often pictured, or a scavenger, eating other animals’ kills. The more he studies fossil clues, the more Horner leans toward accepting the scavenger hypothesis. “Predatory animals require certain characteristics in order to be efficient killers. They need to be able to run fast, and they need to be able to maneuver and leap,” Horner explains. “*T. rex* couldn’t run fast, wasn’t agile, and couldn’t jump around or even fall down without doing serious damage to itself or even dying.”

Decide for Yourself

- Observe the behavior of birds in your area. Focus on one or two species. Note their eating habits, the sounds they make, and their interactions with other birds. Do you think birds might have evolved from dinosaurs? Use your observations to support your theory.

A model of a Maisasaura hatching