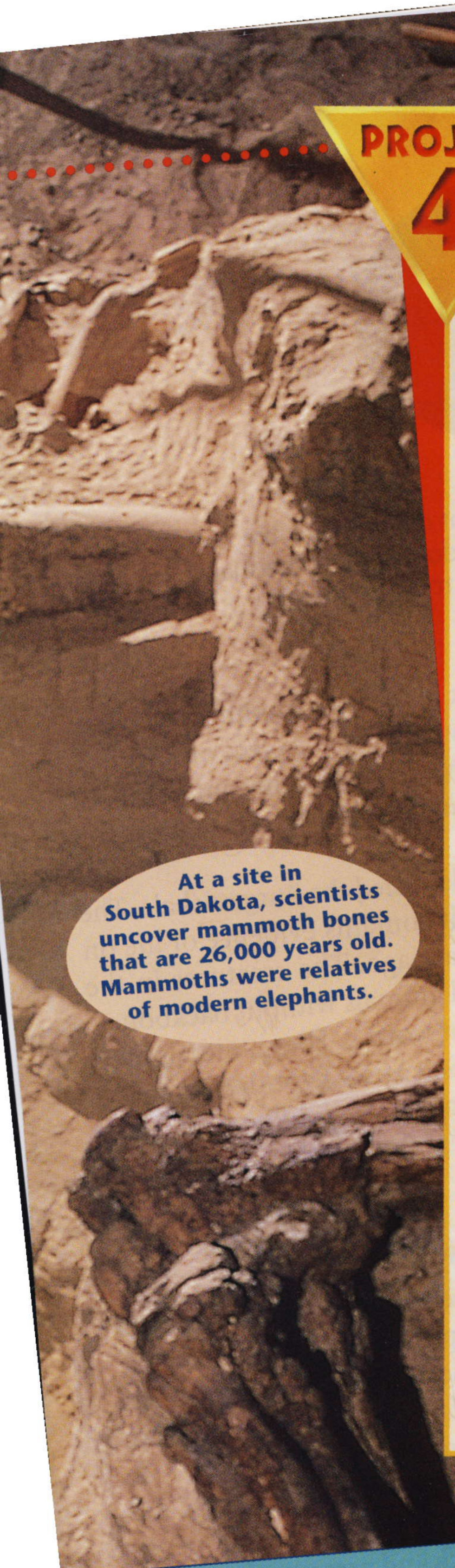


At a site in South Dakota, scientists uncover mammoth bones that are 26,000 years old. Mammoths were relatives of modern elephants.

PROJECT 4

A Journey Back in Time

With great care, scientists remove soil covering the bones of a mammoth. At this site, they have unearthed fossils of more than 30 other animals. These animals lived on the Great Plains during the last Ice Age. From such fossils, scientists can develop a picture of life in the distant past.

This chapter will take you back on a journey through geologic time. You will learn how fossils reveal the history of life on Earth. To guide you on your journey, you and your classmates will make a time line showing the many periods of geologic time.

Your Goal To become an expert on one geologic time period and assist in constructing a time line.

To complete this project, you must

- research a geologic time period of your choice
- create a travel brochure that shows what life was like in this time period
- illustrate your time period for the time line

Get Started Begin by previewing *Exploring Geologic History* on pages 132–135. Select a time period you would like to investigate. Check with your teacher to be sure that all the time periods will be covered by members of your class.

Check Your Progress You will be working on this project as you study this chapter. To keep your project on track, look for Check Your Progress boxes at the following points.

Section 2 Review, page 117: Collect information on the animals, plants, and environment of your time period.

Section 4 Review, page 125: Write a travel brochure about the animals, plants, and environment of your selected time period.

Section 5 Review, page 140: Create illustrations that depict your time period and complete your travel brochure.

Wrap Up At the end of the chapter (page 143), place your illustrations on the time line. Use the travel brochure to present your geologic time period to your classmates.

SECTION 1

Fossils

DISCOVER ACTIVITY

What's in a Rock?

1. Use a hand lens to carefully observe the rock sample provided by your teacher.
2. Make a drawing of any shapes you see in the rock. Include as many details as you can. Beneath your drawing, write a short description of what you see.

Think It Over

Inferring What do you think the rock contains? How do you think the shapes you observed in the rock got there?

GUIDE FOR READING

- How do fossils form?
- What are the different kinds of fossils?
- What do fossils tell about how organisms have changed over time?

Reading Tip As you read, use the headings to make an outline showing what fossils are, how they form, and why they are important.

You are a geologist at work in the high mountains of western Canada. You carefully split apart a piece of soft rock. Pressed into the rock is the shape of a tiny animal about the size of your thumb. The animal looks like no creature you have ever seen.

The rock is from a layer of rocks called the Burgess shale. The Burgess shale is famous because it contains evidence of life on Earth more than 500 million years ago. The creatures in the Burgess shale are tiny, soft-bodied animals without backbones. Some look like present-day crabs or worms. These animals lived on the bottom of a shallow sea. Scientists hypothesize that a mudslide suddenly buried the animals. Over millions of years, the mud turned to shale. The remains of the animals also became solid rock.

Evidence of Ancient Life

Fossils are the preserved remains or traces of living things. Fossils provide evidence of how life has changed over time. Fossils also help scientists infer how Earth's surface has changed. Fossils are clues to what past environments were like.

Most fossils form when living things die and are buried by sediments. The sediments slowly harden into rock and preserve the shapes of the organisms. Scientists who study fossils are called **paleontologists** (pay lee un TAHL uh jists). Fossils are usually found in sedimentary rock.

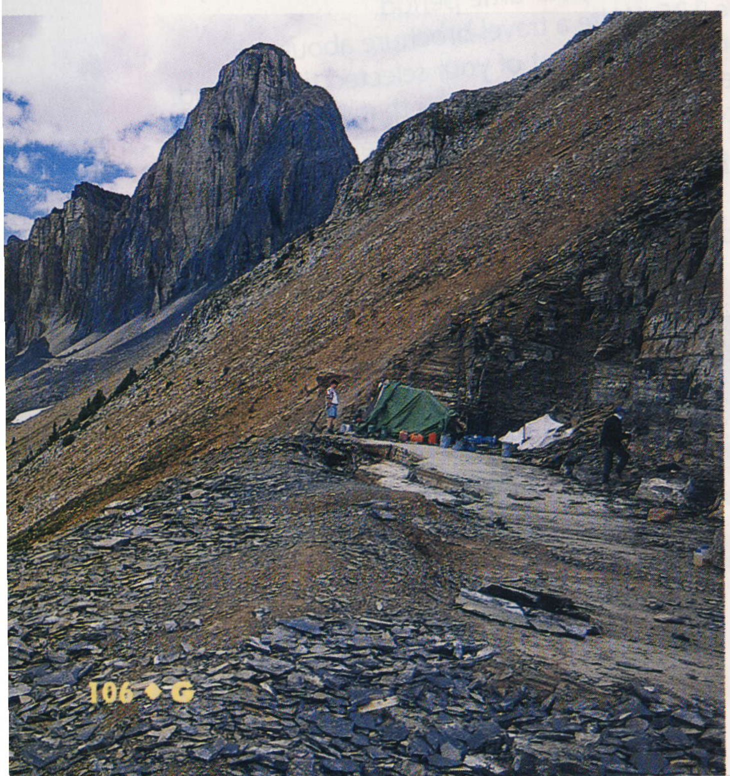
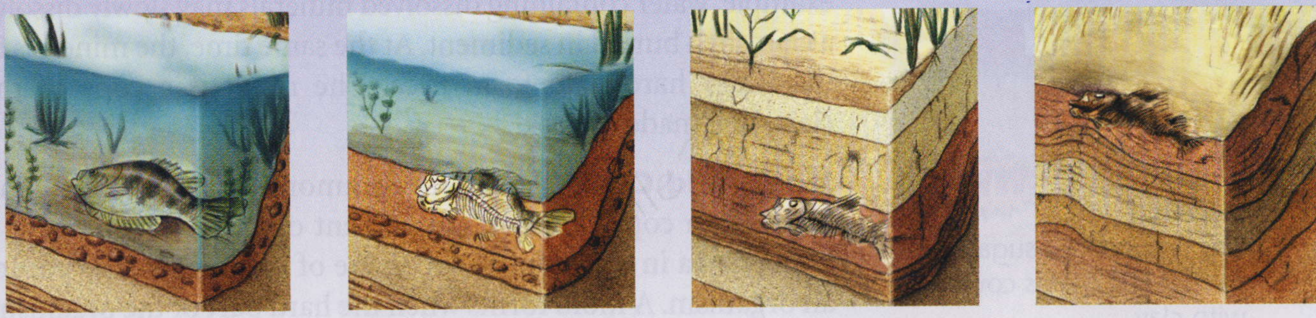


Figure 1 Paleontologists chip out the fossil-bearing rock of the Burgess shale.

Figure 2 A fossil may form when sediment quickly covers an animal's body.
Predicting What would happen to the fossil if erosion continued after Step D?



A. An animal dies and sinks into shallow water.

B. Sediment covers the animal.

C. The sediment becomes rock, preserving parts of the animal.

D. Mountain building, weathering, and erosion eventually expose the fossil at the surface.

Sedimentary rock is the type of rock that is made of hardened sediment. Most fossils form from animals or plants that once lived in or near quiet water such as swamps, lakes, or shallow seas where sediments build up. In Figure 2, you can see how a fossil might form.

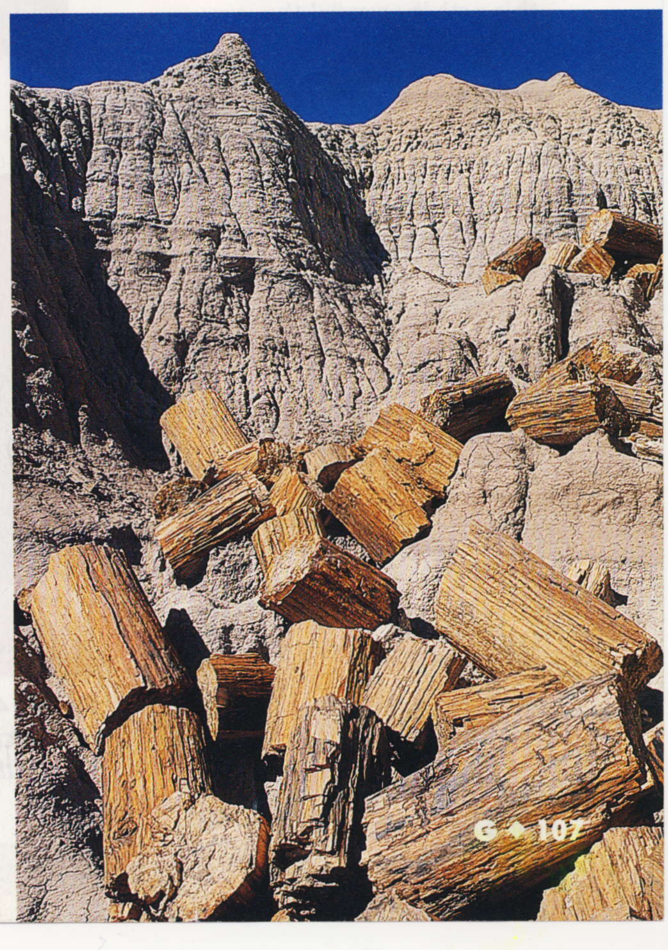
When an organism dies, its soft parts often decay quickly or are eaten by animals. Thus, generally only hard parts leave fossils. These hard parts include bones, shells, teeth, seeds, and woody stems. It is rare for the soft parts of an organism to become a fossil.

Kinds of Fossils

For a fossil to form, the remains or traces of an organism must be protected from decay. Then one of several processes may cause a fossil to form. **Fossils found in rock include petrified fossils, molds and casts, carbon films, and trace fossils. Other fossils form when the remains of organisms are preserved in substances such as tar, amber, or ice.**

Petrified Fossils A fossil may form when the remains of an organism become petrified. The term *petrified* means "turning into stone." **Petrified fossils** are fossils in which minerals replace all or part of an organism. The fossil tree trunks shown in Figure 3 are examples of petrified wood. These fossils formed after sediment covered the wood. Then water rich in dissolved minerals seeped into spaces in the plant's cells. Over time, the water evaporated, leaving the hardened minerals behind. Some of the original wood remains, but the minerals have hardened and preserved it.

Figure 3 Although they look as if they were just cut down, these petrified tree trunks were formed 200 million years ago. These fossils can be seen in the Petrified Forest National Park in Arizona.



TRY THIS

Sweet Fossils

ACTIVITY

1. Wrap a piece of clay around one sugar cube so that half of it is covered with clay.
2. Wrap clay entirely around a second sugar cube and seal it tightly.
3. Drop both cubes into a bowl of water, along with an uncovered sugar cube.
4. Stir until the uncovered sugar cube dissolves completely.
5. Remove the other cubes from the water and examine the remains.

Observing Describe the appearance of the two sugar cubes. Did the clay preserve the sugar cubes? How does this activity model the way fossils form?

Petrified fossils may also form by replacement. In replacement, the minerals in water make a copy of the organism. For example, water containing dissolved minerals may slowly dissolve a clamshell buried in sediment. At the same time, the minerals in the water harden to form rock. The result is a copy of the clamshell made of rock.

Molds and Casts The most common fossils are molds and casts. Both copy the shape of ancient organisms. A **mold** is a hollow area in sediment in the shape of an organism or part of an organism. A mold forms when the hard part of the organism, such as a shell, is buried in sediment.

Later, water carrying dissolved minerals and sediment may seep into the empty space of a mold. If the water deposits the minerals and sediment there, the result is a cast. A **cast** is a copy of the shape of an organism. Figure 4 shows a mold (top) that became filled with minerals to form a cast (bottom). As you can see, a cast is the opposite of its mold. Also notice how the mold and cast have preserved details of the animal's structure.

Figure 4 The fossil mold (top) clearly shows the shape of the animal called *Cryptolithus.* So does the fossil cast (bottom). *Cryptolithus* lived in the oceans about 450 million years ago.

Carbon Films Another type of fossil is a **carbon film,** an extremely thin coating of carbon on rock. How does a carbon film form? Remember that all living things contain carbon. When sediment buries an organism, some of the materials that make up the organism evaporate or become gases. These gases escape from the sediment, leaving carbon behind. Eventually, only a thin film of carbon remains. This process can preserve the delicate parts of plant leaves and insects.

INTEGRATING CHEMISTRY

Figure 5 This carbon film fossil of insects is between 5 million and 23 million years old.

Trace Fossils Most types of fossils preserve the shapes of ancient animals and plants. In contrast, **trace fossils** provide evidence of the activities of ancient organisms. A fossilized footprint is one example of a trace fossil. A dinosaur made the fossil footprint shown in Figure 6. The mud or sand that the animal stepped into eventually was buried by layers of sediment. Slowly the sediment became solid rock, preserving the footprints for millions of years.

Fossil footprints provide clues about an animal's size and behavior. How fast could the animal move? Did it walk on two or four legs? Did it live alone or with others of its kind? A scientist can infer the answers to such questions by looking at fossil footprints.

Other examples of trace fossils include the trails that animals followed or the burrows that they lived in. A trail or burrow can give clues about the size and shape of the organism, where it lived, and how it obtained food.

☑ *Checkpoint* *What can a trace fossil reveal about an early animal?*

Preserved Remains Some processes preserve the remains of organisms with little or no change. For example, some remains are preserved when organisms become trapped in tar. Tar is sticky oil that seeps from Earth's surface. Many fossils preserved in tar have been found at the Rancho La Brea tar pits in Los Angeles, California. Thousands of years ago, animals came to drink the water that covered these pits. Somehow, they became stuck in the tar

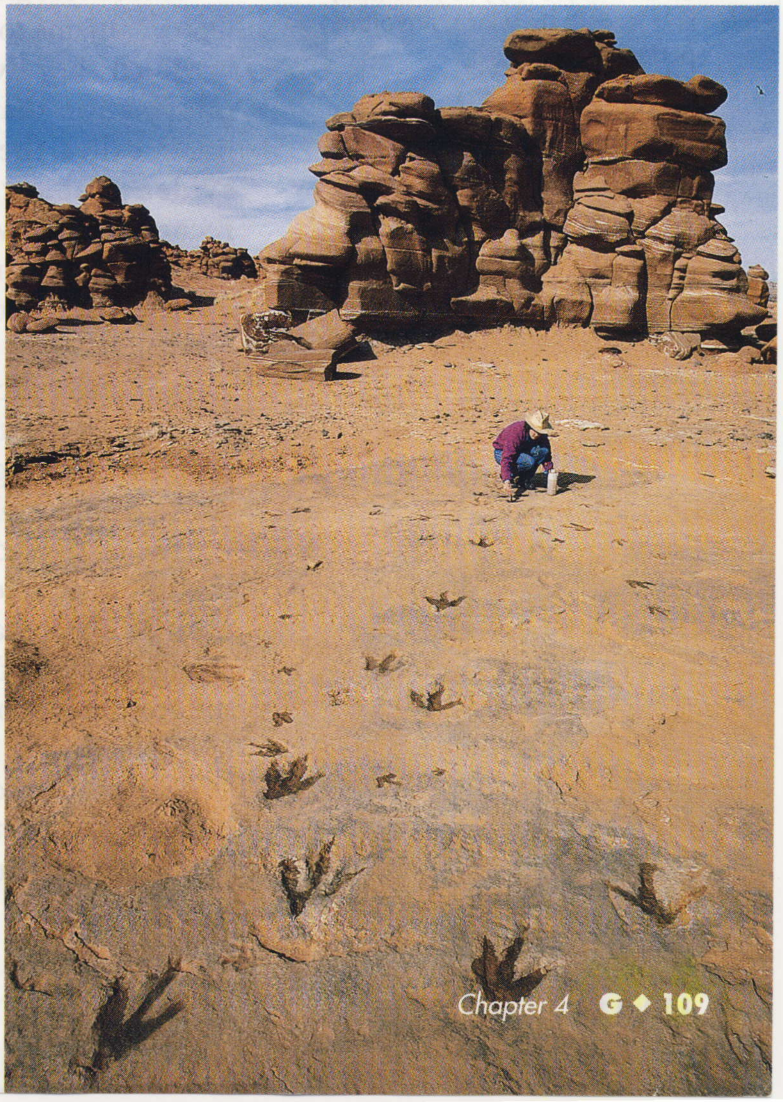


Figure 6 These dinosaur footprints are in the Painted Desert in Arizona. *Inferring What can you infer about this dinosaur from its footprints?*

and then died. The tar soaked into their bones, preserving the bones from decay.

Ancient organisms also have been preserved in amber. Amber is the hardened resin, or sap, of evergreen trees. First, an insect is trapped on sticky resin. After the insect dies, more resin covers it, sealing it from air and protecting its body from decay.

Freezing is another way in which remains can be preserved. The frozen remains of relatives of elephants called woolly mammoths have been found in very cold regions of Siberia and Alaska. Freezing has preserved even the mammoths' hair and skin.

Checkpoint *What are three ways in which the remains of an organism can be preserved?*

Figure 7 A fossil preserved in amber provides a window into the history of past life on Earth. Body parts, including the hairlike bristles on an insect's legs, its antennae, and its delicate wings, are often perfectly preserved.

Change Over Time

Paleontologists collect fossils from sedimentary rocks all over the world. They use this information to determine what past life forms were like.They want to learn what these organisms ate, what ate them, and in what environment they lived.

Paleontologists also classify organisms. They group similar organisms together. They arrange organisms in the order in which they lived, from earliest to latest. Together, all the information that paleontologists have gathered about past life is called the fossil record. **The fossil record provides evidence about the history of life on Earth. The fossil record also shows that different groups of organisms have changed over time.**

The fossil record reveals a surprising fact: Fossils occur in a particular order. Older rocks contain fossils of simpler organisms. Younger rocks contain fossils of more complex organisms. In other words, the fossil record shows that life on Earth has evolved, or changed. Simple, one-celled organisms have given rise to complex plants and animals.

The fossil record provides evidence to support the theory of evolution. A **scientific theory** is a well-tested concept that explains a wide range of observations. **Evolution** is the gradual change in living things over long periods of time. You can trace the evolution of one group of animals in *Exploring the Evolution of Elephants.*

The fossil record shows that millions of types of organisms have evolved. But many others have become extinct. A type of organism is **extinct** if it no longer exists and will never again live on Earth.

EXPLORING the Evolution of Elephants

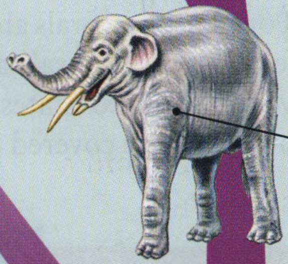
Here are some members of the elephant family. Modern elephants, mammoths, and mastodons all evolved from a common ancestor that lived about 34 million years ago.

Asian Elephant
present day
Asian elephants live in India and Southeast Asia. They can be trained to move objects with their trunks and to carry heavy loads on their backs.

African Elephant
present day
About 4 meters high at the shoulder, the African elephant is larger than the Asian elephant. African elephants are fierce and difficult to tame.

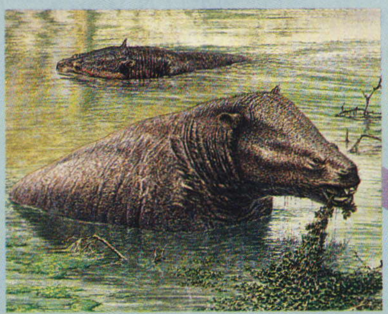
Woolly Mammoth
2 million years ago
The woolly mammoth lived during the last Ice Age. Hunting by humans may have led to their extinction about 10,000 years ago.

Mastodon
25–30 million years ago
Mastodons developed long, flexible trunks and long tusks. Later mastodons looked similar to mammoths, but were smaller and stockier. Mastodons became extinct about 10,000 years ago.



Gomphotherium
23 million years ago
Gomphotherium stood over 2 meters at the shoulder. It had a small trunk, two tusks on the upper jaw, and two tusks on the lower jaw.

Moeritherium
36 million years ago
A pig-sized relative of modern elephants, *Moeritherium* had long front teeth—primitive tusks—and a long upper lip.



Paleomastodon
34 million years ago
Paleomastodons had a short trunk and short tusks on both upper and lower jaws. The paleomastodon was an ancestor of later elephantlike animals.

Figure 8 These are fossils of brachiopods and crinoids that lived more than 435 million years ago. Similar organisms still live in the oceans today. From these fossils, scientists know that the environment where they were found was once a shallow sea.

Fossils and Past Environments

Paleontologists use fossils to build up a picture of Earth's environments in the past. The fossils found in an area tell whether the area was a shallow bay, an ocean bottom, or a fresh-water swamp.

Fossils also provide evidence of Earth's climate in the past. For example, coal has been found in Antarctica. But coal only forms from the remains of plants that grow in warm, swampy regions. As you probably know, thick layers of ice and snow now cover Antarctica. The presence of coal shows that the climate of Antarctica was once much warmer than it is today.

Scientists can use fossils to learn about changes in Earth's surface. For example, corals are organisms that thrive in warm, shallow seas. Yet fossil corals are often found in many areas of the midwestern United States. From this fact, scientists infer that shallow seas once covered those areas.

Section 1 Review

1. Describe the process by which most fossils are formed in rock.
2. What are the five types of fossils that can be found in rock?
3. How does the fossil record support the theory of evolution?
4. Describe one way in which the remains of an organism can be preserved.
5. **Thinking Critically** **Inferring** Fossil seashells have been found in rock beds on land. What can you infer about how the area has changed?

Science at Home

A fossil is something old that has been preserved. Why is it that some old things are preserved, while others are destroyed? With your parents' permission, look around your house for the oldest object you can find. Interview family members to determine how old the object is, why it has been preserved, and how it may have changed since it was new. Make a drawing of the object and bring it to class. Tell your class the story of this "fossil."

Section 2 Finding the Relative Age of Rocks

Discover Activity

In What Order Are Sediments Deposited?

1. Make a stack of different-colored layers of clay. Each layer should be about the size and thickness of a pancake. If these flat layers are sediments, which layer of sediment was deposited first? (*Hint:* This is the oldest layer.)
2. Now form the stack into a dome by pressing it over a small rounded object, such as a small bowl. With a cheese-slicer or plastic knife, carefully cut off the top of the dome. Look at the layers that you have exposed. Which layer is the oldest?

Think It Over

Inferring If you press the stack into a small bowl and trim away the clay that sticks above the edge, where will you find the oldest layer?

Guide for Reading

- How do geologists determine the relative age of rocks?
- How are index fossils useful to geologists?

Reading Tip **Before you read, rewrite the headings in the section as *how, why,* or *what* questions. As you read, look for answers to these questions.**

Have you ever seen rock layers exposed on a cliff beside a road? Often the rock layers differ in color or texture. What are these layers, and how did they form?

The sediment that forms sedimentary rocks is deposited in flat layers one on top of the other. Over years, the sediment becomes deeply buried. Then it hardens and changes into sedimentary rock. At the same time, remains of organisms in the sediment may become fossils. Over time, many layers of sediment become different layers of rock. These rock layers provide a record of Earth's geologic history.

Relative and Absolute Ages

When you look at a rock containing a fossil, your first question may be, "How old is it?" The **relative age** of a rock is its age compared to the ages of other rocks. You have probably used the idea of relative age when comparing your age with someone else's age. For example, if you say that you are older than your brother but younger than your sister, you are describing your relative age.

The relative age of a rock does not provide its absolute age. The **absolute age** of a rock is the number of years since the rock formed. It may be impossible to know a rock's absolute age exactly. But sometimes geologists can determine a rock's absolute age to within a certain number of years.

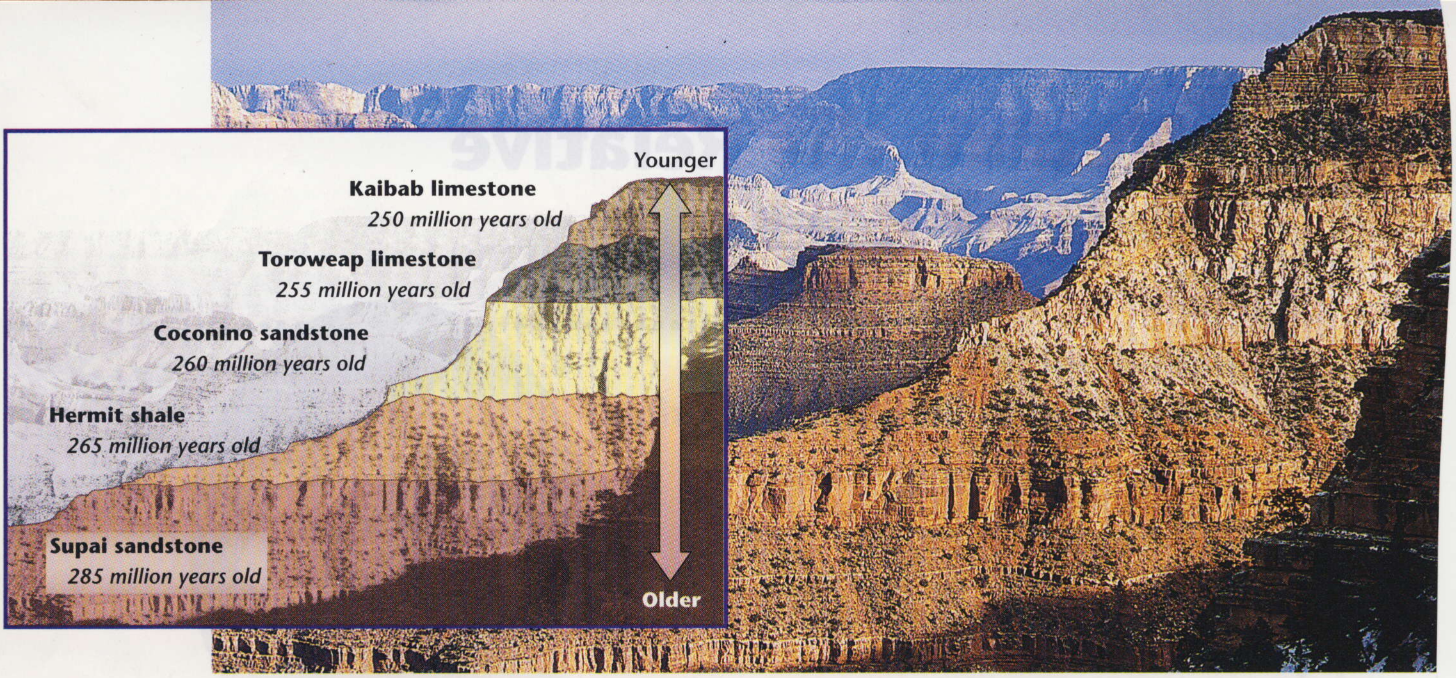


Figure 9 More than a dozen rock layers make up the walls of the Grand Canyon. You can see five layers clearly in the photograph. ***Applying Concepts*** *In which of the labeled layers in the diagram would you find the oldest fossils? Explain.*

TRY THIS

Sampling a Sandwich

ACTIVITY

Your teacher will give you a sandwich that represents rock layers in Earth's crust.

1. Use a round, hollow, uncooked noodle as a coring tool. Push the noodle through the layers of the sandwich.
2. Pull the noodle out of the sandwich. Break the noodle gently to remove your core sample.
3. Draw a picture coloring and labeling what you see in each layer of the core.

Observing If this were a real sample of rock layers, which layer would be the oldest? The youngest? Why do you think scientists study core samples?

The Position of Rock Layers

It can be difficult to determine the absolute age of a rock. So geologists use a method to find a rock's relative age. Geologists use the **law of superposition** to determine the relative ages of sedimentary rock layers. **According to the law of superposition, in horizontal sedimentary rock layers the oldest layer is at the bottom. Each higher layer is younger than the layers below it.** If you did the Discover activity at the beginning of this section, you have already used the law of superposition.

The walls of the Grand Canyon in Arizona illustrate the law of superposition. The sedimentary rock layers in the canyon walls represent 2 billion years of Earth's history. You can see some of the rock layers found in the Grand Canyon in Figure 9. Scientists have given names to all the layers of rock exposed on the walls of the Grand Canyon. By using the law of superposition, you should be able to determine the relative ages of these layers.

If you were to start at the top of the Grand Canyon, you would see Kaibab limestone. Because it is on top, it is the youngest layer. As you began your descent into the canyon, you would pass by Toroweap limestone. Next, you would see Coconino sandstone. The deeper you traveled into the canyon, the older the rocks would become. Your trip into the canyon is like a trip into Earth's history. The deeper you go, the older the rocks.

☑ ***Checkpoint*** *How would a geologist find the relative age of a rock?*

Other Clues to Relative Age

There are other clues to the relative ages of rocks. Geologists find some of these clues by studying extrusions and intrusions of igneous rock and faults.

Clues From Igneous Rock Igneous rock forms when magma or lava hardens. Magma is molten material beneath Earth's surface. Magma that flows onto the surface is called lava.

Lava that hardens on the surface is called an **extrusion.** The rock layers below an extrusion are always older than the extrusion.

Beneath the surface, magma may push into bodies of rock. There, the magma cools and hardens into a mass of igneous rock called an **intrusion.** An intrusion is always younger than the rock layers around and beneath it. Figure 10A shows an intrusion. Geologists study where intrusions and extrusions formed in relation to other rock layers. This helps geologists understand the relative ages of the different types of rock.

Clues From Faults More clues come from the study of faults. A **fault** is a break in Earth's crust. Forces inside Earth cause movement of the rock on opposite sides of a fault.

A fault is always younger than the rock it cuts through. To determine the relative age of a fault, geologists find the the relative age of the most recent rock layer through which the fault slices.

Movements along faults can make it harder for geologists to determine the relative ages of rock layers. In Figure 10B you can see how the rock layers no longer line up because of movement along the fault.

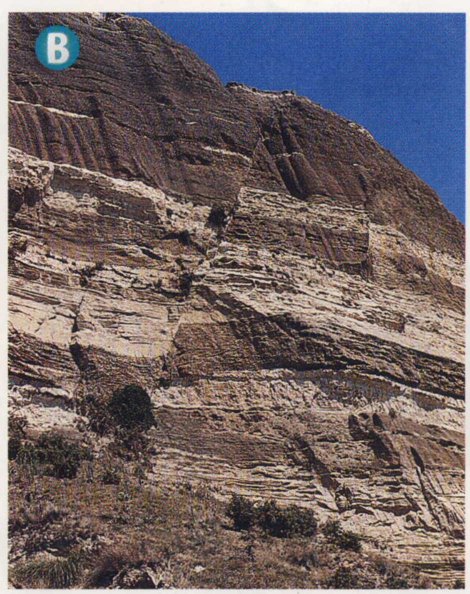
Music CONNECTION

The Grand Canyon provides one of Earth's best views of the geologic record. The American composer Ferde Grofé composed his *Grand Canyon Suite* for orchestra in 1931. The music paints a picture of desert scenery and a trip on muleback into the Grand Canyon.

In Your Journal

Listen to a recording of the *Grand Canyon Suite.* How does Grofé's music express what it's like to visit the Grand Canyon? What words would you use to describe what you heard?

Figure 10 Intrusions and faults give clues to the relative ages of rocks. In 10A, an intrusion cuts through rock layers. In 10B, rock layers are broken and shifted along a fault. *Inferring Which is older, the intrusion in 10A or the rock layers it crosses?*



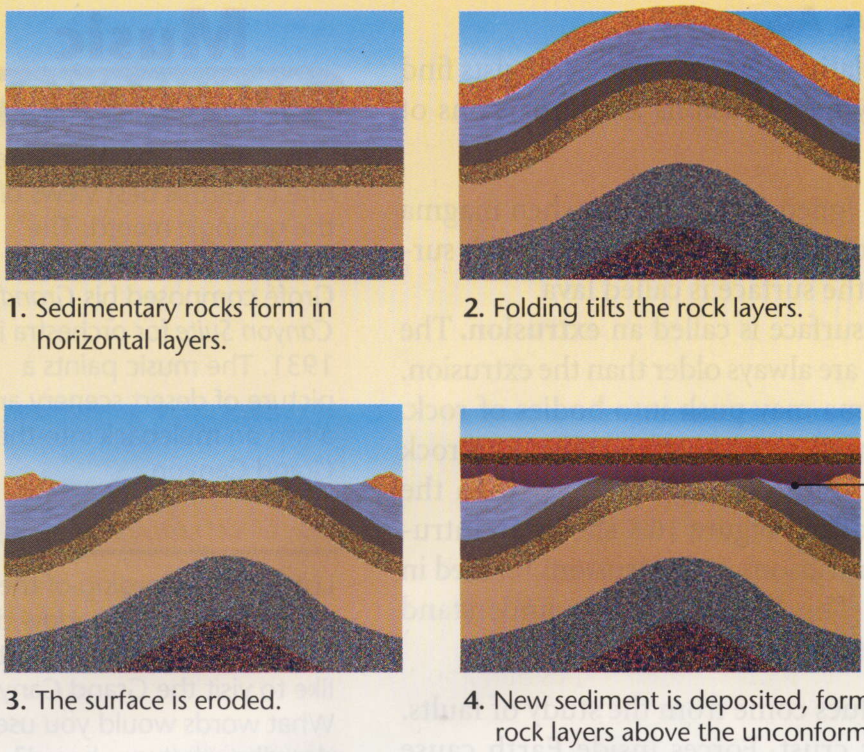


Figure 11 An unconformity occurs where erosion wears away layers of sedimentary rock. Other rock layers then form on top of the eroded surface.

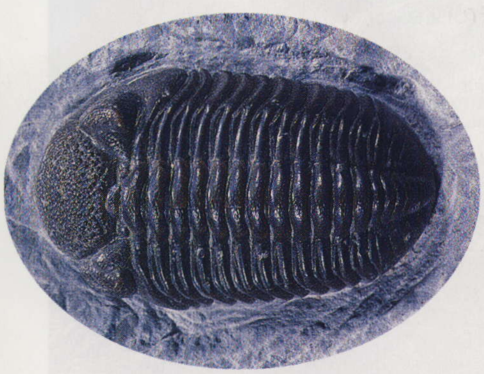
Gaps in the Geologic Record

The geologic record of sedimentary rock layers is not always complete. Deposition slowly builds layer upon layer of sedimentary rock. But some of these layers may erode away, exposing an older rock surface. Then deposition begins again, building new rock layers.

The surface where new rock layers meet a much older rock surface beneath them is called an unconformity. An **unconformity** is a gap in the geologic record. An unconformity shows where some rock layers have been lost because of erosion. Figure 11 shows how an unconformity forms.

Using Fossils to Date Rocks

Figure 12 Trilobite fossils are widely distributed. Some types of trilobites serve as index fossils.



To date rock layers, geologists first give a relative age to a layer of rock at one location. Then they can give the same age to matching layers of rock at other locations.

Certain fossils, called index fossils, help geologists match rock layers. To be useful as an **index fossil,** a fossil must be widely distributed and represent a type of organism that existed only briefly. A fossil is considered widely distributed if it occurs in many different areas. Geologists look for index fossils in layers of rock. **Index fossils are useful because they tell the relative ages of the rock layers in which they occur.**

Geologists use particular types of organisms as index fossils—for example, certain types of trilobites. Trilobites (TRY luh byts) were a group of hard-shelled animals whose bodies had three

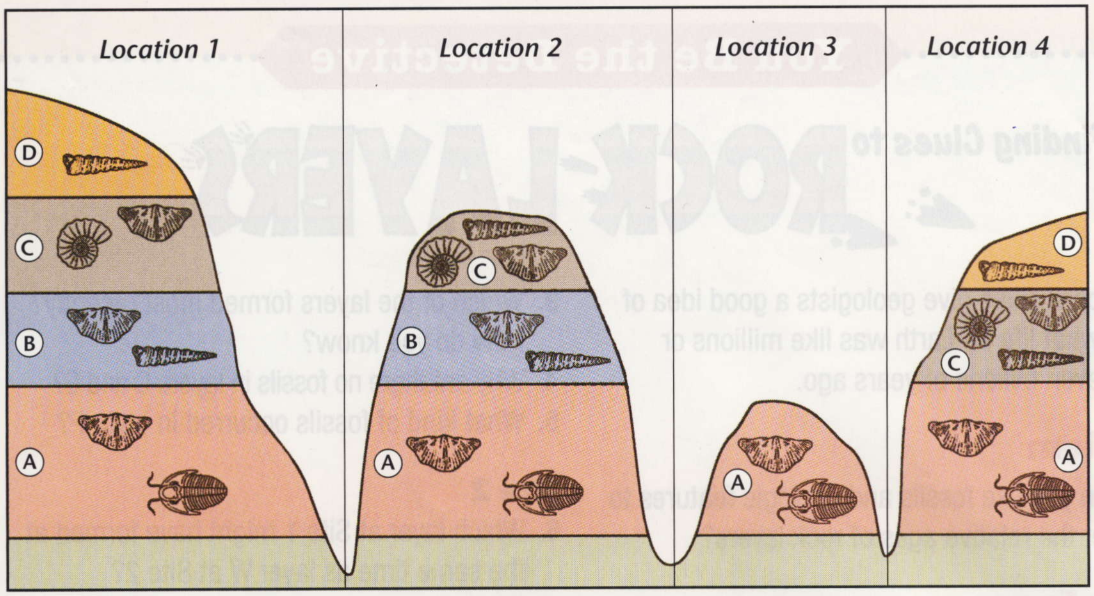


Figure 13 Scientists use index fossils to match up rock layers at locations that may be far apart. The trilobites in Layer A are index fossils. *Interpreting Diagrams* *Can you find another index fossil in the diagram? (Hint:* Look for a fossil that occurs in only one time period, but in several different locations.)

distinct parts. Trilobites evolved in shallow seas more than 500 million years ago. Over time, many different types of trilobites appeared. They became extinct about 245 million years ago. Trilobite fossils have been found in many different places.

To serve as an index fossil, a type of trilobite must be different in some way from other trilobites. One example is a type of trilobite with large eyes. These large-eyed trilobites survived for a time after other trilobites became extinct. Suppose a geologist finds large-eyed trilobites in a rock layer. The geologist can infer that those rocks are younger than rocks containing other types of trilobites.

You can use index fossils to match rock layers. Look at Figure 13, which shows rock layers from four different locations. Notice that two of the fossils are found in only one of these rock layers. These are the index fossils.

Section 2 Review

1. What is the law of superposition?
2. What characteristics are necessary for a fossil to be considered an index fossil?
3. What do unconformities show?
4. **Thinking Critically** **Applying Concepts** Horseshoe crabs are common in the ocean along the east coast of North America. They have existed with very little change for about 200 million years. Would horseshoe crabs be useful as an index fossil? Explain why or why not.

Check Your Progress

CHAPTER PROJECT 4

Locate reference materials you will need to research your chosen geologic time period. Possible sources include library books, magazines, encyclopedias, and Internet articles. Also keep a list of the resources you used. As you do your research, keep in mind the pictures and facts you will need for the class time line and travel brochure. Be sure to include the organisms and environment of the time period.

You Be the Detective

Finding Clues to ROCK LAYERS

Fossil clues give geologists a good idea of what life on Earth was like millions or even billions of years ago.

Problem

How can you use fossils and geologic features to interpret the relative ages of rock layers?

Skills Focus

interpreting data, drawing conclusions

Procedure

1. Study the rock layers at Sites 1 and 2. Write down the similarities and differences between the layers at the two sites.
2. List the kinds of fossils that are found in each rock layer of Sites 1 and 2.

Analyze and Conclude

Site 1

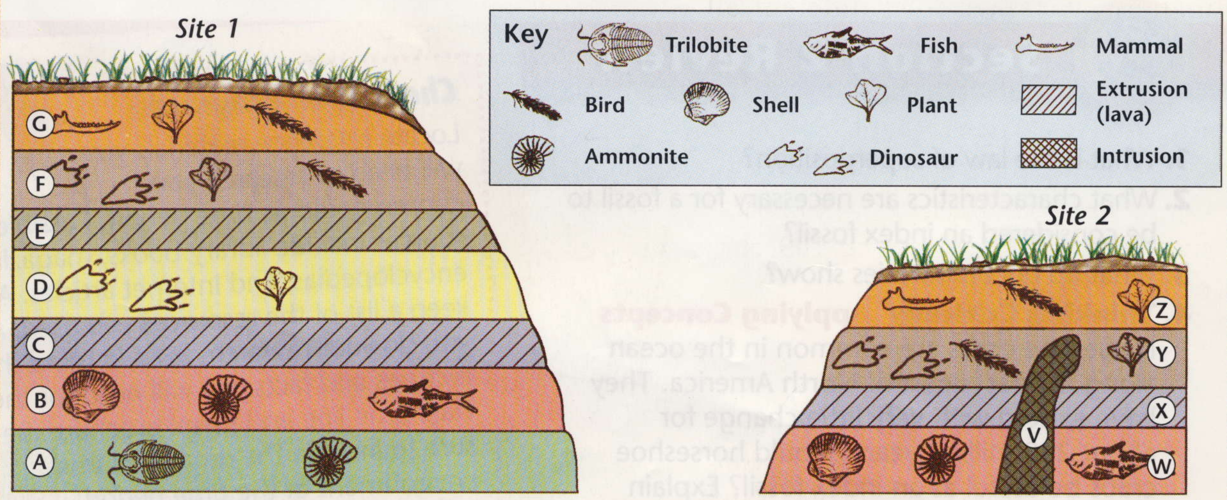
1. What "fossil clues" in layers A and B indicate the kind of environment that existed when these rock layers were formed? How did the environment change in layer D?
2. Which layer is the oldest? How do you know?
3. Which of the layers formed most recently? How do you know?
4. Why are there no fossils in layers C and E?
5. What kind of fossils occurred in layer F?

Site 2

6. Which layer at Site 1 might have formed at the same time as layer W at Site 2?
7. What clues show an unconformity or gap in the horizontal rock layers? Which rock layers are missing? What might have happened to these rock layers?
8. Which is older, intrusion V or layer Y? How do you know?
9. **Think About It** Working as a geologist, you find a rock containing fossils. What information would you need in order to determine this rock's age relative to one of the rock layers at Site 1?

More to Explore

Draw a sketch similar to Site 2 and include a fault that cuts across the intrusion. Have a partner then identify the relative age of the fault, the intrusion, and the layers cut by the fault.



SECTION 3 Radioactive Dating

DISCOVER ACTIVITY

How Long 'Til It's Gone?

1. Make a small cube—about 5 cm × 5 cm × 5 cm—from modeling clay.
2. Carefully use a knife to cut the clay in half. Put one half of the clay aside.
3. Cut the clay in half two more times. Each time you cut the clay, put one half of it aside.

Think It Over

Predicting How big will the remaining piece of clay be if you repeat the process several more times?

GUIDE FOR READING

- What happens during radioactive decay?
- What can be learned from radioactive dating?
- How did scientists determine the age of Earth?

Reading Tip As you read, use the headings to make an outline showing what radioactive elements are and how they are used by geologists to find the absolute age of rocks.

In Australia, scientists have found sedimentary rocks that contain some of the world's oldest fossils—stromatolites (stroh MAT uh lyts). Stromatolites are the remains of reefs built by organisms similar to present-day bacteria. The bacteria grew together in dense mats shaped like stacks of pancakes. The mats formed reefs in shallow water near the shores of ancient oceans. Sediment eventually covered these reefs. As the sediments changed to rock, so did the reefs.

Paleontologists have determined that some stromatolites are more than 3 billion years old. But how did scientists determine the age of these fossils? To understand the methods of absolute dating, you need to learn more about the chemistry of rocks.

Changing From One Element to Another

What do you, the air you breathe, a lemon, and a puddle of water have in common? All are kinds of matter. In fact, everything around you is made of matter. Although different kinds of matter look, feel, or smell different, all the matter you see is made of tiny particles called **atoms.** When all the atoms in a particular type of matter are the same, the matter is an **element.** Carbon, oxygen, iron, lead, and potassium are just a few of the 109 currently known elements.

Figure 14 Stromatolites were formed by clumps of one-celled organisms that lived in shallow seas more than 3 billion years ago. Similar organisms grow in the ocean near Australia today.

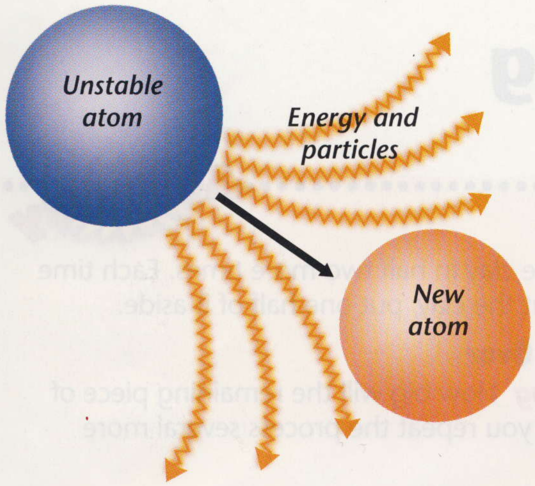


Figure 15 In the process of radioactive decay, an atom releases energy.

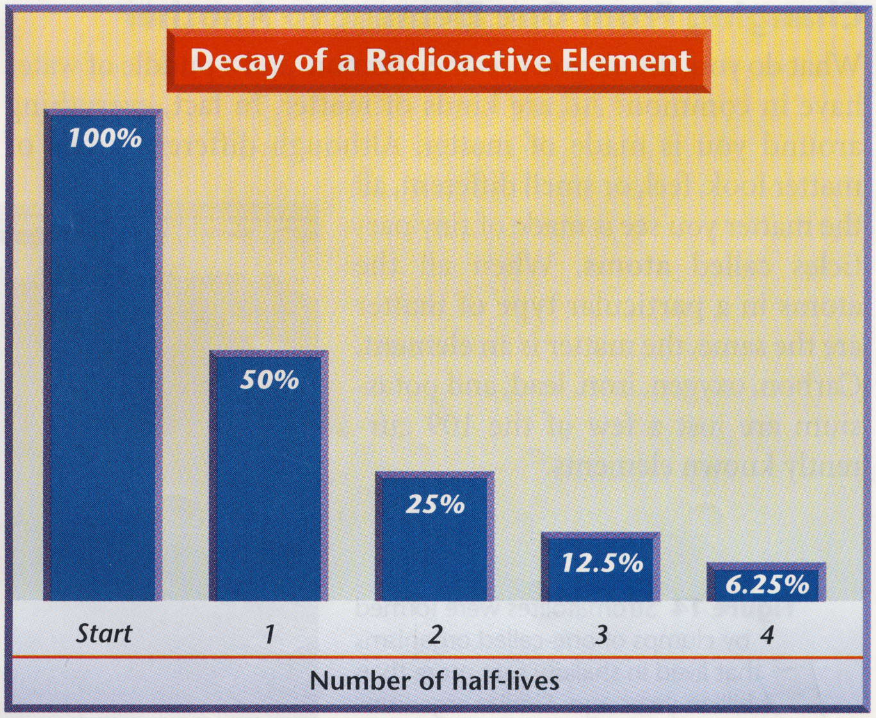
Most elements are stable. They do not change under normal conditions. But some elements exist in forms that are unstable. Over time, these elements break down, or decay, by releasing particles and energy in a process called **radioactive decay.** These unstable elements are said to be radioactive. **During radioactive decay, the atoms of one element break down to form atoms of another element.** Radioactive elements occur naturally in igneous rocks. Scientists use the rate at which these elements decay to calculate the rock's age.

The Rate of Radioactive Decay

You have a birthday, a specific day from which you calculate your age. What's the "birthday" of a rock? For an igneous rock, that "birthday" is when it first hardens to become rock. (Recall that igneous rocks form from molten magma and lava.) As a radioactive element within the igneous rock decays, it changes into another element. So the composition of the rock changes slowly over time. The amount of the radioactive element goes down. But the amount of the new element goes up.

The rate of decay of each radioactive element is constant—it never changes. This rate of decay is the element's half-life. The **half-life** of a radioactive element is the time it takes for half of the radioactive atoms to decay. You can see in Figure 16 how a radioactive element decays over time.

Figure 16 The half-life of a radioactive element is the amount of time it takes for half of the radioactive atoms to decay. *Calculating After three half-lives, how much of the radioactive element remains?*



Elements Used in Radioactive Dating		
Radioactive Element	**Half-life (years)**	**Dating Range (years)**
Carbon-14	5,730	500–50,000
Potassium-40	1.3 billion	50,000–4.6 billion
Rubidium-87	47 billion	10 million–4.6 billion
Thorium-232	14.1 billion	10 million–4.6 billion
Uranium-235	713 million	10 million–4.6 billion
Uranium-238	4.5 billion	10 million–4.6 billion

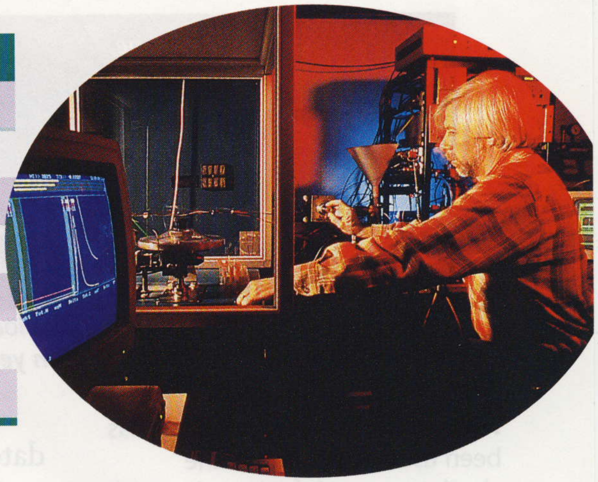


Figure 17 The half-lives of different radioactive elements vary greatly. This scientist is testing a sample of material to determine how much carbon-14 it contains.

Absolute Ages From Radioactive Dating

Geologists use radioactive dating to determine the absolute ages of rocks. In radioactive dating, scientists first determine the amount of a radioactive element in a rock. Then they compare that amount with the amount of the stable element into which the radioactive element decays. Figure 17 lists several common radioactive elements and their half-lives.

Potassium–Argon Dating Scientists often date rocks using potassium-40. This form of potassium decays to stable argon-40 and has a half-life of 1.3 billion years. Potassium-40 is useful in dating the most ancient rocks because of its long half-life.

Carbon-14 Dating A radioactive form of carbon is carbon-14. All plants and animals contain carbon, including some carbon-14. As plants and animals grow, carbon atoms are added to their tissues. After an organism dies, no more carbon is added. But the carbon-14 in the organism's body decays. It changes to stable nitrogen-14. To determine the age of a sample, scientists measure the amount of carbon-14 that is left in the organism's remains. From this amount, they can determine its absolute age. Carbon-14 has been used to date fossils such as frozen mammoths, as well as pieces of wood and bone. Carbon-14 even has been used to date the skeletons of prehistoric humans.

Carbon-14 is very useful in dating materials from plants and animals that lived up to about 50,000 years ago. Carbon-14 has a half-life of only 5,730 years. For this reason, it can't be used to date really ancient fossils or rocks. The amount of carbon-14 left would be too small to measure accurately.

Checkpoint *What are two types of radioactive dating?*

Sharpen your Skills

Calculating ACTIVITY

You have 3 grams of the radioactive element potassium-40. Calculate the mass of the remaining potassium-40 after 4 half-lives. Now calculate how much time has gone by. (*Hint:* One half-life of potassium-40 takes 1.3 billion years.) What would happen to the amount of potassium-40 if you continued through several more half-lives?

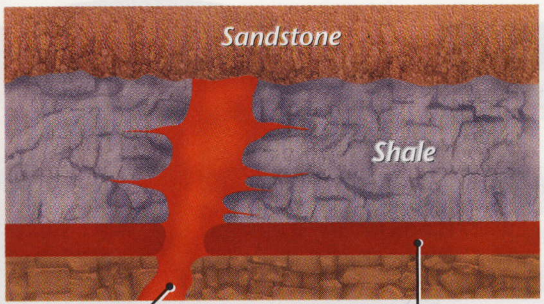


Figure 18 Radioactive dating has been used to determine the absolute ages of the intrusion and extrusion in the diagram. The shale lies above the extrusion and is crossed by the intrusion. Therefore the shale is younger than the extrusion, but older than the intrusion—between 150 million years old and 120 million years old. *Inferring What can you infer about the age of the sandstone?*

Radioactive Dating of Rock Layers

Radioactive dating cannot usually be used for dating rocks other than igneous rocks. As you recall, sedimentary rocks form as sediments are deposited by water or wind. The rock particles in sedimentary rocks are from other rocks, all of different ages. Radioactive dating would provide the age of the particles. It would not provide the age of the sedimentary rock.

How, then, do scientists date sedimentary rock layers? They date the igneous intrusions and extrusions near the sedimentary rock layers. Look at Figure 18. As you can see, sedimentary rock above an igneous intrusion must be younger than that intrusion.

How Old is Earth?

Radioactive dating has been used to calculate the age of Earth. The oldest rocks ever found on Earth have been dated at about 4.0 billion years old. But scientists think Earth formed even earlier than that. According to one theory, Earth and the moon are about the same age. When Earth was very young, a large object from space collided with Earth. This collision threw a large amount of material from both bodies into orbit around Earth. This material combined to form the moon. Scientists have dated moon rocks brought to Earth by astronauts during the 1970s. **Radioactive dating shows that the oldest moon rocks are about 4.6 billion years old. Scientists infer that Earth is only a little older than those moon rocks—roughly 4.6 billion years old.**

Section 3 Review

1. Describe the process of radioactive decay.
2. What is a half-life? How is it used to determine the absolute age of a rock?
3. When do scientists use both radioactive dating and relative dating to find the age of a rock?
4. How were moon rocks used to determine the age of Earth?
5. **Thinking Critically Applying Concepts** Which of the following types of fossils can be dated using carbon-14: molds and casts, trace fossils, frozen remains, remains preserved in tar? Explain your answer.

Science at Home

Collect 10 items out of a drawer that is full of odds and ends such as keys, coins, receipts, photographs, and souvenirs. Have your family members put them in order from oldest to newest. What clues will you use to determine their relative ages? Do you remember when certain items were bought or a photograph was taken? How can you determine the oldest object of all? Make a list of the ten items in order by relative age. Are there any items for which you know the absolute age?

SECTION 4 The Geologic Time Scale

DISCOVER ACTIVITY

This Is Your Life!

1. Make a list of about 10 to 15 important events that you remember in your life.
2. On a sheet of paper, draw a time line to represent your life. Use a scale of 3.0 cm to 1 year.
3. Write each event in the correct year along the time line.
4. Now divide the time line into parts that describe major periods in your life, for example: preschool years, elementary school years, and middle school years.

Think It Over

Making Models Along which part of your time line are most of the events located? Which period of your life does this part of the time line represent? Why do you think this is so?

GUIDE FOR READING

- **Why is the geologic time scale used to show Earth's history?**
- **What are the different units of the geologic time scale?**

Reading Tip **As you read, make a list of the units of geologic time scale. Write a sentence about each.**

Imagine squeezing Earth's 4.6-billion-year history into a 24-hour day. Earth forms at midnight. About seven hours later, the earliest one-celled organisms appear. Over the next 14 hours, simple, soft-bodied organisms such as jellyfish and worms develop. A little after 9:00 P.M.—21 hours later—larger, more complex organisms evolve in the oceans. Reptiles and insects first appear about an hour after that. Dinosaurs arrive just before 11:00 P.M., but are extinct by 11:30 P.M. Modern humans don't appear until less than a second before midnight!

The Geologic Time Scale

Months, years, or even centuries aren't very helpful for thinking about Earth's long history. **Because the time span of Earth's past is so great, geologists use the geologic time scale to show Earth's history.** The **geologic time scale** is a record of the life forms and geologic events in Earth's history. You can see this time scale in Figure 19.

Scientists first developed the geologic time scale by studying rock layers and index fossils worldwide. With this information, scientists placed Earth's rocks in order by relative age. Later, radioactive dating helped determine the absolute age of the divisions in the geologic time scale. As geologists studied the fossil record, they found major changes in life forms at different times. They used these changes to mark where one unit of geologic time ends and the next begins. Therefore the divisions of the geologic time scale depend on events in the history of life on Earth.

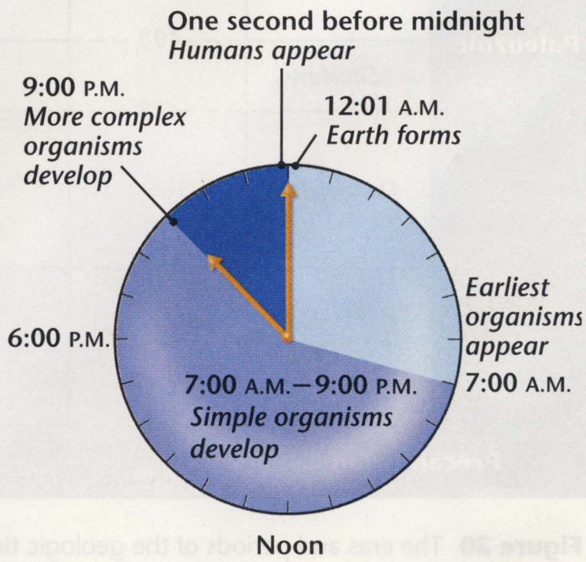


Figure 19 If geologic time went by in a single day, all of human history would take place in less than the last second!

Geologic Time Scale

Era	Period	Millions of Years Ago	Duration (millions of years)
Cenozoic	Quaternary	1.6	1.6 to present
	Tertiary	66.4	65
Mesozoic	Cretaceous	144	78
	Jurassic	208	64
	Triassic	245	37
Paleozoic	Permian	286	41
	Carboniferous	360	74
	Devonian	408	48
	Silurian	438	30
	Ordovician	505	67
	Cambrian	544	39
Precambrian			544 million years ago–4.6 billion years ago

Figure 20 The eras and periods of the geologic time scale are used to date the events in Earth's long history. *Interpreting Diagrams How long ago did the Paleozoic Era end?*

Divisions of Geologic Time

When speaking of the past, what names do you use for different spans of time? You probably use such names as *century, decade, year, month, week,* and *day.* You know that a month is longer than a week but shorter than a year. Scientists use similar divisions for the geologic time scale.

Geologic time begins with a long span of time called Precambrian Time (pree KAM bree un). Precambrian Time, which covers about 88 percent of Earth's history, ended 544 million years ago. **After Precambrian Time, the basic units of the geologic time scale are eras, periods, and epochs.**

☑ *Checkpoint How much of Earth's history is included in Precambrian Time?*

Eras, Periods, and Epochs

Geologists divide the time between Precambrian Time and the present into three long units of time called **eras.** They are the Paleozoic Era, the Mesozoic Era, and the Cenozoic Era.

Eras The Paleozoic (pay lee uh ZOH ik) began about 544 million years ago and lasted for 300 million years. The word part *paleo-* means "ancient or early," and *-zoic* means "life." Many animals that lived during the Paleozoic were animals without backbones, or **invertebrates.**

The Mesozoic (mez uh ZOH ik) began about 245 million years ago and lasted about 180 million years. The word part *meso-* means "middle." People often call the Mesozoic the Age of Dinosaurs. Yet dinosaurs were only one of the many groups of organisms that lived during this era. For example, mammals began to evolve during the Mesozoic Era.

Earth's most recent era is the Cenozoic (sen uh ZOH ik). It began about 65 million years ago and continues to the present day. The word part *ceno-* means "recent." The Cenozoic is sometimes called the Age of Mammals, because mammals became common during this time.

Periods Eras are subdivided into units of geologic time called **periods.** Geologic periods range in length from tens of millions of years to less than two million years. You can see in Figure 20 that the Mesozoic Era includes three periods: the Triassic Period, the Jurassic Period, and the Cretaceous Period.

You may wonder where the names of the geologic periods come from. Many come from places around the world where geologists first described the rocks and fossils of that period. The name Cambrian, for example, refers to Cambria, the old Roman name for Wales. Jurassic refers to the Jura Mountains in France.

The Carboniferous Period is named for the large coal deposits that formed during that period. *Carboniferous* means "carbon bearing." Geologists in the United States often divide the Carboniferous Period into the Mississippian Period (320–360 million years ago) and the Pennsylvanian Period (286–320 million years ago.)

Epochs Geologists further subdivide the periods of the Cenozoic Era into **epochs.** Why are epochs used in the time scale? The fossil record in the Cenozoic is much more complete than the fossil record of earlier eras. There are a lot more events to place in sequence, and using epochs makes this task easier.

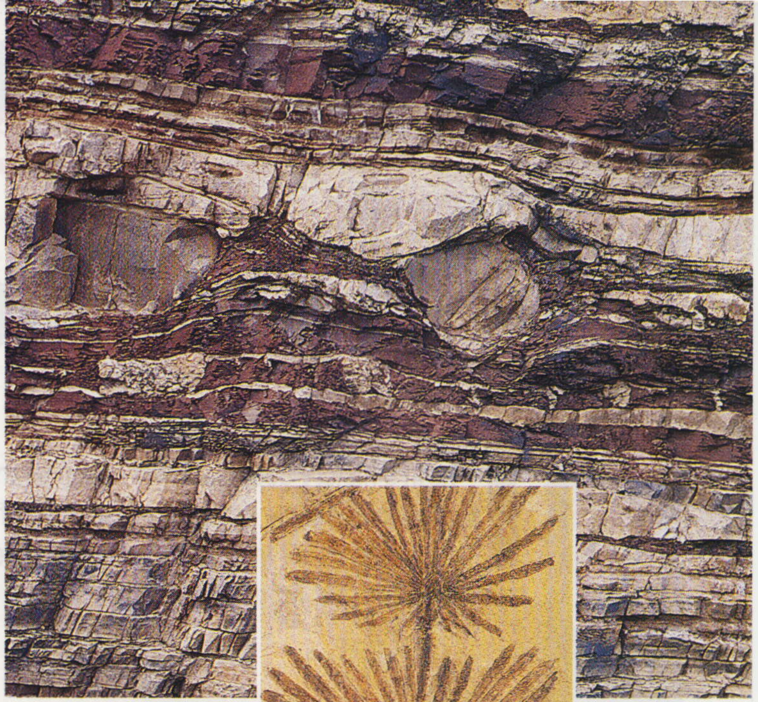


Figure 21 The sedimentary rock layers (top) were laid down during the Ordovician period. The fossil of the plant (bottom) formed during the Carboniferous period.

Section 4 Review

1. What is the geologic time scale?
2. What are geologic periods?
3. What method of dating did geologists first use when they developed the geologic time scale? How is the scale different today?
4. **Thinking Critically Interpreting Diagrams** Which period in the Paleozoic was the longest? If you could travel back in time 100 million years, what period would you be in? What era would you be in?

Check Your Progress

CHAPTER PROJECT 4

Make a list of illustrations for the time line and travel brochure. Before creating the illustrations, think about what they will look like and the materials you will need to complete them. Will they be three dimensional? Will they be drawn using a computer? Begin to plan how you will use illustrations in your travel brochure. Space in a brochure is limited, so focus on the highlights of your geologic period.

Skills Lab

Making Models

As Time Goes By

Earth's history goes back 4.6 billion years. How can people grasp the vast scale of geologic time? In this lab, you will make a model to represent Earth's history.

Problem

How can you make a model of geologic time?

Materials

worksheet with 2,000 asterisks
one ream of paper

Procedure

Part 1 Table A

1. Copy Table A into your lab notebook. Figure how long ago these historic events happened and write the answers on your chart.
2. Obtain a worksheet with 2,000 asterisks printed on it. Each asterisk represents one year. The first asterisk at the top represents one year ago.
3. Starting from this asterisk, circle the asterisk that represents how many years ago each event in Table A occurred.
4. Label each circled asterisk to indicate the event.
5. Obtain a ream of copy paper. There are 500 sheets in a ream. If each sheet had 2,000 asterisks on it, there would be a total of 1 million asterisks. Therefore, each ream would represent 1 million years.

Part 2 Fill in Chart B

6. Copy Table B into your lab notebook. Determine how much paper in reams or sheets would be needed to represent the events in geologic time found in Table B. (*Hint:* Recall that each ream represents 1 million years.)

Table A Historic Events

Event	Date	Number of Years Ago
You are born		
One of your parents is born		
Space shuttle *Challenger* explodes	1986	
Neil Armstrong first walks on the moon	1969	
World War I ends	1918	
Civil War ends	1865	
Declaration of Independence signed	1776	
Columbus crosses Atlantic	1492	
Leif Ericson visits North America	1000	

Table B Geologic Events			
Event	**Number of Years Ago**	**Reams or Sheets of Paper**	**Thickness of Paper**
End of the last Ice Age	10,000		
Whales evolve	50 million		
Pangaea begins to break up	225 million		
First vertebrates develop	530 million		
Multicellular organisms develop (algae)	1 billion		
First life (bacteria)	3.5 billion		
Oldest known rocks form	4.0 billion		
Age of Earth	4.6 billion		

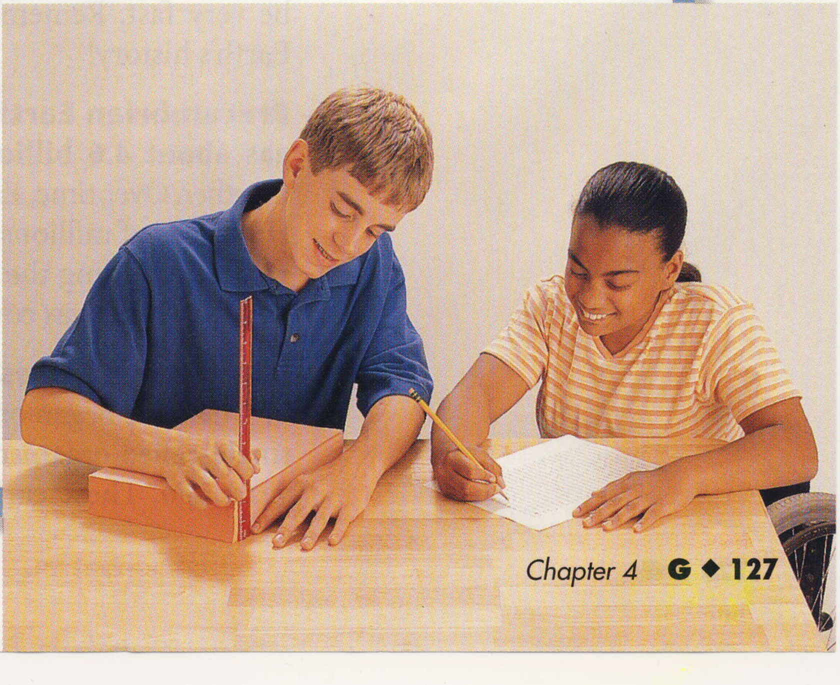
7. Measure the thickness of a ream of paper. Use this thickness to calculate how thick a stack of paper would need to be to represent how long ago each geologic event occurred. (*Hint:* Use a calculator to multiply the thickness of the ream of paper by the number of reams.) Enter your results in Table B.

Analyze and Conclude

1. Measure the height of your classroom. How many reams of paper would you need to reach the ceiling? How many years would the height of the ceiling represent? Which geologic events listed in Table B would fall on a ream of paper inside your classroom?
2. At this scale, how many classrooms would have to be stacked on top of each other to represent the age of Earth? The time when vertebrates appeared?
3. How many times higher would the thickness of the stack be for the age of Earth than for the breakup of Pangaea?
4. On your model, how could you distinguish one era or period from another? How could you show when particular organisms evolved and when they became extinct?
5. **Think About It** Is the scale of your model practical? What would be the advantages and disadvantages of a model that fit geologic time on a time line 1 meter long?

More to Explore

This model represents geologic time as a straight line. Can you think of other ways of representing geologic time graphically? Using colored pencils, draw your own version of the geologic time scale so that it fits on a single sheet of typing paper. (*Hint:* You could represent geologic time as a wheel, a ribbon, or a spiral.)



SECTION 5

Earth's History

DISCOVER — ACTIVITY

What Do Fossils Reveal About Earth's History?

1. Compare the two fossils in photos A and B. How did these organisms become fossils?
2. Work with one or two other students to study the organisms in the two photos. Think about how these organisms may have lived. Then make sketches showing what each of these organisms may have looked like.

Think It Over

Posing Questions If you were a paleontologist, what questions would you want to ask about these organisms?

GUIDE FOR READING

- What were the major events in Earth's geologic history?
- What were the major events in the development of life on Earth?

Reading Tip Preview *Exploring Geologic History* on pages 132–135. Make a list of questions you have about Earth's history. Then look for answers as you read.

Your science class is going on a field trip, but this trip is a little out of the ordinary. You're going to travel back billions of years to the earliest days on Earth. Then you will move forward through time to the present. Enter the time machine and strap yourself in. Take a deep breath—you're off!

A dial on the dashboard shows the number of years before the present. You stare at the dial—it reads 4.6 billion years. You peer out the window as the time machine flies above the planet. Earth looks a little strange. Where are the oceans? Where are the continents? How will Earth change over the next billions of years? You'll answer these and other questions about Earth's history as you take this extraordinary trip.

Precambrian Time

Your journey through the first part of Earth's history will need to be very fast. Remember, Precambrian time includes most of Earth's history!

Precambrian Earth **Earth formed from a mass of dust and gas about 4.6 billion years ago.** Gravity pulled this mass together. Over time, Earth's interior became very hot and molten. Hundreds of millions of years passed. Then lava flowed over the surface, building the first continents. An atmosphere formed, and the world was covered with an ocean.

The Earliest Forms of Life Scientists cannot pinpoint when or where life began on Earth. But scientists have found fossils of single-celled organisms in rocks that formed about 3.5 billion years ago. These earliest life forms were probably similar to present-day bacteria. All other forms of life on Earth evolved from these simple organisms.

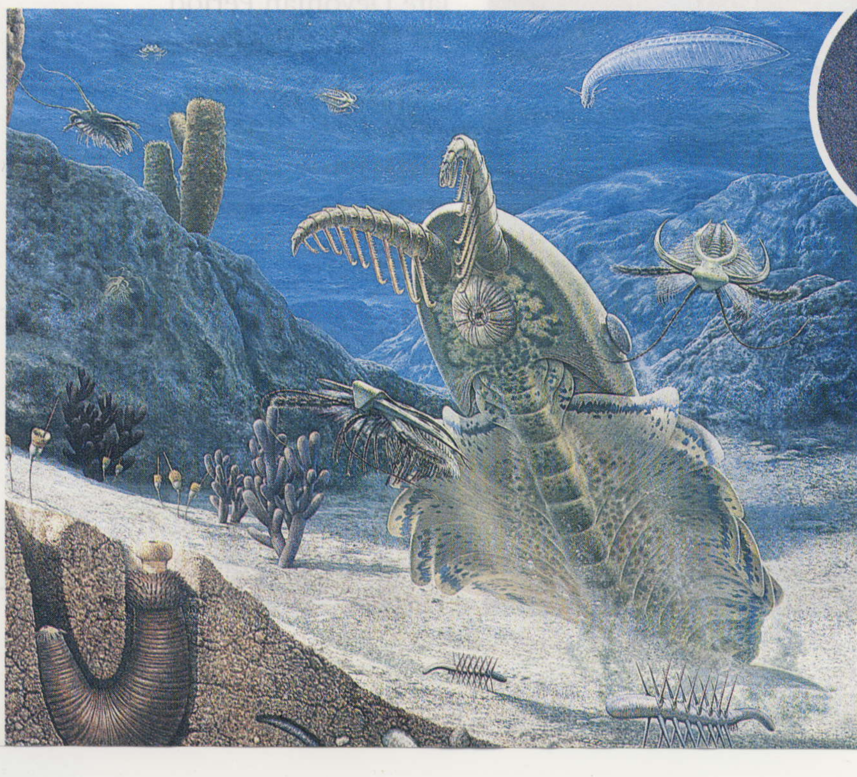
About 2.5 billion years ago, organisms first began using energy from the sun to make their own food. This process is called photosynthesis. One waste product of photosynthesis is oxygen. As oxygen was released into the air, the amount of oxygen in the atmosphere slowly increased. Over time, organisms evolved that could use oxygen to produce energy from food. These organisms included animals that are like today's sponges and worms. Because they all had soft bodies, these animals left few fossils. However, the evolution of these organisms set the stage for great changes during the Paleozoic Era. You can trace the development of life in *Exploring Geologic History* on pages 132–135.

The Paleozoic Era

Your time machine slows. You watch in fascination as you observe the "explosion" of life that began the Paleozoic Era.

Life Explodes During the Cambrian Period life took a big leap forward. **At the beginning of the Paleozoic Era, a great number of different kinds of organisms evolved.** Paleontologists call this event the Cambrian Explosion because so many new life forms appeared within a relatively short time. For the first time, many organisms had hard parts, including shells and outer skeletons.

At this time, all animals lived in the sea. Invertebrates such as jellyfish, worms, and sponges drifted through the water, crawled along the sandy bottom, or attached themselves to the ocean floors. Recall that invertebrates are animals that lack backbones.



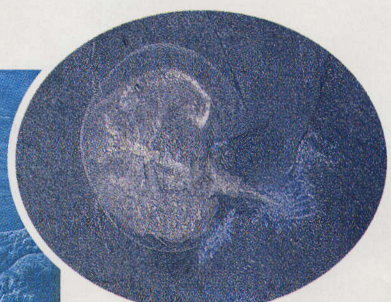


Figure 22 During the early Cambrian period, Earth's oceans were home to many strange organisms unlike any animals that are alive today. The fossil above is an organism of the middle Cambrian called *Burgessia bella* from the Burgess shale.

Brachiopods and trilobites were common in the Cambrian seas. Brachiopods were small ocean animals with two shells. They resembled modern clams. Clams, however, are only distantly related to them.

During the Ordovician (awr duh VISH ee un) and Silurian (sih LOOR ee un) periods, the ancestors of the modern octopus and squid appeared. Some of these organisms, called cephalopods, grew to a length of almost 10 meters. **During this time, jawless fishes evolved. Jawless fishes were the first vertebrates.** A **vertebrate** is an animal with a backbone. These fishes had suckerlike mouths, and they soon became common in the seas.

Life Reaches Land Until the Silurian Period, only one-celled organisms lived on the land. But during the Silurian Period, plants began to grow on land. These first, simple plants grew low to the ground in damp areas. But by the Devonian Period (dih VOH nee un), plants that could grow in drier areas had evolved. Among these plants were the earliest ferns. The first insects also appeared during the Silurian Period.

Figure 23 One of the first amphibians, *Icthyostega* (center), was about 1 meter long. It lived during the late Devonian Period. Another, more fishlike amphibian, *Acanthostega* (bottom), lived at about the same time.

Both invertebrates and vertebrates lived in the Devonian seas. Even though the invertebrates were more numerous, the Devonian Period is often called the Age of Fishes. This is because every main group of fishes was present in the oceans at this time. Most fishes now had jaws, bony skeletons, and scales on their bodies. Sharks appeared in the late Devonian Period.

During the Devonian Period, animals began to invade the land. The first vertebrates to crawl onto land were lungfish with strong, muscular fins. The first amphibians evolved from these fishes. An **amphibian** (am FIB ee un) is an animal that lives part of its life on land and part of its life in water. *Ichthyostega,* shown in Figure 23, was one of the first amphibians.

Throughout the rest of the Paleozoic Era, life expanded over Earth's continents. Other groups of

Figure 24 Forests flourished during the Carboniferous Period. Insects such as dragonflies were common. **Predicting** *What types of fossils would you expect to find from the Carboniferous Period?*

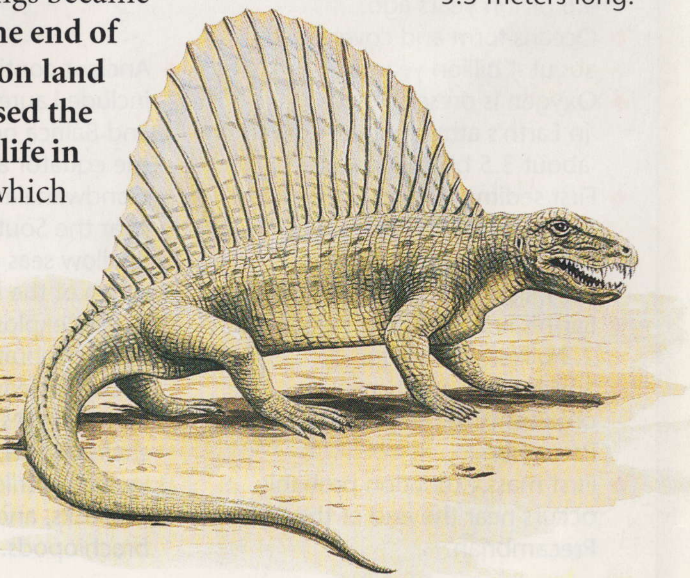
vertebrates evolved from the amphibians. For example, small reptiles developed during the Carboniferous Period. **Reptiles** have scaly skin and lay eggs with tough, leathery shells. Some types of reptiles became very large during the later Paleozoic.

During the Carboniferous Period, winged insects evolved into many forms, including huge dragonflies and cockroaches. Giant ferns and cone-bearing plants and trees formed vast swampy forests called "coal forests." How did the coal forest get its name? The remains of the coal forest plants formed thick deposits of sediment that changed into coal over millions of years.

Mass Extinction Ends the Paleozoic At the end of the Paleozoic Era, many kinds of organisms died out. This was a **mass extinction,** in which many types of living things became extinct at the same time. **The mass extinction at the end of the Paleozoic affected both plants and animals, on land and in the seas. Scientists do not know what caused the mass extinction, but as much as 95 percent of the life in the oceans disappeared.** For example, trilobites, which had existed since early in the Paleozoic, suddenly became extinct. Many amphibians also became extinct. But not all organisms disappeared. The mass extinction did not affect fishes. Many reptiles also survived.

☑ *Checkpoint* ***What were three major events in the development of life during the Paleozoic Era?***

Figure 25 *Dimetrodon,* which lived during the Permian Period, was one of the first reptiles. This meat-eater was about 3.5 meters long.

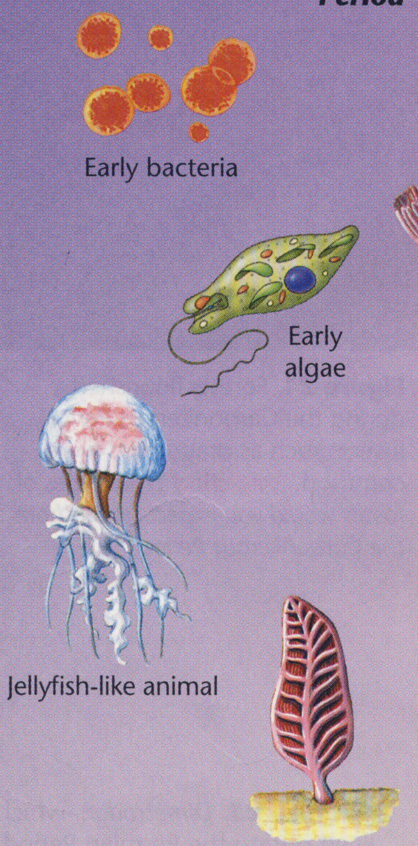


EXPLORING *Geologic History*

Using the fossil record, paleontologists have created a picture of the different types of common organisms in each geologic period.

PRECAMBRIAN TIME
4.6 billion–544 million years ago

Period

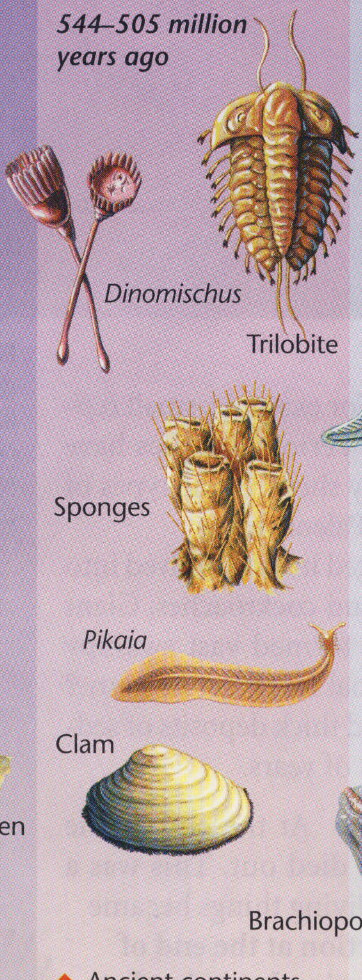


- Earth forms about 4.6 billion years ago.
- Oceans form and cover Earth about 4 billion years ago.
- Oxygen is present in Earth's atmosphere about 3.5 billion years ago.
- First sedimentary rocks form about 3.5 billion years ago.
- Bacteria appear about 3.5 billion years ago.
- Earth's first ice age occurs about 2.3 billion years ago.
- Soft-bodied, multicellular organisms develop late in the Precambrian.
- First mass extinction probably occurs near the end of the Precambrian.

PALEOZOIC ERA
544–245 million years ago

CAMBRIAN

544–505 million years ago



- Ancient continents include Laurentia and Baltica near the equator and Gondwanaland near the South Pole.
- Shallow seas cover much of the land.
- Great "explosion" of invertebrate life occurs in seas.
- Invertebrates with shells appear, including trilobites, mollusks, and brachiopods.

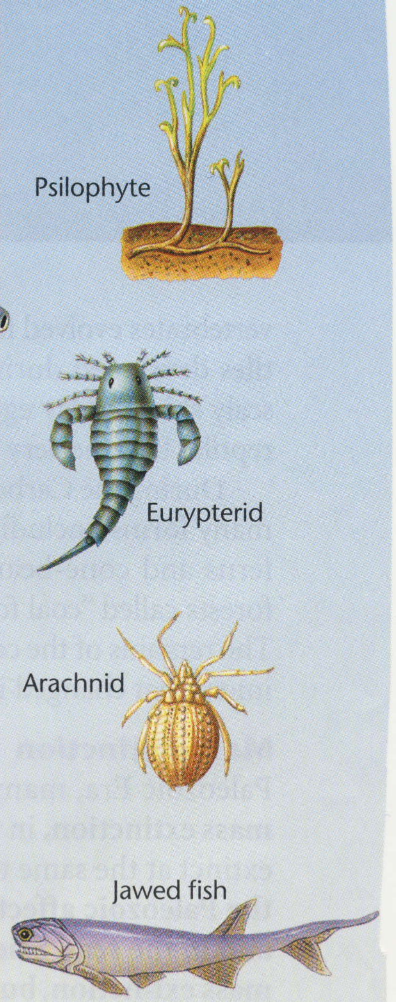
ORDOVICIAN

505–438 million years ago

- Warm, shallow seas cover much of Earth.
- Ice cap covers what is now North Africa.
- Invertebrates dominate the oceans.
- Early vertebrates—jawless fish—become common.

SILURIAN

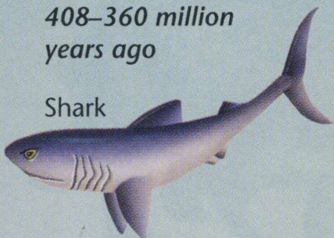
438–408 million years ago



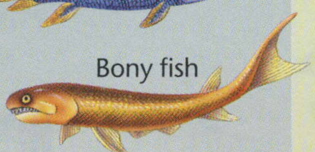
- Early continents Laurentia and Baltica collide.
- Coral reefs develop.
- Fish with jaws develop.
- Land plants appear.
- Insects and spiders appear.

DEVONIAN

408–360 million years ago


Shark


Lungfish


Bony fish


Devonian forest

- Seas rise and fall over what is now North America.
- Age of Fishes begins as sharks and fish with scales and bony skeletons become common.
- Trilobites, corals, brachiopods, and other invertebrates flourish in the oceans.
- Lungfish develop.
- First amphibians reach land.
- Forests grow in swampy areas.

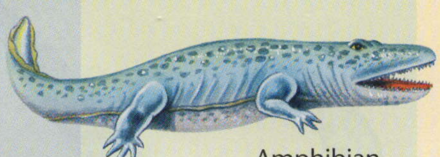
CARBONIFEROUS

360–286 million years ago

MISSISSIPPIAN

(360–320 million years ago)

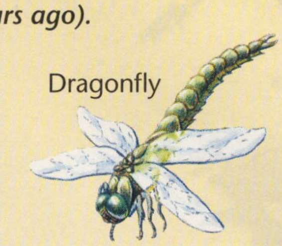

Cockroach


Amphibian

- Appalachian Mountains begin to form.
- North America and Northern Europe lie in warm, tropical region.
- Cold conditions are present in what is now South America and Africa.

PENNSYLVANIAN

(320–286 million years ago).


Dragonfly

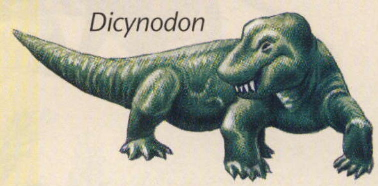

Coal forest

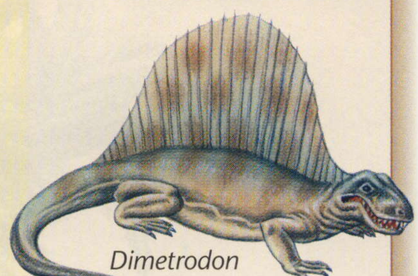
- Great swamp forests of huge, woody trees cover eastern North America and parts of Europe.
- First true reptiles appear.
- Insects become abundant.
- Winged insects appear.

PERMIAN

286–245 million years ago


Conifer


Dicynodon

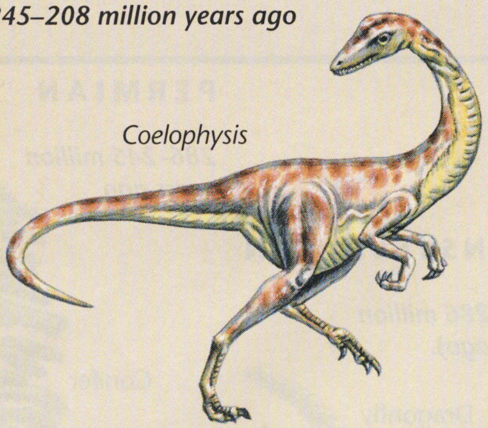

Dimetrodon

- The supercontinent Pangaea forms as all continents join together.
- Deserts become larger in tropical regions.
- Land that later becomes present-day southern continents is in an ice age.
- Reptiles become dominant on land.
- Warm-blooded reptiles appear.
- Mass extinction causes many marine invertebrates, including trilobites, to disappear.

MESOZOIC ERA
245–65 million years ago

Period **TRIASSIC**

245–208 million years ago



Coelophysis

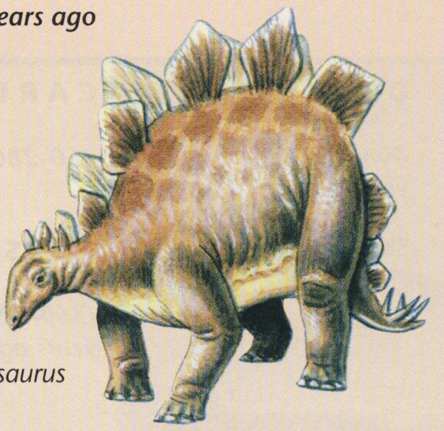
Morganucodon

Cycad

- Pangaea holds together for much of the Triassic.
- Hot, dry conditions dominate center of Pangaea.
- Age of Reptiles begins.
- First dinosaurs appear.
- First mammals, which evolve from warm-blooded reptiles, appear.
- First turtles and crocodiles appear.
- Conifers, palmlike trees, and ginkgo trees dominate forests.

JURASSIC

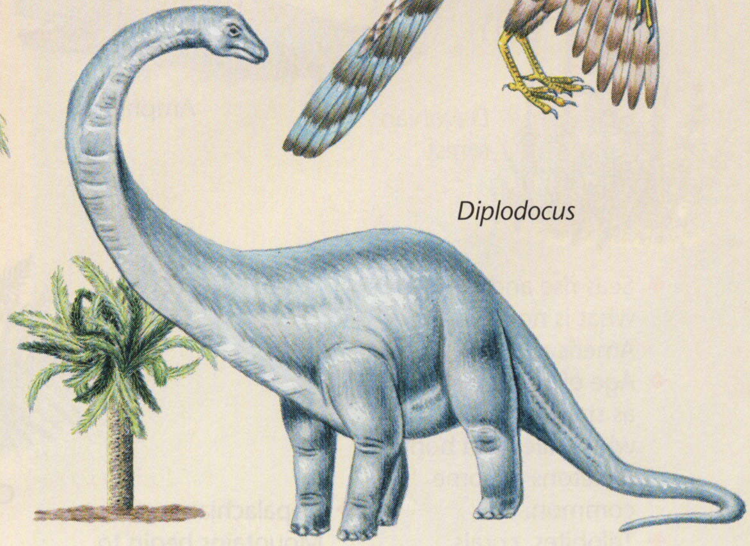
208–144 million years ago



Stegosaurus

Megazostrodon

Archaeopteryx



Diplodocus

- Pangaea continues to break apart as North America separates from Africa and South America.
- Sea levels rise in many parts of the world.
- Largest dinosaurs thrive, including *Stegosaurus*, *Diplodocus*, and *Apatosaurus*.
- First birds appear.
- First flying reptiles, pterosaurs, appear.

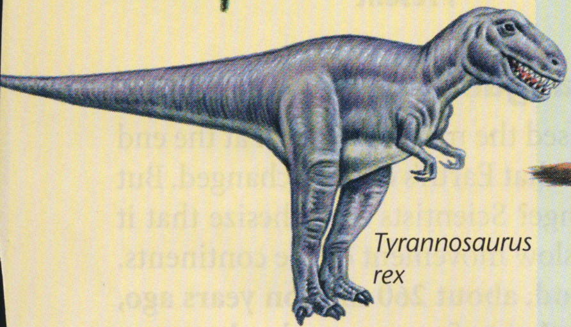
CENOZOIC ERA

65 million years ago to the present

CRETACEOUS

144–65 million years ago

Magnolia



Tyrannosaurus rex

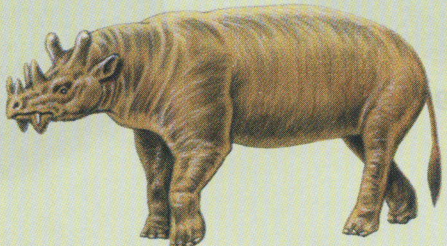
Creodonts

Triceratops

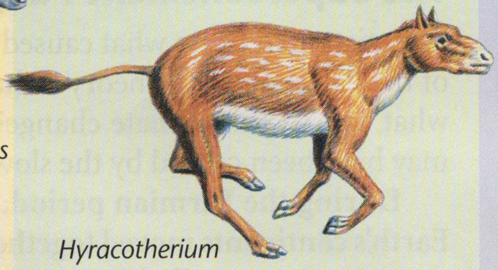
- Continents move toward their present-day positions, as South America splits from Africa.
- Widespread volcanic activity occurs.
- First flowering plants appear.
- Dinosaurs dominate, including *Tyrannosaurus rex.*
- First snakes appear.
- Mass extinction at end causes disappearance of many land and marine life forms, including dinosaurs.

TERTIARY

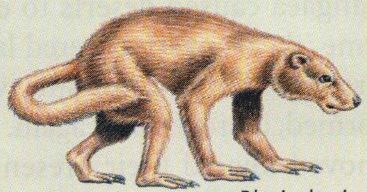
65–1.6 million years ago



Uintatherium



Hyracotherium



Plesiadapis

- The Rocky Mountains, Alps, Andes, and Himalayas form.
- Continents move into present-day positions.
- Continental glacier covers Antarctica about 25 million years ago.
- Flowering plants thrive.
- First grasses appear.
- Age of Mammals begins.
- Modern groups such as horses, elephants, bears, rodents, and primates appear.
- Mammals return to the seas in the forms of whales and dolphins.
- Ancestors of humans evolve.
- Continental glaciers repeatedly cover part of North America beginning about 2.5 million years ago.

QUATERNARY

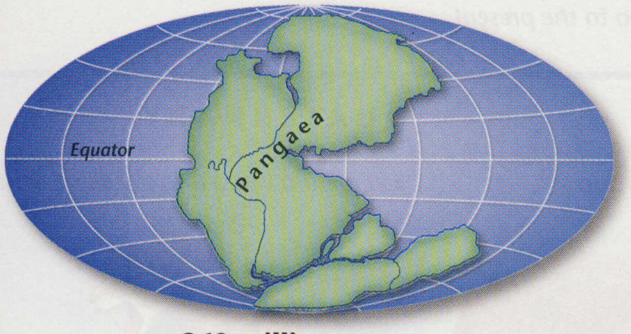
1.6 million years ago to the present

Saber-toothed cat

Megatherium

Homo sapiens

- Thick glaciers advance and retreat over much of North America and Europe, parts of South America and Asia, and all of Antarctica.
- The Great Lakes form.
- Giant mammals flourish in parts of North America and Eurasia not covered by ice. But they become extinct when the Ice Age ends about 10,000 years ago.
- Mammals, flowering plants, and insects dominate land.
- Modern humans evolve in Africa about 100,000 years ago.



260 million years ago

Figure 26 The supercontinent Pangaea began to break apart about 225 million years ago. ***Observing*** *How have North America and South America moved in relation to Africa and Europe?*

Present

TRY THIS

Life and Times

ACTIVITY

1. Place these events in their relative order: continental glaciers retreat; first fish appear; oldest fossils form; human ancestors appear; "explosion" of invertebrates occurs; dinosaurs become extinct; Pangaea forms.
2. Draw a time line and graph these dates:
   - 3.5 billion years ago
   - 544 million years ago
   - 400 million years ago
   - 260 million years ago
   - 65 million years ago
   - 3.5 million years ago
   - 10,000 years ago

   Choose a scale so the oldest date fits on the paper.

Interpreting Data Match each event with the correct date on your time line. How does the time since the dinosaurs became extinct compare with the time since the oldest fossil formed?

The Supercontinent Pangaea

Scientists aren't sure what caused the mass extinction at the end of the Paleozoic. One theory is that Earth's climate changed. But what caused this climate change? Scientists hypothesize that it may have been caused by the slow movement of the continents.

During the Permian period, about 260 million years ago, Earth's continents moved together to form a great landmass, or supercontinent, called Pangaea (pan JEE uh). The formation of Pangaea caused deserts to expand in the tropics. At the same time, sheets of ice covered land closer to the South Pole. Many organisms could not survive the new climate. After Pangaea formed, it broke apart again. Figure 26 shows how the continents moved toward their present-day positions. They moved very slowly—only a few centimeters per year.

The movement of continents is sometimes called continental drift. But the continents don't really "drift." The continents move slowly over Earth's surface because of forces inside Earth.

☑ ***Checkpoint*** *What was Pangaea?*

The Mesozoic Era

Millions of years flash by. Your time machine cruises above Pangaea and the landmasses that formed when it broke apart. Watch out—there's a dinosaur! You're observing an era that you've read about in books and seen in movies.

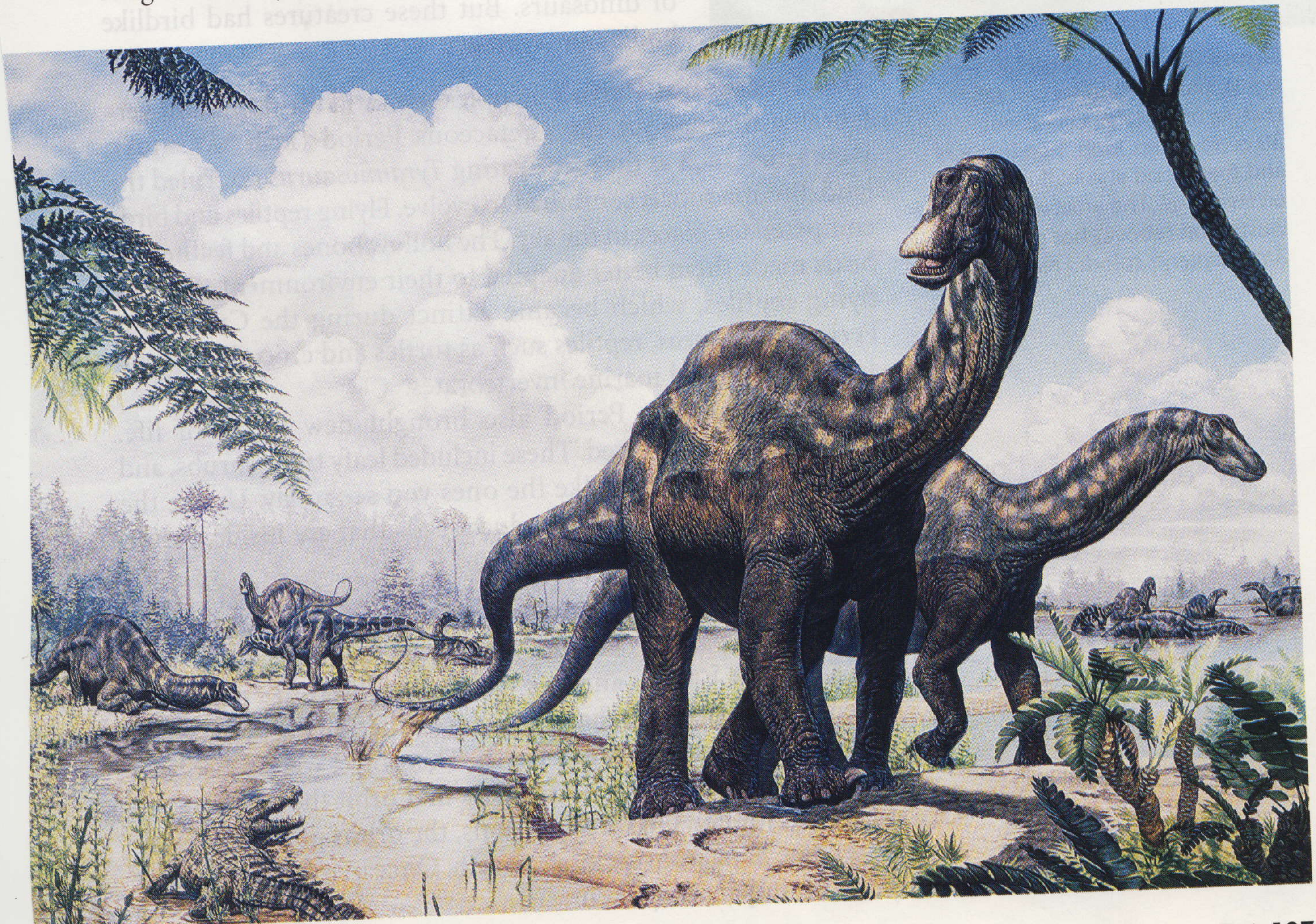
The Triassic Period Some living things survived the Permian mass extinction. These organisms became the main forms of life early in the Triassic Period (try AS ik). Plants and animals that survived included fish, insects, reptiles, and cone-bearing plants called conifers. **Reptiles were so successful during the Mesozoic Era that this time is often called the Age of Reptiles.**

About 225 million years ago, the first dinosaurs appeared. One of the earliest dinosaurs, *Coelophysis*, was a meat eater that had light, hollow bones and ran swiftly on its hind legs. It was about 2.5 meters long.

Mammals also first appeared during the Triassic Period. A **mammal** is a warm-blooded vertebrate that feeds its young milk. Mammals probably evolved from warm-blooded reptiles. The mammals of the Triassic Period were very small, about the size of a mouse or shrew. From these first small mammals, all mammals that live today evolved.

The Jurassic Period During the Jurassic Period (joo RAS ik), dinosaurs became the dominant animal on land. Scientists have identified several hundred different kinds of dinosaurs. Some were plant eaters, while others were meat eaters. Dinosaurs "ruled" Earth for about 150 million years, but different types lived at different times. At 20 meters long, *Dicraeosaurus* was one of the larger dinosaurs of the Jurassic Period. The smallest known dinosaur, *Compsognathus*, was only about 50 centimeters long when fully grown.

Figure 27 *Dicraeosaurus* was a plant-eating dinosaur that lived during the late Jurassic Period.



One of the first birds, called *Archaeopteryx*, appeared during the Jurassic Period. The name *Archaeopteryx* means "ancient wing thing." Many paleontologists now think that birds evolved from dinosaurs. During the 1990s, scientists discovered fossils in China with the skulls and teeth of dinosaurs. But these creatures had birdlike bodies and feathers.

Figure 28 From a fossil (above right), paleontologists can tell that *Archaeopteryx* was about 30 centimeters long, had feathers and teeth, and also had claws on its wings. The artist of the illustration (above) has given *Archaeopteryx* colorful feathers.

The Cretaceous Period Reptiles were still the dominant vertebrates throughout the Cretaceous Period (krih TAY shus). Dinosaurs, such as the meat-eating *Tyrannosaurus rex*, ruled the land. But mammals continued to evolve. Flying reptiles and birds competed for places in the sky. The hollow bones and feathers of birds made them better adapted to their environment than the flying reptiles, which became extinct during the Cretaceous Period. In the seas, reptiles such as turtles and crocodiles swam among fishes and marine invertebrates.

The Cretaceous Period also brought new forms of life. Flowering plants evolved. These included leafy trees, shrubs, and small flowering plants like the ones you see today. Unlike the conifers, flowering plants produce seeds that are inside a fruit. The fruit helps the seeds survive.

Another Mass Extinction **At the close of the Cretaceous**

INTEGRATING SPACE SCIENCE

Period, about 65 million years ago, another mass extinction occurred. Scientists hypothesize that this mass extinction occurred when an object from space struck Earth. This object was probably an asteroid. Asteroids are rocky masses that orbit the sun between Mars and Jupiter. On rare occasions, the orbits of certain asteroids come dangerously close to Earth. Once in many millions of years, an impact may occur.

When the asteroid hit Earth, the impact threw huge amounts of dust and water vapor into the atmosphere. Many organisms on land and in the oceans died immediately. Dust and heavy clouds blocked sunlight around the world for years. Without sunlight, plants died, and plant-eating animals starved. This mass extinction wiped out over half of all plant and animal groups. No dinosaurs survived. Many other kinds of reptiles also became extinct.

Not all scientists agree that an asteroid impact caused the mass extinction. Some scientists think that climate changes caused by increased volcanic activity were responsible.

☑ **Checkpoint** *What major groups of organisms developed during the Mesozoic Era?*

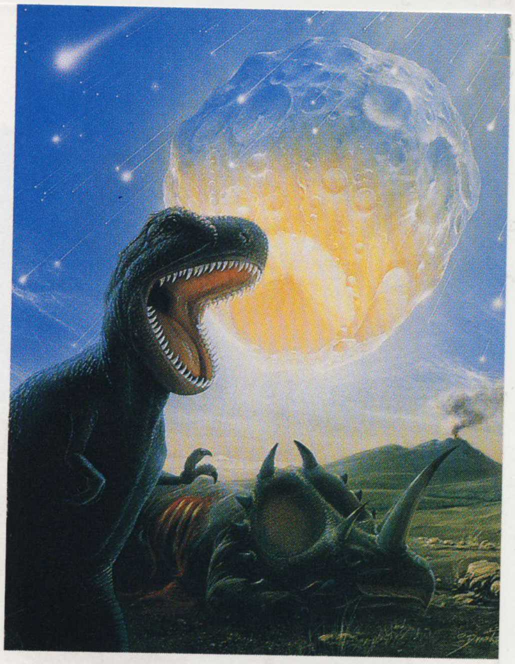


Figure 29 Scientists hypothesize that during the Cretaceous an asteroid hit Earth near the present-day Yucatán Peninsula, in southeastern Mexico.
Relating Cause and Effect *How did the asteroid impact affect life on Earth?*

The Cenozoic Era

Your voyage through time continues through the Cenozoic Era toward the present. Paleontologists often call the Cenozoic Era the Age of Mammals. During the Mesozoic Era, mammals had a hard time competing with dinosaurs for food and places to live. **The extinction of dinosaurs created an opportunity for mammals. During the Cenozoic Era, mammals evolved adaptations that allowed them to live in many different environments—on land, in water, and even in the air.**

The Tertiary Period During the Tertiary Period, Earth's climates were generally warm and mild. In the oceans, many types of mollusks appeared. Marine mammals such as whales and dolphins evolved. On land, flowering plants, insects, and mammals flourished. When grasses evolved, they provided a food source for grazing mammals. These were the ancestors of today's cattle, deer, sheep, and other grass-eating mammals. Some mammals became very large, as did some birds.

Figure 30 This extinct mammal was related to present-day horses. The fossil formed during the Tertiary Period between 36 and 57 million years ago.

The Quaternary Period

The Quaternary Period The mammals that had evolved during the Tertiary Period eventually faced a changing environment. **Earth's climate cooled, causing a series of ice ages during the Quaternary Period.** Repeatedly, thick continental glaciers advanced and retreated over parts of Europe and North America.

So much of Earth's water was frozen in continental glaciers that the level of the oceans fell by more than 100 meters. Then, about 20,000 years ago, Earth's climate began to warm. Over thousands of years, the continental glaciers melted. This caused sea level to rise again.

In the oceans, algae, coral, mollusks, fish, and mammals thrived. Insects and birds shared the skies. On land, flowering plants and mammals such as bats, cats, dogs, cattle, and humans—just to name a few—became common.

The fossil record suggests that human ancestors appeared about 3.5 million years ago. Modern humans, or *Homo sapiens,* may have evolved as early as 100,000 years ago. By about 12,000 to 15,000 years ago, humans had migrated around the world to every continent except Antarctica.

Your time machine has now arrived back in the present. You and all organisms on Earth are living in the Quaternary Period of the Cenozoic Era. Is this the end of evolution and the changing of Earth's surface? No, these processes will continue as long as Earth exists. But you'll have to take your time machine into the future to see just what happens!

Figure 31 Scientists nicknamed this fossil skeleton Lucy. An early ancestor of modern humans, Lucy lived about 3.3 million years ago.

Section 5 Review

1. What is the "Cambrian explosion"? Why is it important to the history of life on Earth?
2. What was Pangaea? When did it form?
3. How did the extinction of dinosaurs affect the evolution of mammals?
4. What do scientists think was the source of the oxygen in Earth's atmosphere?
5. **Thinking Critically Making Generalizations** How do you think mass extinctions have affected evolution?

Check Your Progress

CHAPTER PROJECT 4

Create illustrations of your portion of the time line. How will you show animals, plants, and environments of that time? When you have finished your illustrations, place them on the time line. Then make a rough draft of your travel brochure. Have a classmate or teacher edit your rough draft before you write the final draft. Do you have all the information about your geologic period that will make a person want to travel there?

Section 1 Fossils

Key Ideas

- Most fossils form when living things die and are quickly buried by sediments. Those sediments eventually harden and preserve parts of the organisms.
- The major kinds of fossils include petrified remains, molds, casts, carbon films, trace fossils, and preserved remains.
- The fossil record shows that many different organisms have lived on Earth at different times and that groups of organisms have changed over time.

Key Terms

fossil
paleontologist
sedimentary rock
petrified fossil
mold
cast
carbon film
trace fossil
scientific theory
evolution
extinct

Section 2 Finding the Relative Age of Rocks

Key Ideas

- The law of superposition can be used to determine the relative ages of rock layers.
- Scientists also study faults, intrusions, and extrusions to find the relative ages of rock layers.
- Index fossils are useful in dating rock layers because they are easily recognized, occur in many different areas, and represent organisms that lived during only one short period of Earth's history.

Key Terms

relative age
absolute age
law of superposition
unconformity
fault
intrusion
extrusion
index fossil

Section 3 Radioactive Dating

INTEGRATING CHEMISTRY

Key Ideas

- During radioactive decay, the atoms of one element decay into atoms of another element.
- Scientists use radioactive dating to determine the absolute ages of rocks.

Key Terms

atom
element
radioactive decay
half-life

Section 4 The Geologic Time Scale

Key Ideas

- Scientists use the geologic time scale because the time span of Earth's history is so great.
- The basic divisions of the geologic time scale are eras, periods, and epochs.

Key Terms

geologic time scale
era
invertebrate
period
epoch

Section 5 Earth's History

Key Ideas

- A great number of different kinds of living things evolved during the "Cambrian explosion" at the beginning of the Paleozoic Era.
- During the Permian Period, Earth's continents joined together and formed the supercontinent called Pangaea.
- The extinction of the dinosaurs at the end of the Mesozoic Era created an opening for mammals, which evolved to live in most environments on land, in water, and in the air.

Key Terms

vertebrate
amphibian
reptile
mass extinction
mammal

ACTIVITY

USING THE INTERNET

www.science-explorer.phschool.com

Reviewing Content

For more review of key concepts, see the Interactive Student Tutorial CD-ROM.

Multiple Choice

Choose the answer that best completes each sentence.

1. A hollow area in sediment in the shape of all or part of an organism is called a
   a. mold. **b.** cast.
   c. trace fossil. **d.** carbon film.
2. A gap in the geologic record formed when sedimentary rocks cover an erosion surface is called a(n)
   a. intrusion.
   b. unconformity.
   c. fault.
   d. extrusion.
3. When a radioactive element decays, it releases
   a. atoms.
   b. potassium-40.
   c. particles and energy.
   d. carbon-14.
4. Eras of geologic time are subdivided into
   a. epochs. **b.** centuries.
   c. decades. **d.** periods.
5. What is an animal that doesn't have a backbone called?
   a. vertebrate **b.** mammal
   c. invertebrate **d.** amphibian

True or False

If the statement is true, write true. If it is false, change the underlined word or words to make the statement true.

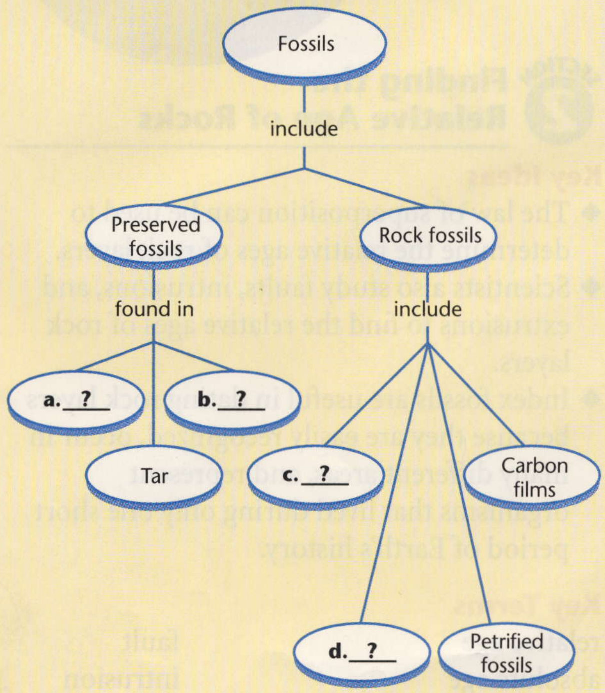
6. A dinosaur footprint in rock is an example of a trace fossil.
7. A carbon film is a fossil in which minerals have replaced all or part of an organism.
8. The relative age of something is the exact number of years since an event has occurred.
9. A period is the time required for half of the atoms of a radioactive element to decay.
10. The Paleozoic Era is often called the Age of Reptiles.

Checking Concepts

11. How does a petrified fossil form?
12. Which organism has a better chance of leaving a fossil: a jellyfish or a bony fish? Explain.
13. Describe a process that could cause an unconformity.
14. What evidence would a scientist use to determine the absolute age of a fossil found in a sedimentary rock?
15. What era is often called the Age of Mammals? Why is this appropriate?
16. **Writing to Learn** Imagine that your time machine comes to a halt just as a big event occurs at the end of the Mesozoic Era. Describe what you see, and then describe how this event affects the life you see on Earth.

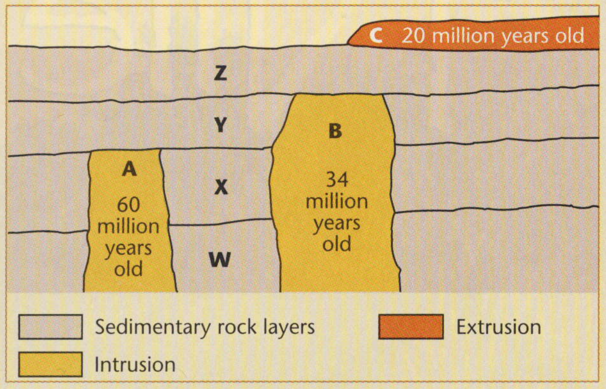
Thinking Visually

17. **Concept Map** Copy the concept map about fossils onto a piece of paper. Then complete it and add a title. (For more on concept maps, see the Skills Handbook.)



Applying Skills

Use the diagram of rock layers below to answer Questions 18–21.



18. **Inferring** Which is the oldest layer of sedimentary rock? Which is the youngest? How do you know?
19. **Measuring** What method did a scientist use to determine the age of the intrusion and extrusion?
20. **Interpreting Data** What is the relative age of layer Y (*Hint:* With what absolute ages can you compare it?)
21. **Interpreting Data** What is the relative age of layer Z?

Thinking Critically

22. **Applying Concepts** Suppose that paleontologists found a certain kind of trilobite in a rock layer at the top of a hill in South America. Then they found the same kind of trilobite in a rock layer at the bottom of a cliff in Africa. What could the paleontologists conclude about the two rock layers?
23. **Making Judgments** If you see a movie in which early humans fight giant dinosaurs, how would you judge the scientific accuracy of that movie? Give reasons for your judgment.
24. **Relating Cause and Effect** When Pangaea formed, the climate changed and the land on Earth became drier. Why do you think that this climate change favored reptiles over amphibians?
25. **Problem Solving** Carbon-14 has a half-life of 5,730 years, while uranium-235 has a half-life of 713 million years. Which would be better to use in dating a fossil from Precambrian time? Explain.

Performance Assessment

CHAPTER PROJECT 4

Wrap Up

Present Your Project You have completed your illustrations for the time line and travel brochure. Now you are ready to present the story of the geologic time period you researched. Be sure to include the wonderful and awesome things people will see when they travel to this time period. Don't forget to warn them of any dangers that await them.

Reflect and Record In your journal, reflect on what you have learned about Earth's history. What were the most interesting things you found out? If you could travel back in time, how far back would you go?

Getting Involved

In Your Community Brainstorm with your class about places in your community where you might find fossils. Fossils may be found in sedimentary rocks exposed at the surface or in the sandstone and limestone used in buildings. Accompanied by an adult, visit one of these locations. Sketch or photograph any fossil you find. What type of organism does the fossil represent? How did the fossil form? Make a display showing the fossil that you found and your conclusions about it.