Section 2

The Relative Age of Rocks

Reading Preview

Key Concepts

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

Key Terms

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

Target Reading Skill

Asking Questions Before you read, preview the red headings. In a graphic organizer like the one below, ask a *what* or *how* question for each heading. As you read, write answers to your questions.

Relative Age

Question	Answer
What does the position of rock layers reveal?	The position of rock layers shows . . .

Lab zone Discover Activity

Which Layer Is the Oldest?

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?

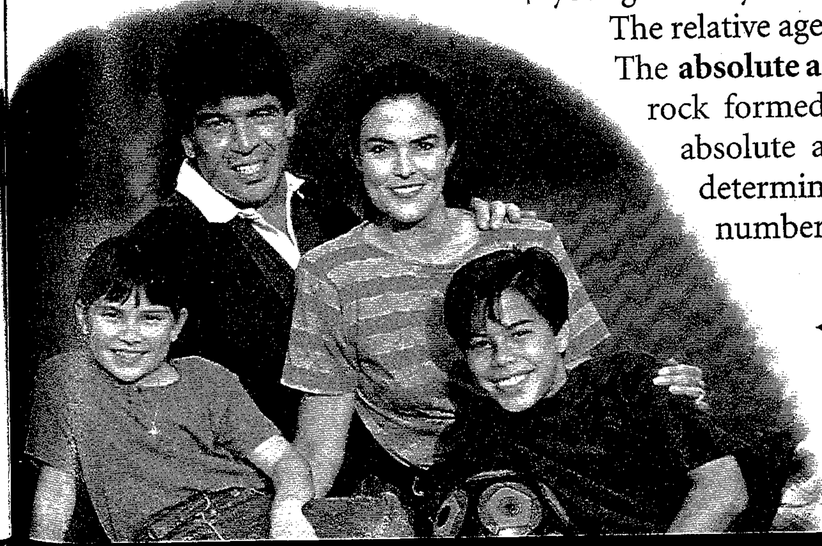
Think It Over

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?

As sedimentary rock forms, the remains of organisms in the sediment may become fossils. Millions of years later, if you split open the rock, you might see the petrified bones of an extinct reptile or insect.

Your first question about a new fossil might be, "What is it?" Your next question would probably be, "How old is it?" Geologists have two ways to express the age of a rock and any fossil it contains. 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.



◀ The age of each family member could be given as relative age or absolute age.

Discovery Channel School

A Trip Through Geologic Time

Video Preview
▶ Video Field Trip
Video Assessment

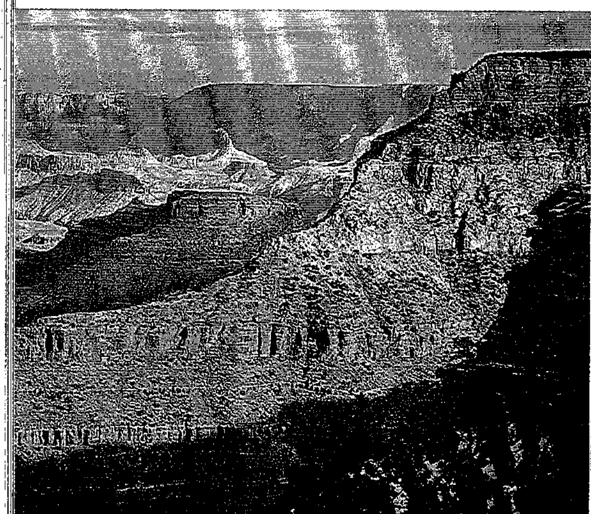
The Position of Rock Layers

Have you ever seen rock layers of different colors on a cliff beside a road? 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 time, the sediment hardens and changes into sedimentary rock. These rock layers provide a record of Earth's geologic history.

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.**

The walls of the Grand Canyon in Arizona illustrate the law of superposition. You can see some of the rock layers found in the Grand Canyon in Figure 5. The deeper down you go in the Grand Canyon, the older the rocks.

Reading Checkpoint **Why do sedimentary rocks have layers?**



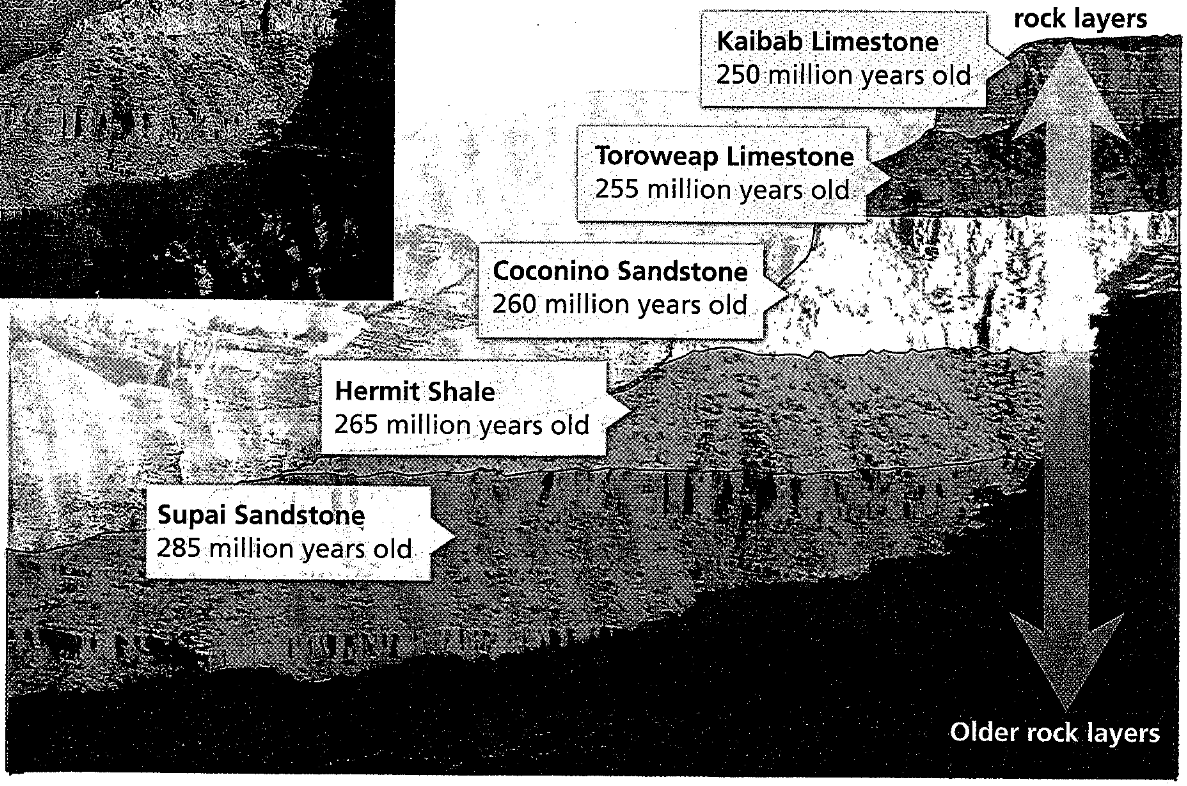
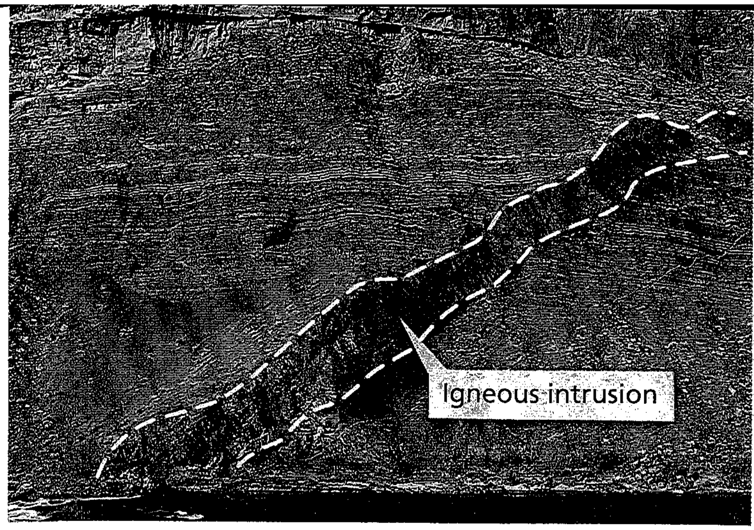


FIGURE 5
The Grand Canyon
More than a dozen rock layers make up the walls of the Grand Canyon. You can see five layers clearly in the photograph. **Applying Concepts** *In which labeled layers would you find the oldest fossils? Explain.*



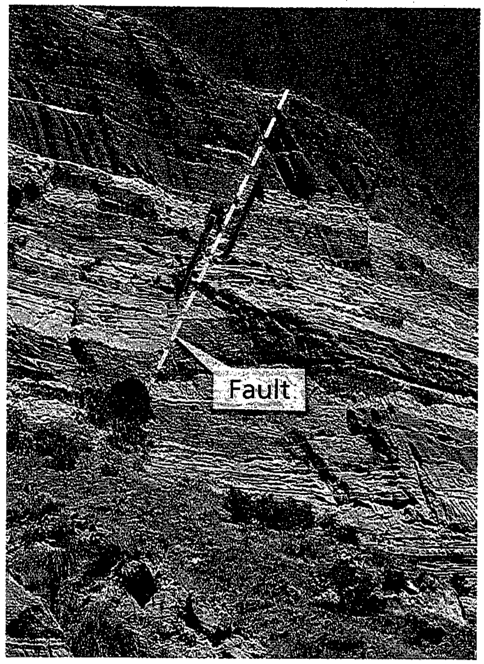


FIGURE 6
Intrusions and Faults
Intrusions and faults give clues to the relative ages of rocks. An intrusion (left) cuts through rock layers. Rock layers are broken and shifted along a fault (right).

Determining Relative Age

There are other clues besides the position of rock layers to the relative ages of rocks. **To determine relative age, geologists also study extrusions and intrusions of igneous rock, faults, and gaps in the geologic record.**

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.** An extrusion is always younger than the rocks below it.

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 6 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 relative age of the youngest layer cut by the fault.

Movements along faults can make it harder for geologists to determine the relative ages of rock layers. You can see in Figure 6 how the rock layers no longer line up because of movement along the fault.

Lab zone Try This Activity

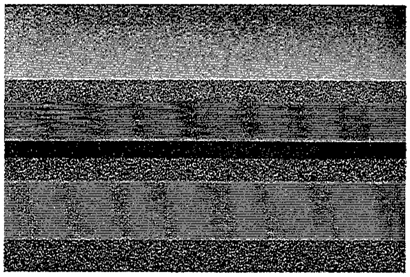
Sampling a Sandwich

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

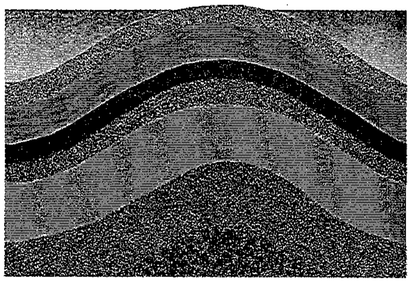
1. Use a round, hollow, uncooked noodle as a coring tool. Push the noodle through the layers of the sandwich.
2. Pull the noodle out of the sandwich. Break the noodle gently to remove your core sample.
3. Draw a picture of what you see in each layer of the core.

Making Models Which layer of your sandwich is the "oldest"? The "youngest"? Why do you think scientists study core samples?

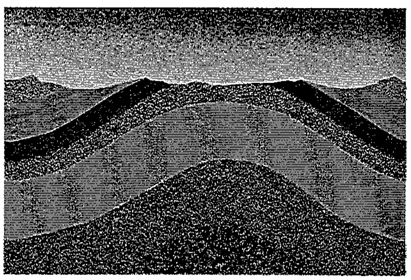
FIGURE 7
Unconformity
An unconformity occurs where erosion wears away layers of sedimentary rock. Other rock layers then form on top.
Sequencing *What two processes must take place before an unconformity can form?*



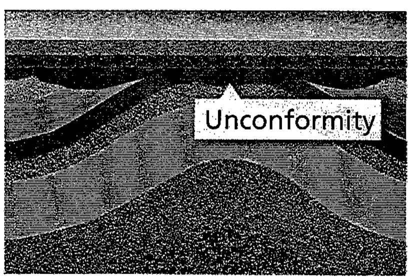
1 Sedimentary rocks form in horizontal layers.



2 Folding tilts the rock layers.



3 The surface is eroded.



4 New sediment is deposited, forming rock layers above the unconformity.

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 7 shows how an unconformity forms.

Reading Checkpoint **What is an unconformity?**

Using Fossils to Date Rocks

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 ammonites. Ammonites (AM uh nyts) were a group of hard-shelled animals. Ammonites evolved in shallow seas more than 500 million years ago and became extinct about 65 million years ago.

Ammonite fossils make good index fossils for two reasons. First, they are widely distributed. Second, many different types of ammonites evolved and then became extinct after a few million years.

Geologists can identify the different types of ammonites through differences in the structure of their shells. Based on these differences, geologists can identify the rock layers in which a particular type of ammonite fossil occurs.

You can use index fossils to match rock layers. Look at Figure 8, 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.

Reading Checkpoint **What characteristics must a fossil have to be useful as an index fossil?**

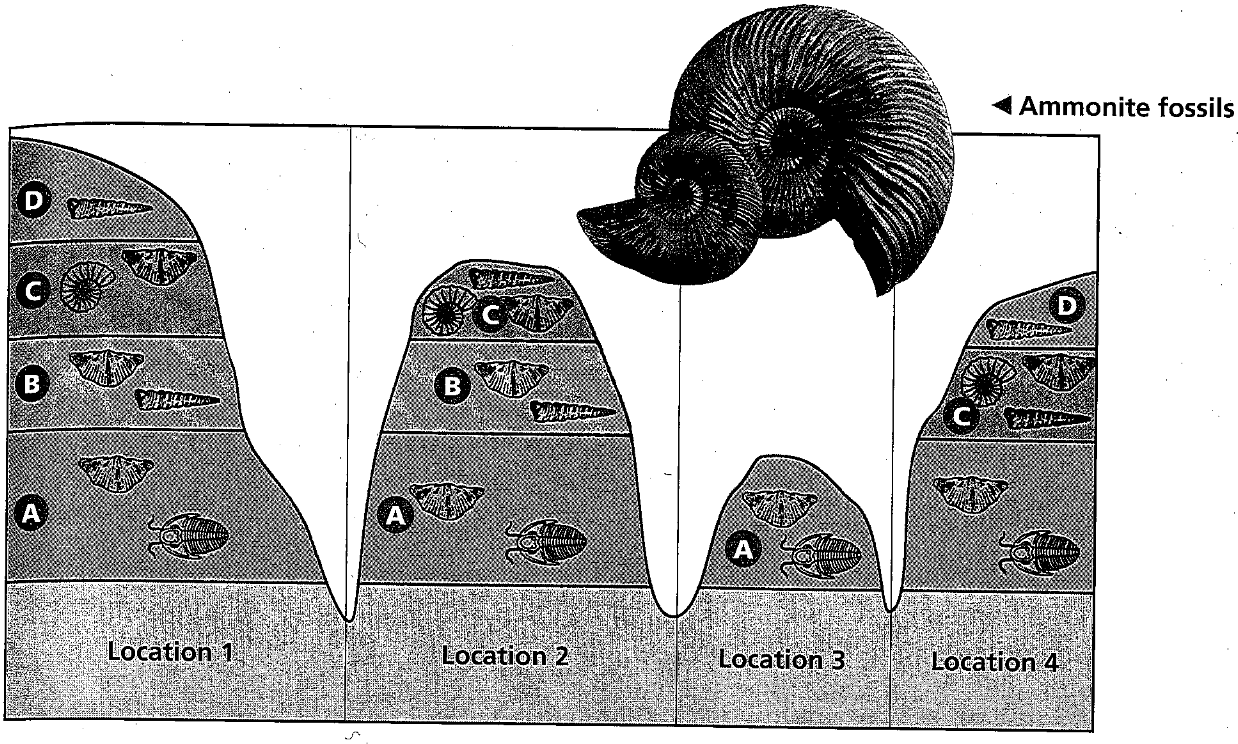


FIGURE 8
Using Index Fossils
Scientists use index fossils to match up rock layers at locations that may be far apart. The ammonites in layer C are index fossils. **Interpreting Diagrams** *Can you find another index fossil in the diagram? (Hint: Look for a fossil that occurs in only one time period, but in several different locations.)*

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active art

For: Index Fossil activities
Visit: PHSchool.com
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Section 2 Assessment

Target Reading Skill Asking Questions Use the answers to the questions you wrote about the headings to help you answer the questions below.

Reviewing Key Concepts

1. a. **Defining** In your own words, define the terms *relative age* and *absolute age*.
   b. **Explaining** What is the law of superposition?
   c. **Inferring** A geologist finds a cliff where the edges of several different rock layers can be seen. Which layer is the oldest? Explain.
2. a. **Reviewing** Besides the law of superposition, what are three types of clues to the relative age of rock layers?
   b. **Comparing and Contrasting** Compare and contrast extrusions and intrusions.
   c. **Sequencing** An intrusion crosses an extrusion. Which layer is the older? Explain.
3. a. **Defining** What is an index fossil?
   b. **Applying Concepts** The fossil record shows that horseshoe crabs 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.

Lab zone At-Home Activity

Drawer to the Past Collect ten items out of a drawer 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? How can you determine the oldest object of all? List the ten items in order of their relative age. Do you know the absolute age of any of the items?

Radioactive Dating

Reading Preview

Key Concepts

- What happens during radioactive decay?
- What can be learned from radioactive dating?

Key Terms

- atom
- element
- radioactive decay
- half-life

Target Reading Skill

Identifying Main Ideas As you read the Determining Absolute Ages section, write the main idea in a graphic organizer like the one below. Then write three supporting details that give examples of the main idea.

Main Idea

Using radioactive dating, scientists can determine . . .

Detail	Detail	Detail

Lab zone Discover Activity

How Long Till 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?

In Australia, scientists have found sedimentary rocks that contain some of the world's oldest fossils. These are fossils of stromatolites (stroh MAT uh lyts). Stromatolites are the remains of reefs built by organisms similar to present-day bacteria. Sediment eventually covered these reefs. As the sediment changed to rock, so did the reefs. Using absolute dating, scientists have determined that some stromatolites are more than 3 billion years old. To understand absolute dating, you need to learn more about the chemistry of rocks.

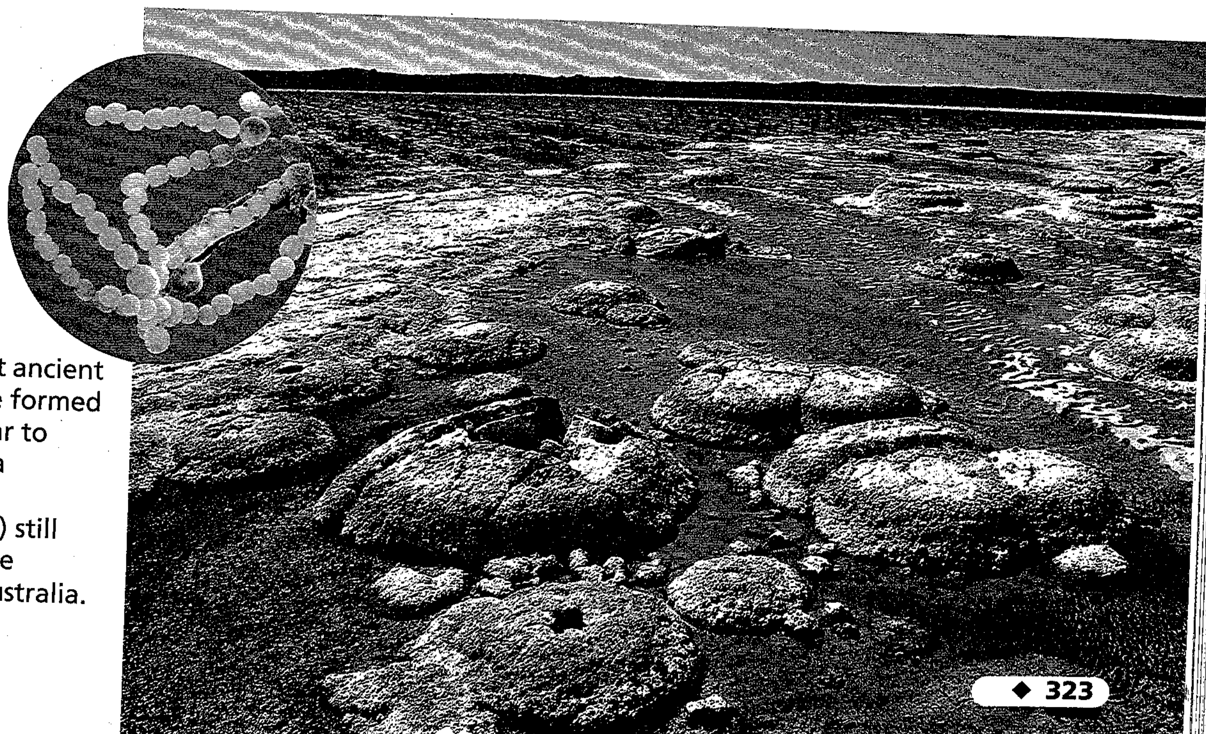

FIGURE 9
Stromatolites
Scientists think that ancient stromatolites were formed by organisms similar to blue-green bacteria (above). Modern stromatolites (right) still form reefs along the western coast of Australia.

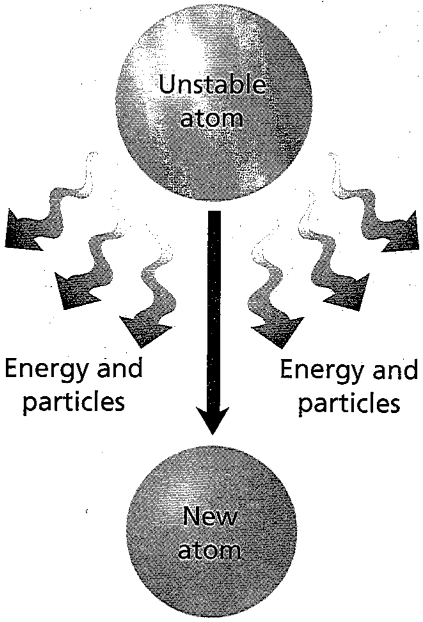

FIGURE 10
Radioactive Decay
In the process of radioactive decay, an atom releases energy and particles as it changes to a new kind of atom.

Radioactive Decay

Rocks are a form of matter. All the matter you see, including rocks, 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 some of the more than 110 currently known elements.

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. You calculate your age based on a specific day—your birthday. What's the "birthday" of a rock? For an igneous rock, that "birthday" is when it first hardens to become rock. 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 11 how a radioactive element decays over time.

Reading Checkpoint **What is the meaning of the term "half-life"?**

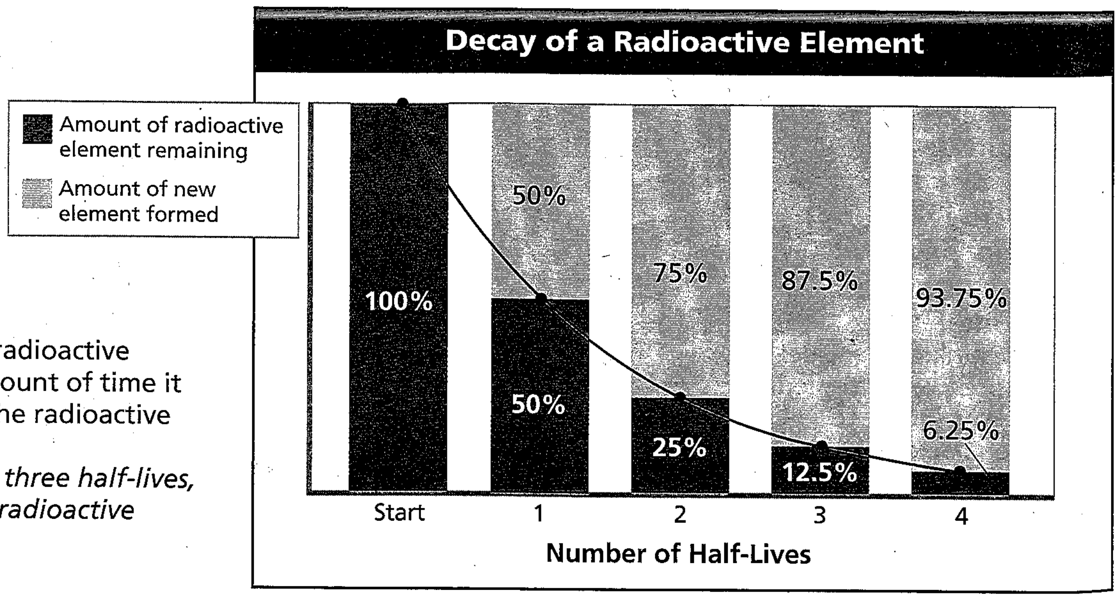

FIGURE 11
The half-life of a radioactive element is the amount of time it takes for half of the radioactive atoms to decay.
Calculating *After three half-lives, how much of the radioactive element remains?*

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	48.8 billion	10 million–4.6 billion
Thorium-232	14 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 12
The half-lives of different radioactive elements vary greatly.

Determining Absolute Ages

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 12 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 very ancient fossils or rocks. The amount of carbon-14 left would be too small to measure accurately.

Math Skills

Percentage What percentage of a radioactive element will be left after 3 half-lives? First, multiply $\frac{1}{2}$ three times to determine what fraction of the element will remain.

$$\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \frac{1}{8}$$

You can convert this fraction to a percentage by setting up a proportion:

$$\frac{1}{8} = \frac{d\%}{100\%}$$

To find the value of d, begin by cross multiplying, as for any proportion:

$1 \times 100 = 8 \times d$

$d = \frac{100}{8}$

$d = 12.5\%$

Practice Problems What percentage of a radioactive element will remain after 5 half-lives?

Dan Miller

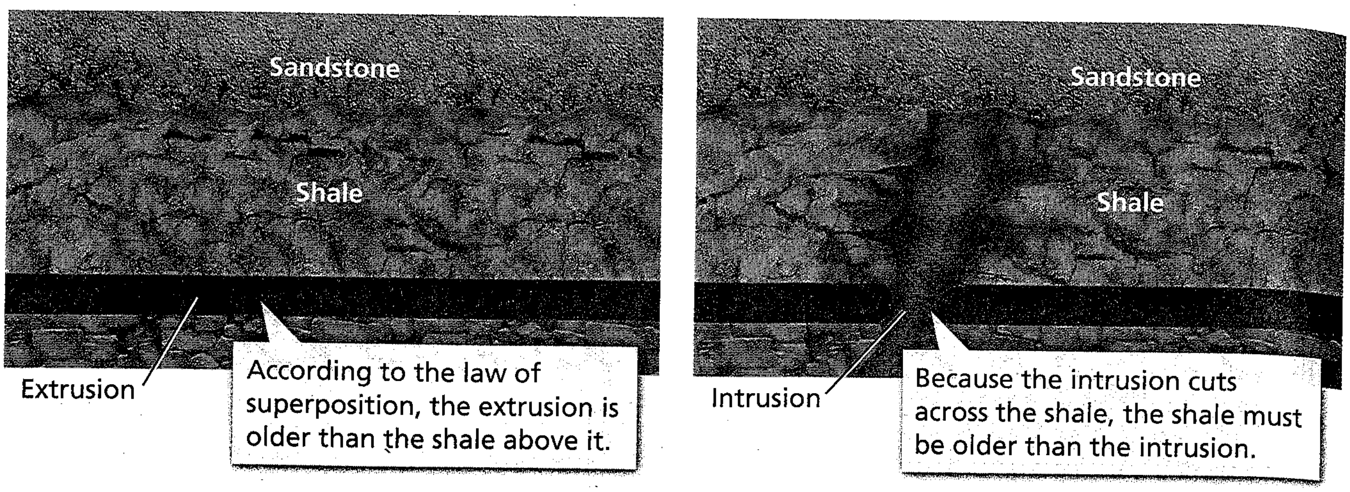

FIGURE 13
Inferring the Age of Rocks
A layer of shale forms above an extrusion (left). Later (right), an intrusion crosses the shale.
Inferring *What can you infer about the age of the shale?*

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Radioactive Dating of Rock Layers Radioactive dating works well for igneous rocks, but not for sedimentary rocks. 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 13. As you can see, sedimentary rock (sandstone) above an igneous intrusion must be younger than that intrusion.

Reading Checkpoint **What are two types of radioactive dating?**

Section 3 Assessment

Target Reading Skill Identifying Main Ideas Use your graphic organizer to help you answer Question 2 below.

Reviewing Key Concepts

1. a. **Defining** In your own words, define the term *radioactive decay*.
   b. **Describing** How does the composition of a rock containing a radioactive element change over time?
   c. **Applying Concepts** How is a radioactive element's rate of decay like the ticking of a clock? Explain.
2. a. **Identifying** What method do geologists use to determine the absolute age of a rock?
   b. **Explaining** Why is it difficult to determine the absolute age of a sedimentary rock?
   c. **Problem Solving** A geologist finds a fossil in a layer of sedimentary rock that lies in between two igneous extrusions. How could the geologist determine the age of the fossil?

Math Practice

3. **Percentage** What percentage of a radioactive element will remain after 7 half-lives?

Section 4

The Geologic Time Scale

Reading Preview

Key Concepts

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

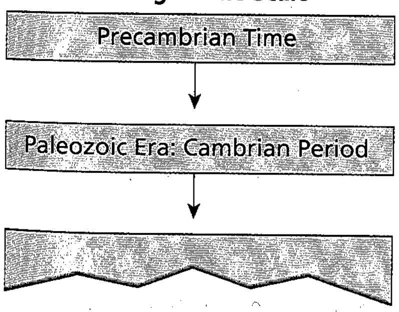
Key Terms

- geologic time scale
- era
- period

Target Reading Skill

Sequencing As you read, make a flowchart like the one below that shows the eras and periods of geologic time. Write the name of each era and period in the flowchart in the order in which it occurs.

Geologic Time Scale



Lab zone 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 timeline to represent your life. Use a scale of 3.0 cm to 1 year.
3. Write each event in the correct year along the timeline.
4. Now divide the timeline into parts that describe major periods in your life, such as preschool years, elementary school years, and middle school years.

Think It Over

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

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!

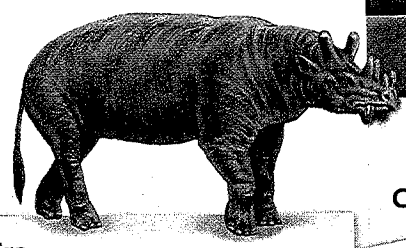
The Geologic Time Scale

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 14.

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.

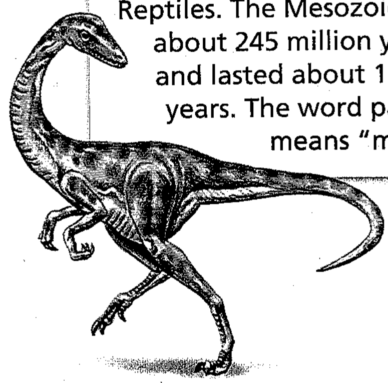
FIGURE 14
The Geologic Time Scale

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?*



Cenozoic Era
The Cenozoic (sen uh ZOH ik) began about 66 million years ago and continues to the present. The word part *ceno-* means "recent," and *-zoic* means "life." Mammals became common during this time.

Mesozoic Era
People often call the Mesozoic (mez uh ZOH ik) the Age of Reptiles. The Mesozoic began about 245 million years ago and lasted about 180 million years. The word part *meso-* means "middle."



Paleozoic Era
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."

Geologic Time Scale

Era	Period	Millions of Years Ago	Duration (millions of years)
Cenozoic	*Quaternary*	1.8	1.8 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*

Divisions of Geologic Time

As geologists studied the fossil record, they found major changes in life forms at certain 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.

When speaking of the past, what names do you use for different spans of time? You probably use names such as century, decade, year, month, week, and day. 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 and periods.** 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 are subdivided into units of geologic time called **periods.** You can see in Figure 14 that the Mesozoic Era includes three periods: the Triassic Period, the Jurassic Period, and the Cretaceous Period.

The names of many of the geologic periods come from places around the world where geologists first described the rocks and fossils of that period. For example, the name Cambrian refers to Cambria, the old Roman name for Wales.

Reading Checkpoint To what era does the Jurassic Period belong?

FIGURE 15
Fossil of the Quaternary Period
This saber-toothed cat lived during the Quaternary Period.

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For: More on the geologic time scale
Visit: PHSchool.com
Web Code: cfd-2044

Section 4 Assessment

Target Reading Skill Sequencing Refer to your flowchart about the geologic time scale as you answer Question 2.

Reviewing Key Concepts

1. a. **Defining** What is the geologic time scale?
   b. **Explaining** What information did geologists use in developing the geologic time scale?
2. a. **Listing** What are the basic units into which the geologic time scale is divided?
   b. **Interpreting Diagrams** Study Figure 14. Which major division of geologic time was the longest? When did it begin? When did it end?
   c. **Sequencing** Place the following in the correct order from earliest to latest: Tertiary, Jurassic, Quaternary, Triassic, Cretaceous.

Writing in Science

An Address in Time Pick one of the periods in the geologic time scale. Write a paragraph that describes, as completely as you can, that period's place in geologic time relative to the other periods and eras.

Section 5

Early Earth

Reading Preview

Key Concepts

- When did Earth form?
- How did Earth's physical features develop during Precambrian Time?
- What were early Precambrian organisms like?

Key Terms

- comet • continental drift

Target Reading Skill

Comparing and Contrasting As you read, compare and contrast early Earth with Earth later in Precambrian Time by completing a table like the one below.

Precambrian Earth

Feature	Early Earth	Later Precambrian Earth
Atmosphere		
Oceans		
Continents		

Lab zone Discover Activity

How Could Planet Earth Form in Space?

1. Place a sheet of paper on top of a small magnet. The paper represents outer space and the magnet models gravity.
2. Sprinkle a half teaspoon of iron filings along one end of the paper to model the materials that formed Earth.
3. Gently blow through a straw for about 10 seconds from the end of the paper with the iron filings toward the magnet. **CAUTION:** *Be sure the straw is pointed away from other students.*
4. Observe what happens to the iron filings.

Think It Over

Making Models If you repeated Steps 2 and 3, what would happen to the size of your "planet"? How is this model like the early Earth? How is it different?

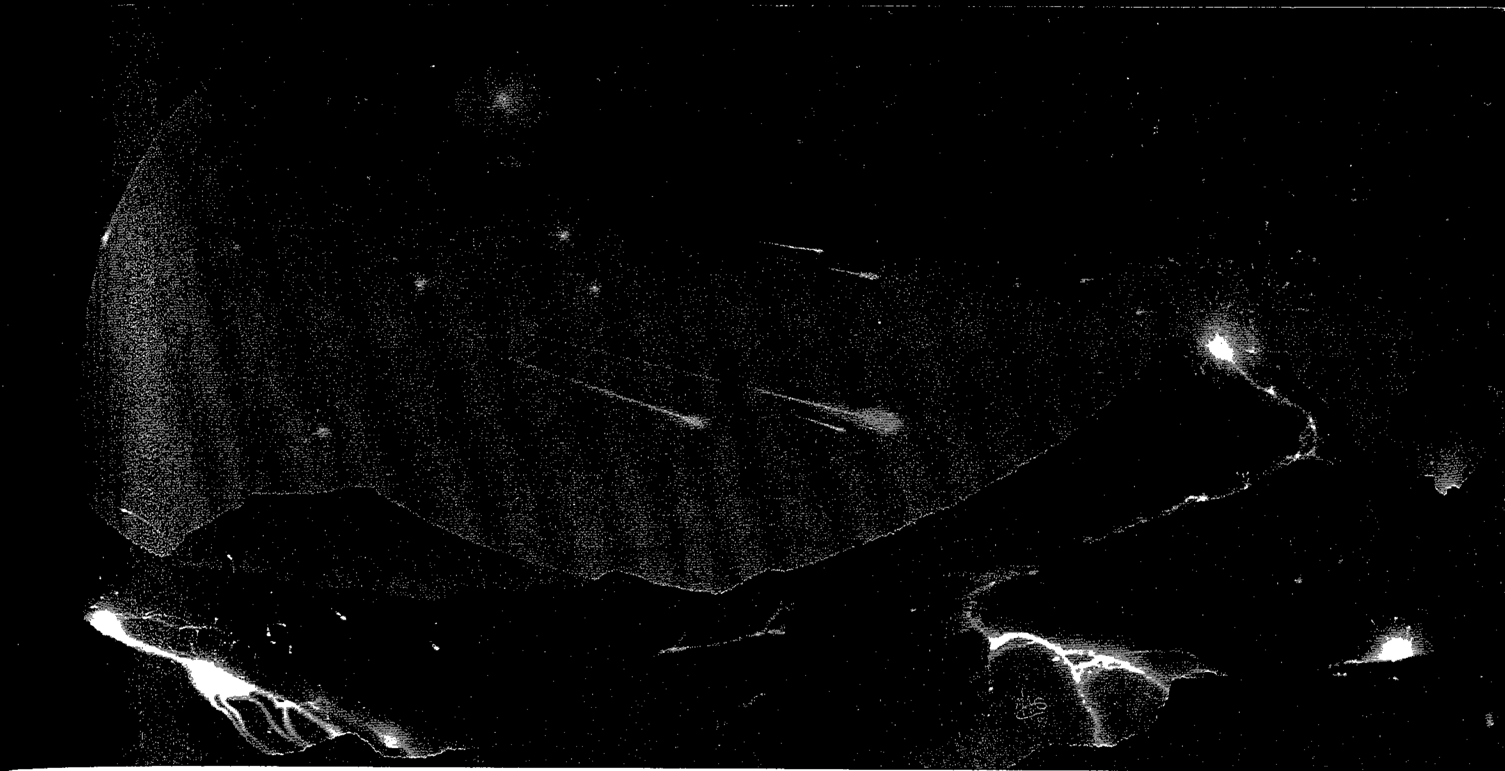
Your science class is going on a field trip, but this trip is a little out of the ordinary. You're going to travel back billions of years to the earliest days on Earth. Then you will move forward through time to the present. Enter the time machine and strap yourself in. Take a deep breath—you're off!

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.

The Planet Forms

Your journey starts at the beginning of Precambrian Time with the formation of planet Earth. **Scientists hypothesize that Earth formed at the same time as the other planets and the sun, roughly 4.6 billion years ago.**

The Age of Earth How do scientists know the age of Earth? Using radioactive dating, scientists have determined that the oldest rocks ever found on Earth are about 4 billion years old. But scientists think Earth formed even earlier than that.



According to this hypothesis, Earth and the moon are about the same age. When Earth was very young, it collided with a large object. The 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 that were 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 also roughly 4.6 billion years old—only a little older than those moon rocks.

Earth Takes Shape Scientists think that Earth began as a ball of dust, rock, and ice in space. Gravity pulled this mass together. As Earth grew larger, its gravity increased, pulling in dust, rock, and ice nearby. As objects made of these materials struck Earth at high speed, their kinetic energy was changed into thermal energy.

The energy from these collisions caused Earth's temperature to rise until the planet was very hot. Scientists think that Earth may have become so hot that it melted. Denser materials sank toward the center, forming Earth's dense, iron core. At the same time, Earth continuously lost heat to the cold of space. Less dense, molten material hardened to form Earth's outer layers—the solid crust and mantle.

As the growing Earth traveled around the sun, its gravity also captured gases such as hydrogen and helium. But this first atmosphere was lost when the sun released a strong burst of particles. These particles blew away Earth's first atmosphere.

Reading Checkpoint **What force caused the materials that formed Earth to come together?**

FIGURE 16
Early Earth
This artist's illustration shows Earth shortly after the moon formed. Notice the rocky objects from space striking Earth, and the molten rock flowing over the surface.

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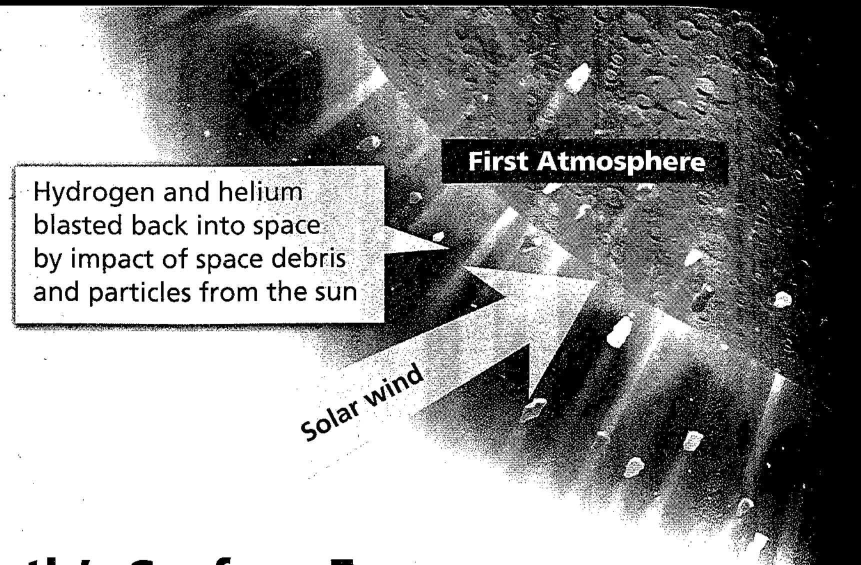
Visit: www.SciLinks.org
Web Code: scn-0745

FIGURE 17
Development of the Atmosphere
Earth soon lost its first atmosphere (left) of hydrogen and helium. Earth's second atmosphere (right) slowly developed the mixture of gases—nitrogen, oxygen, carbon dioxide, water vapor, and argon—of the atmosphere today. As oxygen levels increased, the ozone layer also developed.
Comparing and Contrasting *Compare and contrast Earth's first and second atmospheres.*



Earth's Surface Forms

Watching early Earth from your time machine, you can see the planet change as the years speed by. **During the first several hundred million years of Precambrian Time, an atmosphere, oceans, and continents began to form.**

The Atmosphere After Earth lost its first atmosphere, a second atmosphere formed. This new atmosphere was made up mostly of carbon dioxide, water vapor, and nitrogen. Volcanic eruptions released carbon dioxide, water vapor, and other gases from Earth's interior. Collisions with comets added other gases to the atmosphere. A **comet** is a ball of dust and ice that orbits the sun. The ice in a comet consists of water and frozen gases, including carbon dioxide.

The Oceans At first, Earth's surface was too hot for water to remain as a liquid. All water evaporated into water vapor. However, as Earth's surface cooled, the water vapor began to condense to form rain. Gradually, rainwater began to accumulate to form an ocean. Rain also began to erode Earth's rocky surface. Over time, the oceans affected the composition of the atmosphere by absorbing much of the carbon dioxide.

The Continents During early Precambrian Time, more and more of Earth's rock cooled and hardened. Less than 500 million years after Earth's formation, the less dense rock at the surface formed large landmasses called continents.

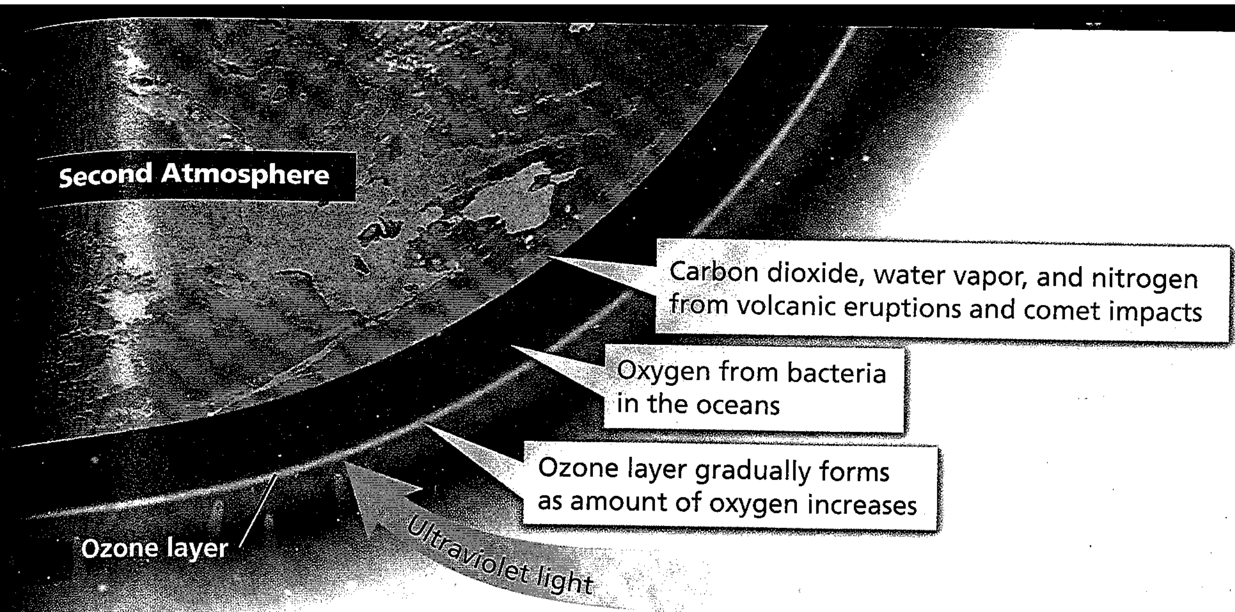
Scientists have found that the continents move very slowly over Earth's surface because of forces inside Earth. This process is called **continental drift.** The movement is very slow—only a few centimeters per year. Over billions of years, Earth's landmasses have repeatedly formed, broken apart, and then crashed together again, forming new continents.

Reading Checkpoint **What is continental drift?**

Lab zone Skills Activity

Calculating

Precambrian Time lasted about 4 billion years. What percentage is this of Earth's entire history of 4.6 billion years? If the first continents formed about 500 million years after Earth itself formed, what percentage of Precambrian Time had elapsed? (*Hint:* To review percentages, see the Math Review section in the Skills Handbook.)



Life Develops

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.** Scientists hypothesize that all other forms of life on Earth arose from these simple organisms.

About 2.5 billion years ago, many organisms began using energy from the sun to make their own food. This process is called photosynthesis. One waste product of photosynthesis is oxygen. As organisms released oxygen into the air, the amount of oxygen in the atmosphere slowly increased. Processes in the atmosphere changed some of this oxygen into a form called ozone. The atmosphere developed a layer rich in ozone that blocked out the deadly ultraviolet rays of the sun. Shielded from the sun's ultraviolet rays, organisms could live on land.

Section 5 Assessment

Target Reading Skill Comparing and Contrasting Use the information in your table about early Earth to answer the questions below.

Reviewing Key Concepts

1. a. **Reviewing** How long ago did Earth form?
   b. **Summarizing** Summarize the process by which scientists determined the age of Earth.
2. a. **Listing** What physical features formed during Earth's first several hundred million years?
   b. **Explaining** How did volcanic eruptions and comets change early Earth?
   c. **Relating Cause and Effect** What caused water erosion to begin on Earth's surface?
3. a. **Identifying** What do scientists think were the first organisms to evolve on Earth?
   b. **Predicting** How would Earth's atmosphere be different if organisms capable of photosynthesis had not evolved? Explain.

Writing in Science

Web Site Plan a Web site for early Earth. To plan your Web site, make a list of the topics you will include. Make sketches of the screens that visitors to the Web site will see. Then write short descriptions for each topic.

Section 6

Eras of Earth's History

Reading Preview

Key Concepts

- What were the major events in the Paleozoic Era?
- What were the major events in the Mesozoic Era?
- What were the major events in the Cenozoic Era?

Key Terms

- invertebrate
- vertebrate
- amphibian
- reptile
- mass extinction
- mammal

Target Reading Skill

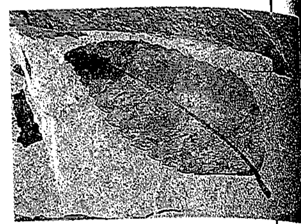
Previewing Visuals Before you read, preview Figure 22. Then write three questions that you have about Earth's history in a graphic organizer like the one below. As you read, answer your questions.

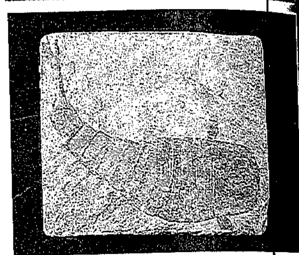
Earth's History

Q. What geologic events happened during Precambrian Time?
A.
Q.

Lab zone 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?

As your time machine nears the end of Precambrian Time, you notice that Earth's organisms have begun to change. Along with organisms made up of single cells, living things resembling jellyfish now float in Earth's oceans. You also notice the fronds of feathery, plantlike organisms anchored to the seafloor. Scientists have found fossils of such organisms in Australia, Russia, China, and southern Africa. Fossils like the ones in Figure 18 are more than 600 million years old! But a much greater variety of living things evolved during the next phase of geologic time—the Paleozoic Era.

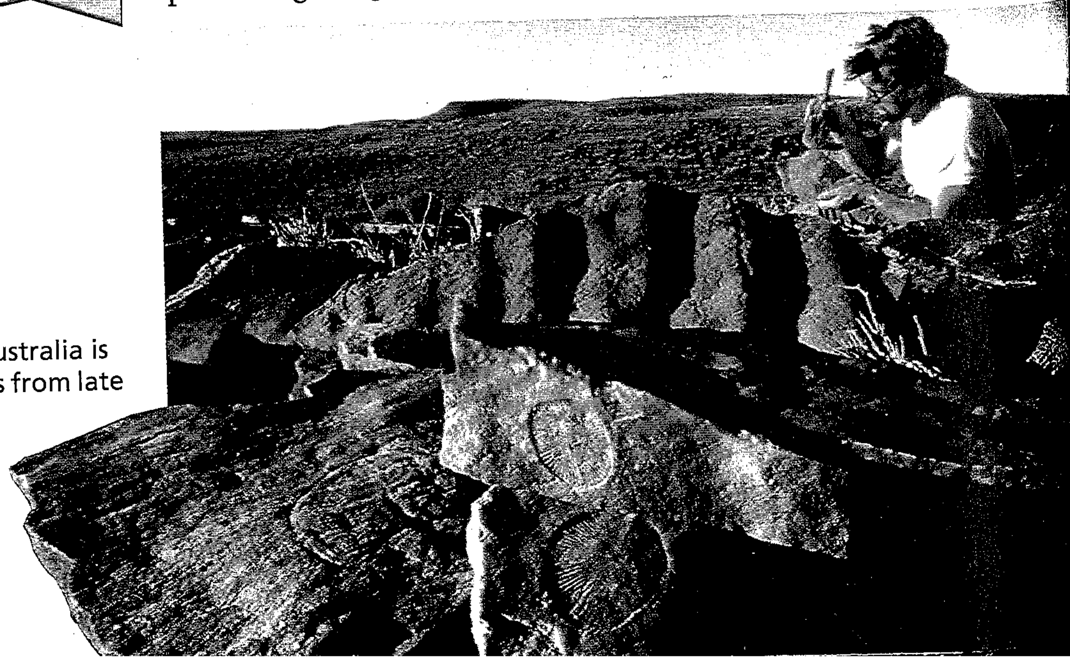


FIGURE 18
Paleontologist at Work
This paleontologist in Australia is uncovering fossil animals from late Precambrian Time.

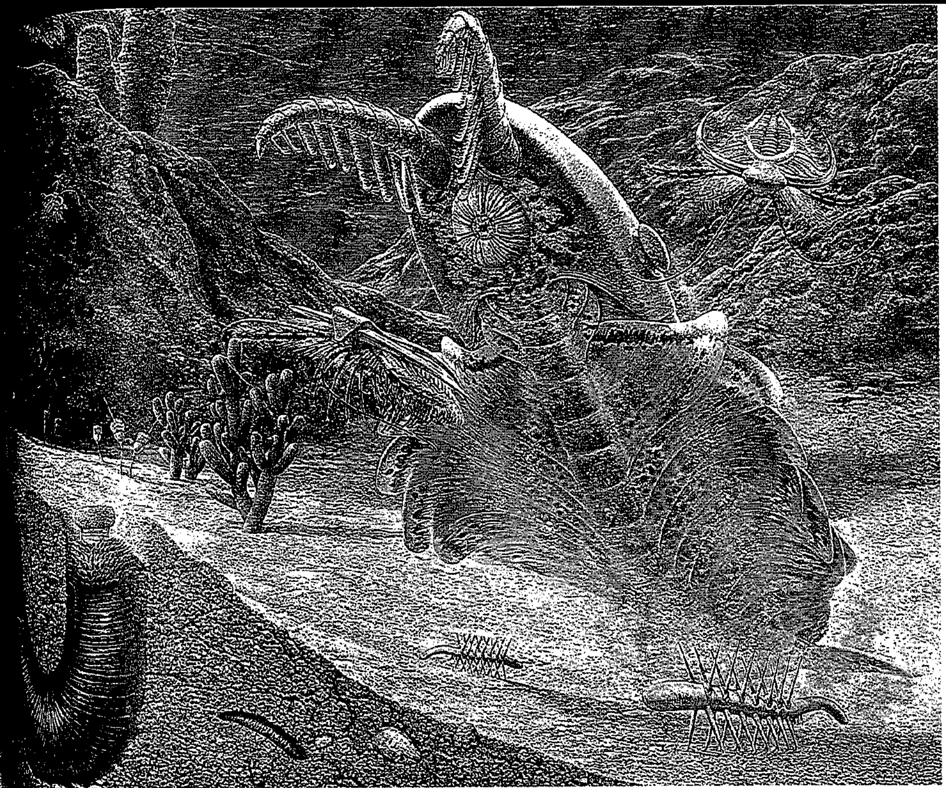


FIGURE 19
The Cambrian Explosion
During the early Cambrian period, Earth's oceans were home to many strange organisms unlike any animals that are alive today.

The Paleozoic Era

Your time machine slows. You observe the "explosion" of life that began the Paleozoic Era.

The Cambrian Explosion 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. Many were animals without backbones, or **invertebrates.** Invertebrates such as jellyfish, worms, and sponges drifted through the water, crawled along the sandy bottom, or attached themselves to the ocean floors.

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

Vertebrates Arise During the Ordovician (awr duh VISH ee un) and Silurian (sih LOOR ee un) periods, the ancestors of the modern octopus and squid appeared. But these invertebrates soon shared the seas with a new type of organism. **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.

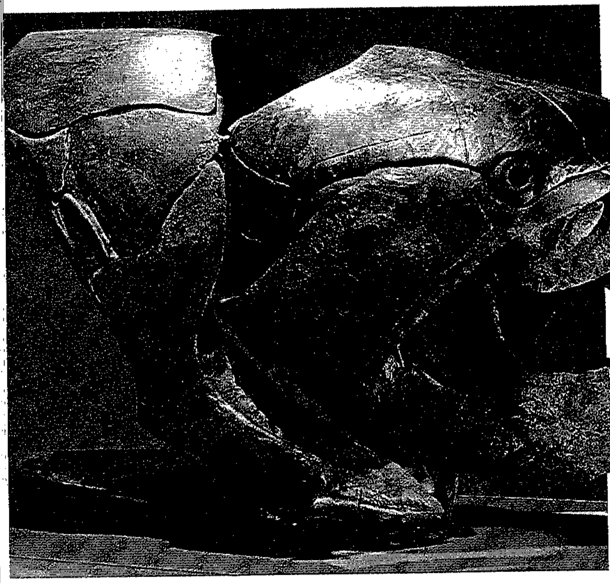


FIGURE 20
Devonian Armored Fish
Paleontologists have found fossils of huge armored fish, like this *Dunkleosteus,* that lived during the Devonian Period.

Life Reaches Land Until the Silurian Period, only one-celled organisms lived on the land. But during the Silurian Period, plants became abundant. These first, simple plants grew low to the ground in damp areas. 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.

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. 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. Some fishes, like the one in Figure 20, were huge. 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 lung fish. An **amphibian** (am FIB ee un) is an animal that lives part of its life on land and part of its life in water.

The Carboniferous Period Throughout the rest of the Paleozoic, life expanded over Earth's continents. Other 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.

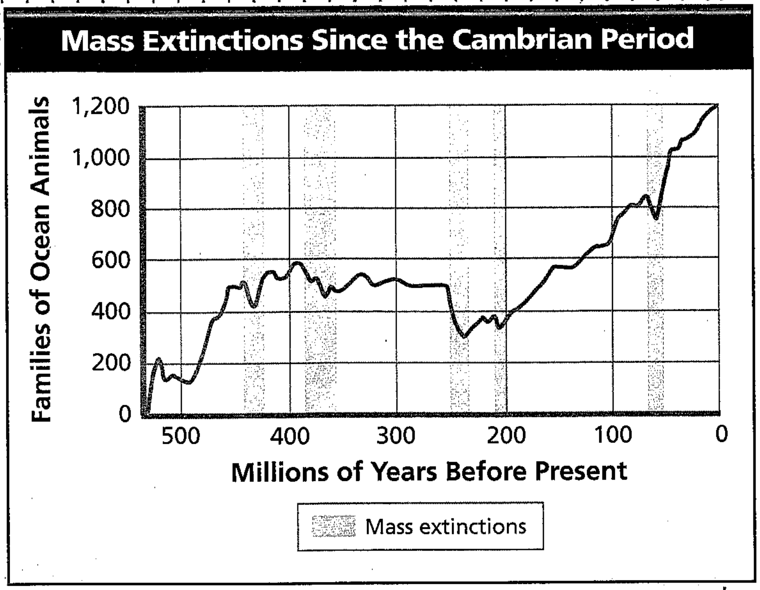
FIGURE 21
The Coal Forest
Forests of the Carboniferous Period later formed coal deposits. **Predicting** *What types of fossils would you expect to find from the Carboniferous Period?*

Math Analyzing Data

Mass Extinctions

The graph shows how the number of families of animals in Earth's oceans has changed.

1. **Reading Graphs** What variable is shown on the *x*-axis? On the *y*-axis of the graph?
2. **Interpreting Data** How long ago did the most recent mass extinction occur?
3. **Interpreting Data** Which mass extinction produced the greatest drop in the number of families of ocean animals?
4. **Relating Cause and Effect** In general, how did the number of families change between mass extinctions?



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." 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 many kinds of organisms, such as trilobites, suddenly became extinct.

The Supercontinent Pangaea Scientists hypothesize that climate change resulting from continental drift may have caused the mass extinction at the end of the Paleozoic. **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, as shown in Figure 22.

Reading Checkpoint What was Pangaea?

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active art
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FIGURE 23
Flying Reptile
Dimorphodon was a flying reptile that lived during the Jurassic Period. Like dinosaurs, flying reptiles became extinct at the end of the Cretaceous period.
Comparing and Contrasting *How is* Dimorphodon *similar to the bird in Figure 24?*

The Mesozoic Era

Millions of years flash by as your time machine travels. 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. 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 animals 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.

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.

FIGURE 24
Early Bird
The artist of the illustration (left) has given *Archaeopteryx* colorful feathers. From a fossil (right), paleontologists can tell that *Archaeopteryx* was about 30 centimeters long, had feathers and teeth, and also had claws on its wings.

The Cretaceous Period Reptiles, including dinosaurs, were still the dominant vertebrates throughout the Cretaceous Period (krih TAY shus). 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. The Cretaceous Period also brought new forms of life. Flowering plants like the ones you see today evolved. Unlike the conifers, flowering plants produce seeds that are inside a fruit. The fruit helps the seeds survive.

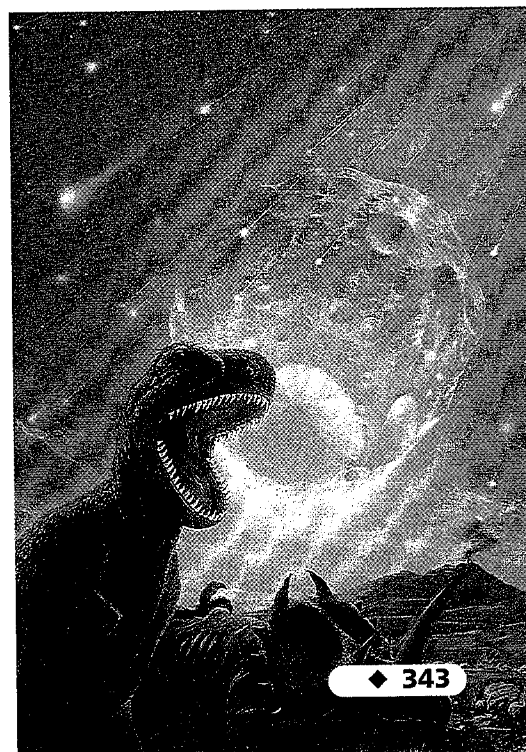
Another Mass Extinction **At the close of the Cretaceous Period, about 65 million years ago, another mass extinction occurred. Scientists hypothesize that this mass extinction occurred when an object from space struck Earth.** This object was probably an asteroid. Asteroids are rocky masses that orbit the sun between Mars and Jupiter. Once in many millions of years, an asteroid may collide with Earth.

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.

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

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

FIGURE 25
The End of the Dinosaurs
Many scientists hypothesize that during the Cretaceous an asteroid hit Earth near the present-day Yucatán Peninsula, in southeastern Mexico.



Lab zone Try This Activity

Life and Times

1. Place these events in their correct 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 timeline 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
   - 20,000 years ago

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

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

The Cenozoic Era

Your voyage through time continues on through the Cenozoic Era—often called 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 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, 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.

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.** Thick continental glaciers advanced and retreated over parts of Europe and North America. Then, about 20,000 years ago, Earth's climate began to warm. Over thousands of years, the continental glaciers melted, except in Greenland and Antarctica.

FIGURE 26
Ice-Age Environment
Large mammals roamed the ice-free parts of North America and Eurasia during the Ice Ages of the Quaternary Period.

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 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!

Reading Checkpoint **How did Earth's climate change during the Quaternary Period?**

FIGURE 27
Ice Age Art
An early ancestor of modern humans painted these beautiful images of animals in a cave in France more than 15,000 years ago.

Section 6 Assessment

Target Reading Skill **Previewing Visuals** Compare your questions and answers about Figure 22 with those of a partner.

Reviewing Key Concepts

1. a. **Listing** What are the periods of the Paleozoic Era?
   b. **Describing** How did Earth's organisms change during the first period of the Paleozoic?
   c. **Relating Cause and Effect** What event do scientists think may have caused the mass extinction at the end of the Paleozoic?
2. a. **Reviewing** Which group of animals was dominant during the Mesozoic Era?
   b. **Inferring** How was their small size helpful to the mammals of the Mesozoic?
   c. **Developing Hypotheses** Many scientists think that the asteroid impact at the end of the Cretaceous prevented plant growth for many years. Although many dinosaurs were plant eaters, some were meat eaters. Develop a hypothesis to explain why no dinosaurs survived.
3. a. **Identifying** What term do scientists apply to the Cenozoic Era?
   b. **Inferring** What conditions allowed so many different kinds of mammals to evolve during the Cenozoic Era?

Writing in Science

Description Suppose that you are going on a tour of Earth during one era of geologic time. Write a paragraph describing the organisms and environments that you see on the tour. Your tour should include at least one stop in each geologic period of the era you chose.