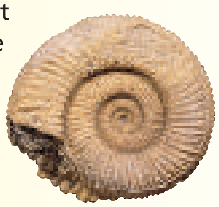
Unit 5

History & Biology

1500 1600 1700

1593 The Roman city of Pompeii is discovered.

1500 Leonardo da Vinci recognizes that fossil shells represent ancient marine life.



Fossil shell

Change Through Time

What You'll Learn

Why It's Important

Life on Earth has a history of change that is called evolution. An enormous variety of fossils, such as those of early birds, provides evidence of evolution. Genetic studies of populations of bacteria, protists, plants, insects, and even humans provide further evidence of the history of change among organisms that live or have lived on Earth.

California Standards
The following standards are covered in Unit 5:
Investigation and Experimentation: 1a, 1d, 1g, 1h, 1i, 1j, 1k, 1n
Biology/Life Sciences: 2g, 7a, 7c, 7d, 8, 8a, 8c, 8d, 8e, 8f, 8g

Understanding the Photo
These African elephants are well-adapted to their environment. Scientists study these and other organisms to learn about their adaptations and how the organisms have changed through time.

(t)Breck P. Kent/Earth Scenes, (crossover)Daryl Balfour/Getty Images

1773
The Boston Tea Party occurs.

1778
The first assertion that the age of Earth exceeds a few thousand years is published.

1841
The first university degrees are granted to women in the United States.

1856
The first humanlike fossil remains (Neandertals) are discovered in Germany.

Neandertal skull

1900

1936
Jesse Owens wins four gold medals in track and field at the Berlin Olympics.

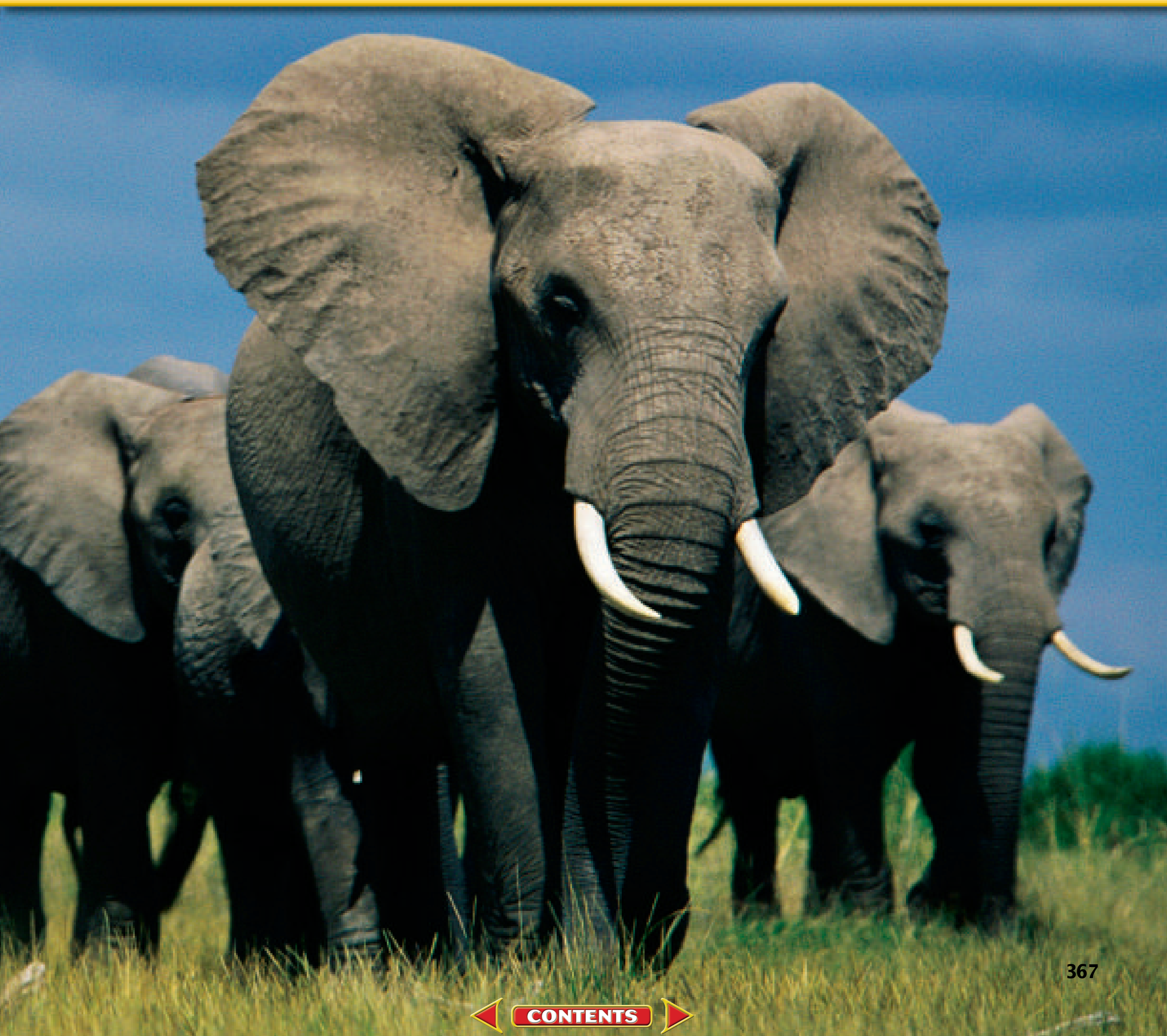
1974
The partial skeleton of *Australopithecus afarensis,* known as "Lucy," is discovered in Ethiopia.

1999
Meave Leakey discovers a new fossil hominid, *Kenyanthropus,* in Kenya.

2000

2001
A hominid fossil is discovered in Africa that is 6 to 7 million years old.

J. Breckett/D. Fannin/American Museum of Natural History



Chapter 14

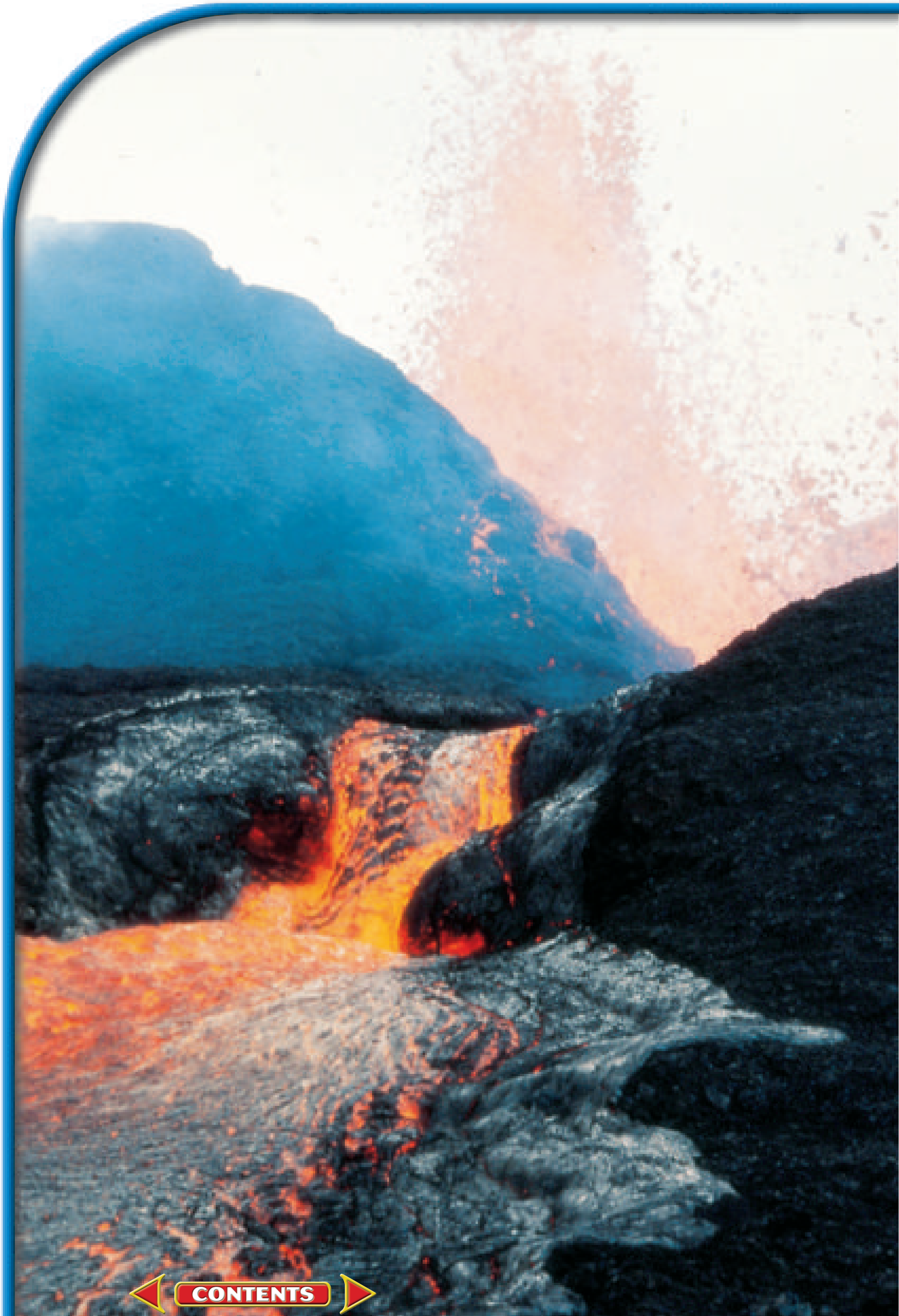
The History of Life

What You'll Learn

- You will examine how rocks and fossils provide evidence of changes in Earth's organisms.
- You will correlate the geologic time scale with biological events.
- You will sequence the steps by which small molecules may have produced living cells.

Why It's Important

Knowing the geological history of Earth and understanding ideas about how life began provide background for an understanding of the theory of evolution.



Understanding the Photo

Erupting volcanoes and lava flows, such as this one in Hawaii, may provide a model for conditions on early Earth.

Biology Online

Visit ca.bdol.glencoe.com to
- study the entire chapter online
- access Web Links for more information on the origin of life
- review content with the Interactive Tutor and self-check quizzes

Soames Summerhays/Photo Researchers

Section 14.1

The Record of Life

California Standards Standard 8g* Students know how several independent molecular clocks, calibrated against each other and combined with evidence from the fossil record, can help to estimate how long ago various groups of organisms diverged evolutionarily from one another.

SECTION PREVIEW

Objectives

Identify the different types of fossils and how they are formed.

Summarize the major events of the geologic time scale.

Review Vocabulary

isotope: atoms of the same element that have different numbers of neutrons (p. 144)

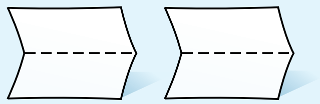
New Vocabulary

fossil
plate tectonics

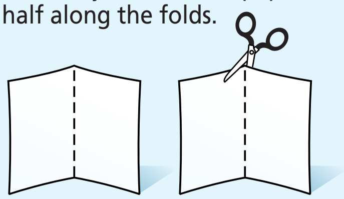
FOLDABLES Study Organizer

Geologic Time Make the following Foldable to help you organize events in Earth's history and the major life forms that appeared during each event.

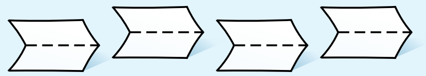
STEP 1 **Fold** two vertical sheets of paper in half from top to bottom.



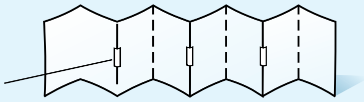
STEP 2 **Turn** both papers horizontally and **cut** the papers in half along the folds.



STEP 3 **Fold** the four vertical pieces in half from top to bottom.



STEP 4 **Turn** the papers horizontally. **Tape** the short ends of the pieces together (overlapping the edges slightly) to make an accordion time line.



STEP 5 **Label** each fold.

Sequence As you read Chapter 14, arrange the divisions of the geologic scale from oldest to youngest beginning at the far left of the Foldable. Then write the major life forms and events that appeared in each era.

Physical Science Connection

Movement of heat The movement of heat from Earth's interior out to space involves the processes of conduction, convection, and radiation. Earth's interior can behave like a fluid, so that heat is transferred to the outer crust by convection and conduction. Heat then moves through the solid crust by conduction and into space by radiation.

Early History of Earth

What was early Earth like? Some scientists suggest that it was probably very hot. The energy from colliding meteorites could have heated its surface, while both the compression of minerals and the decay of radioactive materials heated its interior. Volcanoes might have frequently spewed lava and gases, relieving some of the pressure in Earth's hot interior. These gases helped form Earth's early atmosphere. Although it probably contained no free oxygen, water vapor and other gases, such as carbon dioxide and nitrogen, most likely were present. If ancient Earth's atmosphere was like this, you would not have survived in it.

About 4.4 billion years ago, Earth might have cooled enough for the water in its atmosphere to condense. This might have led to millions of years of rainstorms with lightning—enough rain to fill depressions that became Earth's oceans. Some scientists propose that life originated in Earth's oceans between 3.9 and 3.4 billion years ago.

History in Rocks

Can scientists be sure that Earth formed in this way? No, they cannot. There is no direct evidence of the earliest years of Earth's history. The physical processes of Earth constantly destroy and form rocks. The oldest rocks that have been found on Earth formed about 3.9 billion years ago. Although rocks cannot provide information about Earth's infancy, they are an important source of information about the diversity of life that has existed on the planet.

Fossils—Clues to the past

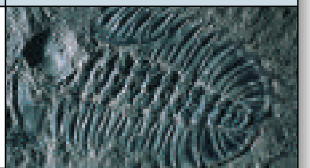
If you've ever visited a zoo or toured a botanical garden, you've seen evidence of the diversity of life. But the millions of species living today are probably only a small fraction of all the species that ever existed. About 95 percent of the species that have existed are extinct—they no longer live on Earth. Among other techniques, scientists study fossils to learn about ancient species. A **fossil** is evidence of an organism that lived long ago.

Because fossils can form in many different ways, there are many types of fossils, as you can see in ***Table 14.1.*** Use the *MiniLab* on the next page to observe some marine fossils under your microscope.

Paleontologists—Detectives to the past

The study of fossils is a lot like solving a mystery. Paleontologists (pay lee ahn TAHL uh justs), scientists who study ancient life, are like detectives who use fossils to understand events that happened long ago. They use fossils to determine the kinds of organisms that lived during the past and sometimes to learn about their behavior. For example, fossil bones and

Table 14.1 Some Types of Fossils

Fossils Types	Formation	Example
Trace fossils	A trace fossil is any indirect evidence left by an animal and may include a footprint, a trail, or a burrow.	
Casts	When minerals in rocks fill a space left by a decayed organism, they make a replica, or cast, of the organism.	
Molds	A mold forms when an organism is buried in sediment and then decays, leaving an empty space.	
Petrified/ Permineralized fossils	Petrified—minerals sometimes penetrate and replace the hard parts of an organism. Permineralized—void spaces in original organism infilled by minerals.	
Amber-preserved or frozen fossils	At times, an entire organism was quickly trapped in ice or tree sap that hardened into amber.	

(1)T.A. Wiewandt/DRK Photo, (2)Breck P. Kent/Earth Scenes, (3)Michael Collier, (4)John Gerlach/DRK Photo, (5)Jeff J. Daly/Visuals Unlimited

CONTENTS

teeth can indicate the size of animals, how they moved, and what they ate.

Paleontologists also study fossils to gain knowledge about ancient climate and geography. For example, when scientists find a fossil like the one in ***Figure 14.1,*** which resembles a present-day plant that lives in a mild climate, they may reason that the ancient environment was also mild.

By studying the condition, position, and location of rocks and fossils, geologists and paleontologists can make deductions about the geography of past environments. You can use the *Problem-Solving Lab* on the next page to try to solve a fossil mystery.

Reading Check **Infer** how fossil teeth could be used to determine an animal's diet.

Fossil formation

For fossils to form, organisms usually have to be buried in mud, sand, or clay soon after they die. These particles are compressed over time and harden into a type of rock called sedimentary rock. Today, fossils still form at the bottoms of lakes, streams, and oceans.

Most fossils are found in sedimentary rocks. These rocks form at relatively low temperatures and pressures that may prevent damage to the organism. How do these fossils become visible millions of years later?

MiniLab 14.1

Observe and Infer

Marine Fossils Certain sedimentary rocks are formed almost totally from the fossils of once-living marine or ocean organisms called diatoms. These sedimentary rocks usually form in oceans, but can be lifted above sea level during periods of geological change.

Color-enhanced LM Magnification: 130×

Present-day diatoms

Procedure

1. Prepare a wet mount of a small amount of diatomaceous earth. **CAUTION:** ***Use care in handling microscope slides and coverslips. Do not breathe in dry diatomaceous earth.***
2. Examine the material under low-power magnification.
3. Draw several of the different shapes you see.
4. Compare the shapes of the fossils you observe to present-day diatoms shown in the photograph. Remember, however, that the fossils you observe are probably only pieces of the whole organism.

Analysis

1. **Describe** Describe the appearance of fossil diatoms.
2. **Compare and Contrast** How are fossil diatoms similar to and different from the diatoms in the photo? Can you use these similarities and differences to predict how diatoms have changed over time? Explain your answer.
3. **Infer** What part of the original diatom did you observe under the microscope? How did this part survive millions of years? Why were the fossils you observed broken?

Figure 14.1
This fossil leaf is from rocks about 200 million years old **(A).** They are remarkably similar to the leaves of *Ginkgo biloba* **(B),** trees that are planted as ornamentals throughout the United States.

(t)Jan Hinsch/Science Photo Library/Photo Researchers, (bl)Patti Murray/Earth Scenes, (br)Gilbert S. Grant/Photo Researchers

Problem-Solving Lab 14.1

Think Critically

Could ferns have lived in Antarctica? Scientists have discovered fossil remains of ferns in the rocks of Antarctica. These fern fossils are related to ferns that grow in temperate climates on Earth today.

Fern fossil from Antarctica

Solve the Problem

Read each statement below and critique whether or not the statement is reasonable. Explain the reason for each of your critiques.

Thinking Critically

1. Fern fossils in Antarctica are of plants that could withstand freezing temperatures.
2. The ferns in Antarctica may have been mutated forms of ferns that grew in warm climates.
3. The temperature of Earth may have been much warmer millions of years ago than it is today.

Figure 14.2
Most sedimentary rocks form in primarily horizontal layers with the younger layers closer to the surface. Older rocks and fossils will be found deeper in the sequence, with the oldest at the bottom. **Infer** ***What might have happened to a section with the oldest fossils at the top of the sequence?***

To answer the question, look at ***Figure 14.3.*** Fossils are not usually found in other types of rock because of the ways those rocks form. For example, metamorphic rocks form when heat, pressure, and chemical reactions change other rocks. The conditions under which metamorphic rocks form often destroy any fossils that were in the original sedimentary rock.

Relative dating

Scientists use a variety of methods to determine the age of fossils. One method is a technique called relative dating. To understand relative dating, imagine yourself stacking newspapers at home. As each day's newspaper is added to the stack, the stack becomes taller. If the stack is left undisturbed, the newspapers at the bottom are older than ones at the top.

The relative dating of rock layers uses the same principle. In ***Figure 14.2,*** you see fossils in different layers of rock. If the rock layers have not been disturbed, the layers at the surface must be younger than the deeper layers. The fossils in the top layer must also be younger than those in deeper layers. Using this principle, scientists can determine relative age and the order of appearance of the species that are preserved as fossils in the layers.

Radiometric dating

You cannot determine the actual age in years of a fossil or rock by using relative dating techniques. To find the specific ages of rocks, scientists use radiometric dating techniques utilizing the radioactive isotopes in rocks. Most fossils and sedimentary rocks cannot be directly radiometrically dated. Most dates are for volcanic or other igneous rocks, or metamorphic rocks that are closely associated with the sedimentary rocks.

Louie Psihoyos/Matrix

INSIDE STORY

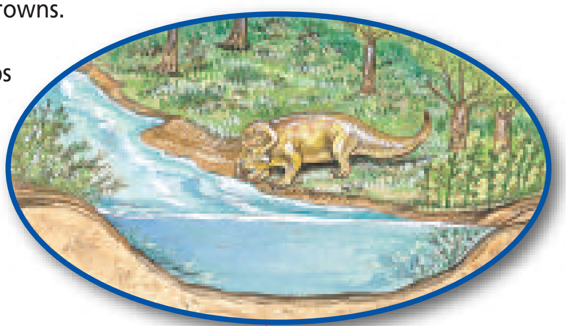
The Fossilization Process

Figure 14.3

Few organisms become fossilized because, without burial, bacteria and fungi immediately decompose their dead bodies. Occasionally, however, organisms do become fossils in a process that usually takes many years. Most fossils are found in sedimentary rocks. **Critical Thinking** ***Describe how the movements of Earth might expose a fossil.***

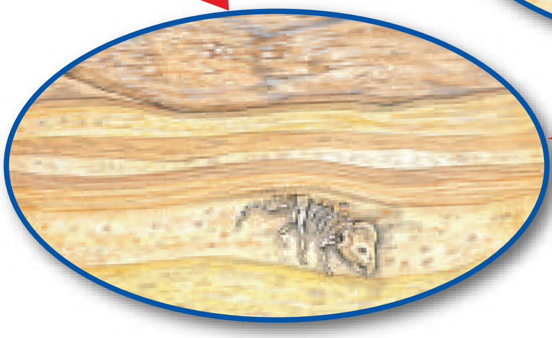
Protoceratops skull

A **A Protoceratops*** drinking at a river falls into the water and drowns. *An adult Protoceratops was about 2.4 meters long (8 feet).

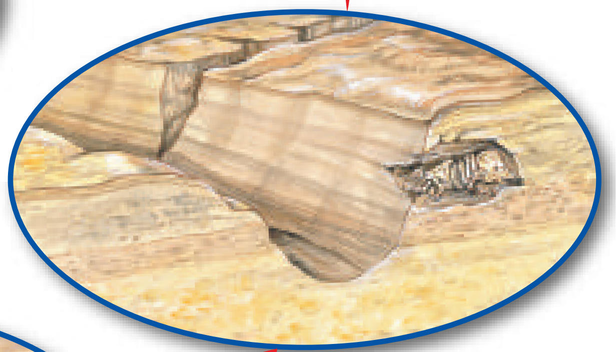


B **Sediments from upstream** rapidly cover the body, slowing its decomposition. Minerals from the sediments seep into the body.

C **Over time,** additional layers of sediment compress the sediments around the body, forming rock. Minerals eventually replace all the body's bone material.



D **Earth movements** or erosion may expose the fossil millions of years after it formed.



E **After discovery,** scientists carefully extract the fossil from the surrounding rock.

(tr)Louis Psihoyos/Matrix, (br)Associated Press/*The Mesa Tribune*

CAREERS IN BIOLOGY

Animal Keeper

Would you like to make a career out of caring for animals? There are many opportunities if you love animals.

Skills for the Job

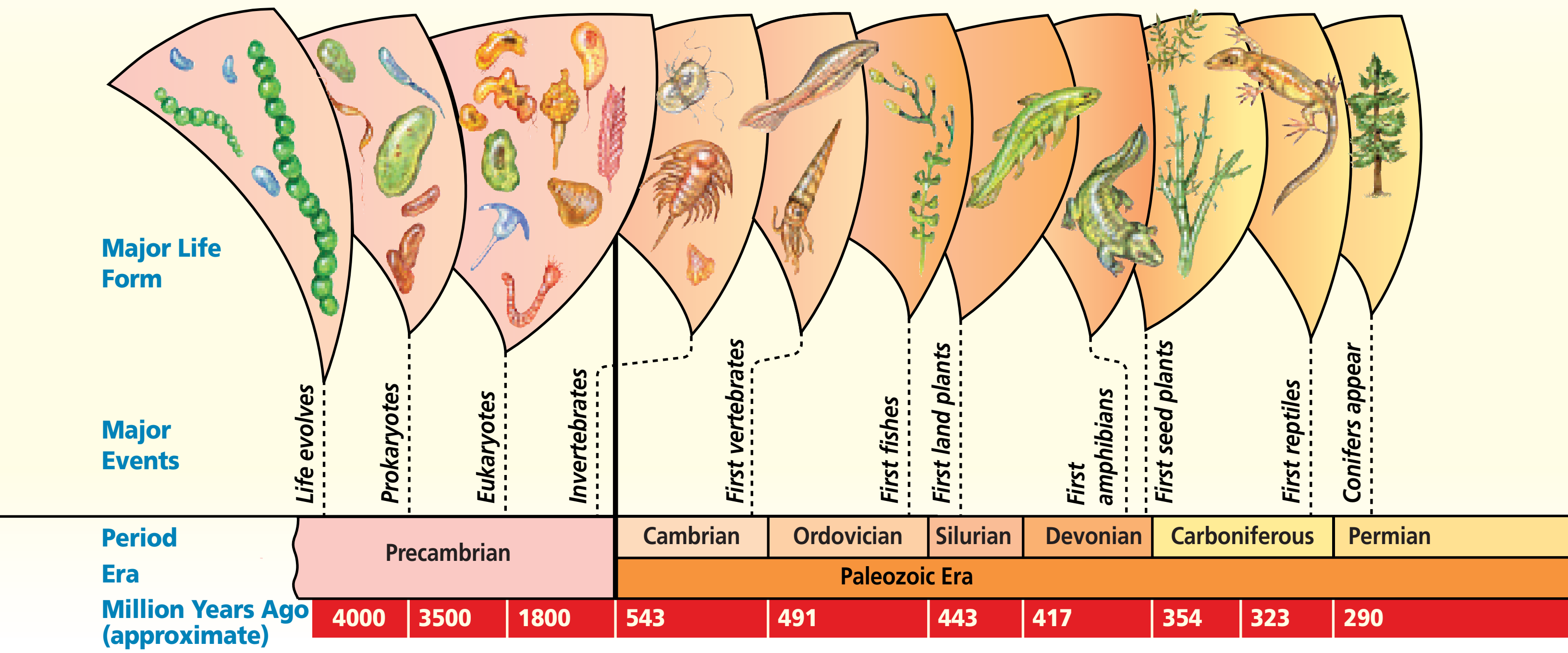
Animal keepers or caretakers give animals food and water, exercise them, clean their cages, groom them, monitor their health, and sometimes administer medicines. Keepers must finish high school. Many pet shops, kennels, shelters, and stables provide on-the-job training. Humane societies, veterinarians, and research laboratories hire graduates of two-year programs in animal health. Most zoos and aquariums employ keepers with four-year degrees in zoology or biology. Taking care of animals often means working weekends and holidays, so keepers must care about their work.

For more careers in related fields, visit ca.bdol.glencoe.com/careers

Recall that radioactive isotopes are atoms with unstable nuclei that break down, or decay, over time, giving off radiation. A radioactive isotope forms a new isotope after it decays. The rate at which a radioactive isotope decays is related to the half-life of the isotope. The half-life is the length of time needed for half of the atoms of the isotope to decay.

Scientists try to determine the approximate ages of rocks by comparing the amount of a radioactive isotope and the new isotope into which it decays. For example, suppose that when a rock forms it contains a radioactive isotope that decays to half its original amount in one million years. Today, if the rock contains equal amounts of the original radioactive isotope and the new isotope into which it decays, then the rock must be about 1 million years old.

Scientists use potassium-40, a radioactive isotope that decays to argon-40, to date rocks containing potassium-bearing minerals. Based on chemical analysis, chemists have determined that potassium-40 decays to half its original amount in 1.3 billion years. Scientists use carbon-14 to date fossils



Kathy Sloane/Photo Researchers

less than 50 000 years old. Again, based on chemical analysis, they know that carbon-14 decays to half its original amount in 5730 years.

Use the *BioLab* at the end of this chapter to simulate this dating technique. Scientists always analyze many samples of a rock using as many methods as possible to obtain consistent values for the rock's age. Errors can occur if the rock has been heated, causing some of the radioactive isotopes to be lost or gained. If this occurs, the age obtained will be inaccurate.

A Trip Through Geologic Time

By examining sequences containing sedimentary rock and fossils and dating some of the igneous or metamorphic rocks that are found in the sequences, scientists have put together a chronology, or calendar, of Earth's history. This chronology, called the geologic time scale, is based on evidence from Earth's rocks and fossils.

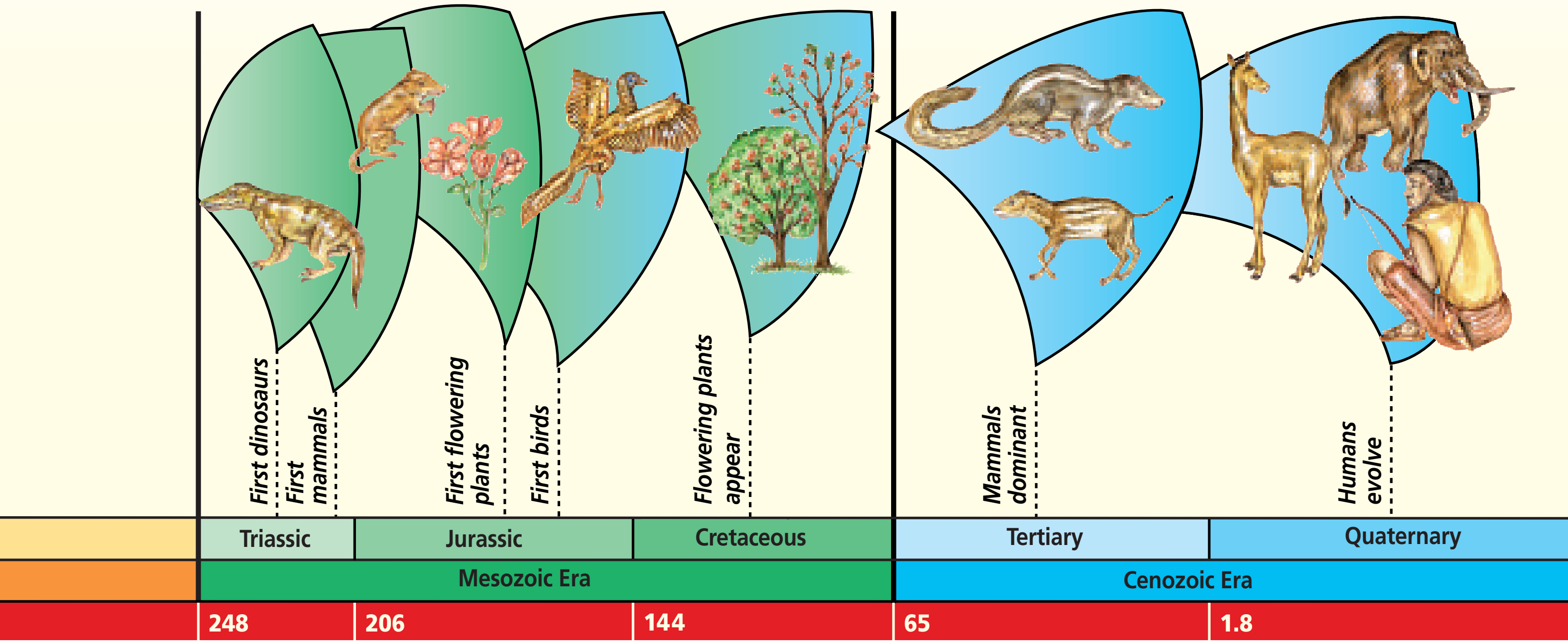
The geologic time scale

Rather than being based on months or even years, the geologic time scale is divided into four large sections that you see in ***Figure 14.4***—the Precambrian (pree KAM bree un), the Paleozoic (pay lee uh ZOH ihk) Era, the Mesozoic (me zuh ZOH ihk) Era, and the Cenozoic (se nuh ZOH ihk) Era. An era is a large division in the scale and represents a very long period of time. Each era is subdivided into periods.

The divisions in the geologic time scale are distinguished by the organisms that lived during that time interval. The fossil record indicates that there were several episodes of mass extinction that fall between time divisions. A mass extinction is an event that occurs when many organisms disappear from the fossil record almost at once.

The geologic time scale begins with the formation of Earth about 4.6 billion years ago. To understand the large size of this number, try the *MiniLab* on the next page, and also try scaling down

Figure 14.4
The geologic time scale is a calendar of Earth's history based on evidence found in rocks. Life probably first appeared on Earth between 3.9 and 3.4 billion years ago.



MiniLab 14.2

Organize Data

A Time Line In this activity, you will construct a time line that is a scale model of the geologic time scale. Use a scale in which 1 meter equals 1 billion years. Each millimeter then represents 1 million years.

Procedure

1. Use a meterstick to draw a continuous line down the middle of a 5-m strip of adding-machine tape.
2. At one end of the tape, draw a vertical line and label it "The Present."
3. Measure off the distance that represents 4.6 billion years ago. Draw a vertical line at that point and label it "Earth's Beginning."
4. Using the table at right, plot the location of each event on your time line. Label the event, and label when it occurred.

Geologic Time Scale

Event	Estimated Years Ago
Earliest evidence of life	3.4 billion
Paleozoic Era begins	543 million
First land plants	443 million
Mesozoic Era begins	248 million
Triassic Period begins	248 million
Jurassic Period begins	206 million
First dinosaurs	225 million
First birds	150 million
Cretaceous Period begins	144 million
Dinosaurs become extinct	65 million
Cenozoic Era begins	65 million
Primates appear	65 million
Humans appear	200 000

Analysis

1. **Calculate** Which era is the longest? The shortest?
2. **Interpret Data** In which eras did dinosaurs and birds appear on Earth?
3. **Interpret Data** What major group first appeared around the same time that dinosaurs became extinct?

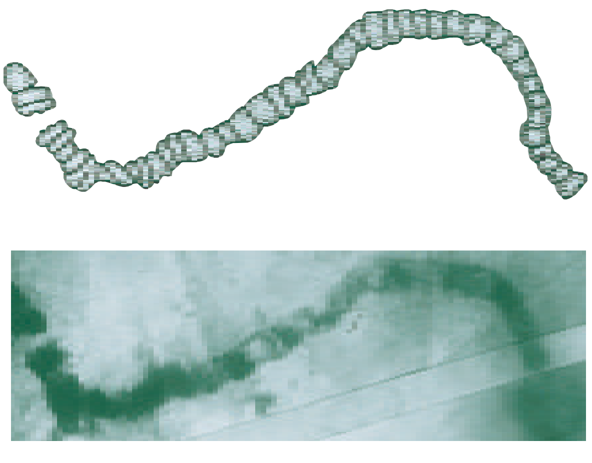


Figure 14.5
The filamentous fossils of these ancient organisms resemble some modern cyanobacteria.

J. William Schopf/UCLA

the history of Earth into a familiar, but hypothetical, calendar year.

Life during the Precambrian

In your hypothetical calendar year, the first day of January becomes the date on which Earth formed. The oldest fossils are found in Precambrian rocks that are about 3.4 billion years old—near the end of March on the hypothetical calendar. Scientists found these fossils, which are shown in ***Figure 14.5,*** in rocks found in the deserts of western Australia. They have found more examples of similar types of fossils on other continents. The fossils resemble the forms of modern species of photosynthetic cyanobacteria (si a noh bak TIHR ee uh). You will read more about cyanobacteria in a later chapter.

Scientists have also found dome-shaped structures called stromatolites (stroh MAT ul ites) in Australia and on other continents. Stromatolites still form today in Australia from mats of cyanobacteria, ***Figure 14.6.*** Thus, the stromatolites are evidence of the existence of photosynthetic organisms on Earth during the Precambrian.

The Precambrian accounts for about 87 percent of Earth's history—until about the middle of October in the hypothetical calendar year. Near the beginning of the Precambrian, unicellular prokaryotes—cells that do not have a membrane-bound nucleus—appear to have been the only life forms on Earth. About 2.1 billion years ago, the fossil record shows that more complex eukaryotic organisms, living things with membrane-bound nuclei in their cells, appeared. By the end of the Precambrian, about

543 million years ago, multicellular eukaryotes, such as sponges and jellyfishes, diversified and filled the oceans.

Diversity during the Paleozoic

In the Paleozoic Era, which lasted until 248 million years ago, many more types of animals and plants were present on Earth, and some were preserved in the fossil record. The earliest part of the Paleozoic Era is called the Cambrian Period. Paleontologists often refer to a "Cambrian explosion" of life because the fossil record shows an enormous increase in the diversity of life forms during this time. During the Cambrian Period, the oceans teemed with many types of animals, including worms, sea stars, and unusual arthropods, similar to the one shown in ***Figure 14.7.***

During the first half of the Paleozoic, fishes, the oldest animals with backbones, appeared in Earth's waters. There is also fossil evidence of ferns and early seed plants existing on land about 400 million years ago. Around the middle of the Paleozoic, four-legged animals such as amphibians appeared on Earth. During the last half of the era, the fossil record shows that reptiles appeared and began to flourish on land.

The largest mass extinction recorded in the fossil record marked the end of the Paleozoic. About 90 percent of Earth's marine species and 70 percent of the land species disappeared at this time.

Life in the Mesozoic

The Mesozoic Era began about 248 million years ago, which would be about December 10 on the hypothetical one-year calendar. Many changes, in both Earth's organisms and its geology, occurred over the span of this era.

Figure 14.6
Fossils of stromatolites, similar to the modern Australian examples shown here, provide evidence that photosynthetic cyanobacteria lived on Earth 3.4 billion years ago.

The Mesozoic Era is divided into three periods. Fossils from the Triassic Period, the oldest period, show that mammals appeared on Earth at this time. These fossils of mammals indicate that early mammals were small and mouselike. They probably scurried around in the shadows of huge fern forests, trying to avoid dinosaurs, reptiles that also appeared during this time.

The middle of the Mesozoic, called the Jurassic Period, began about 206 million years ago, or mid-December on the hypothetical calendar.

Recent fossil discoveries support the idea that modern birds evolved from one of the groups of dinosaurs toward the end of this period.

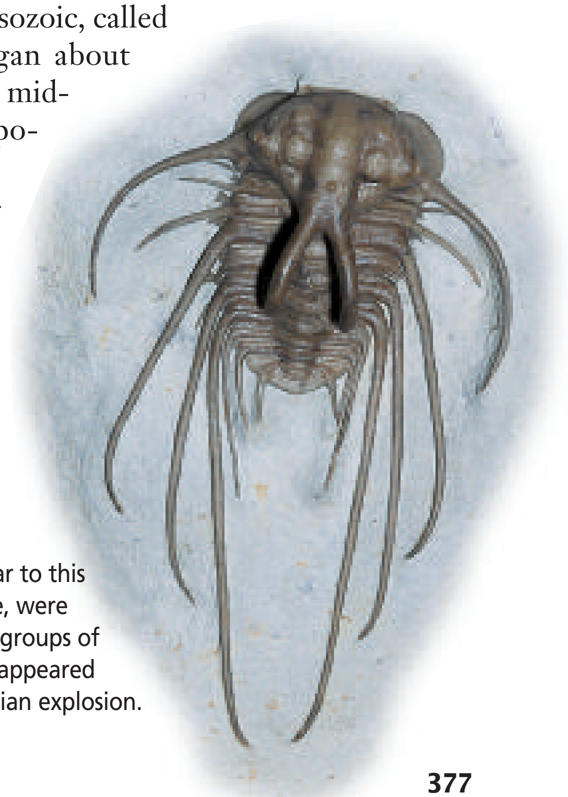


Figure 14.7
Arthropods, similar to this Devonian trilobite, were among the many groups of animals that first appeared during the Cambrian explosion.

(t)Fred Bavendam/Peter Arnold, Inc., (b0Ken Lucas/Visuals Unlimited

Figure 14.8
Both fossil evidence like this *Archaeopteryx* **(A)** and some characteristics of present-day birds like this hoatzin **(B)** suggest that dinosaurs might have been the ancestors of today's birds.

For example, in ***Figure 14.8A,*** you see the fossil of *Archaeopteryx*, a small bird discovered in Germany. The fossil reveals that *Archaeopteryx* had feathers, a birdlike feature. You also see a present-day bird, the hoatzin, in ***Figure 14.8B.*** This bird has a reptilian feature, claws on its wings, for its first few weeks of life. It also flies poorly, as the earliest birds probably did. Scientists suggest that such evidence supports the idea that modern birds evolved from dinosaurs.

Word Origin

tectonics from the Greek word *tecton,* meaning "builder"; Plate tectonics is a theory that explains mountain building.

A mass extinction

The last period in the Mesozoic, the Cretaceous, began about 144 million years ago. During this period, many new types of mammals appeared and flowering plants flourished on Earth. The mass extinction of the dinosaurs marked the end of the Cretaceous Period about 65 million years ago. Scientists estimate that not only dinosaurs, but more than two-thirds of all living species at the time became extinct. Some scientists propose that a large meteorite collision caused this mass extinction. Such a collision could have filled the atmosphere with thick, possibly toxic dust that, in turn, changed the climate to one in which many species could no longer survive. Based on geological evidence of a large crater of Cretaceous age in the waters off eastern Mexico, scientists theorize that this was the impact site.

Changes during the Mesozoic

Geological events during the Mesozoic changed the places in which species lived and affected their distribution on Earth. The theory of continental drift, which is illustrated in ***Figure 14.9***, suggests that Earth's continents have moved during Earth's history and are still moving today at a rate of about six centimeters per year. This is about the same rate at which your hair grows. Early in the Mesozoic, the continents were merged into one large landmass. During the era, this supercontinent broke up and the pieces drifted apart.

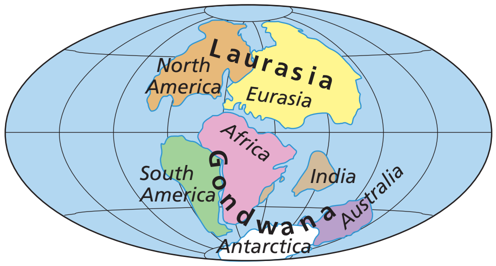
(l)Louis Psihoyos/Matrix, (r)Michael Dick/Animals Animals

The theory that explains how the continents move is called **plate tectonics** (tek TAH nihks). According to this idea, Earth's surface consists of several rigid plates that drift on top of a plastic (capable of flow), partially molten layer of rock. These plates are continually moving—spreading apart, sliding by, or pushing against each other. The movements affect organisms. For example, after a long time, the descendants of organisms living on plates that are moving apart may be living in areas with very different climates.

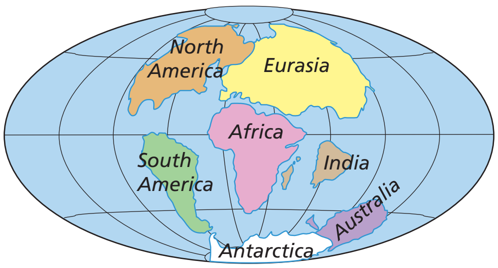
The Cenozoic Era

The Cenozoic began about 65 million years ago—around December 26 on the hypothetical calendar of Earth's history. It is the era in which you now live. Mammals began to flourish during the early part of this era. Among the mammals that appeared was a group of animals to which you belong, the primates. Primates first appeared approximately more than 65 million years ago and have diversified greatly. The modern human species appeared perhaps as recently as 200 000 years ago. On the hypothetical calendar of Earth's history, 200 000 years ago is late in the evening of December 31.

A About 245 million years ago, the continents were joined in a landmass known as Pangaea.



B By 135 million years ago, Pangaea broke apart resulting in two large landmasses.



C By 65 million years ago, the end of the Mesozoic, most of the continents had taken on their modern shapes.

Figure 14.9
The theory of continental drift describes the movement of the landmasses over geological time.
Describe ***How has Africa moved over time?***

Section Assessment

Understanding Main Ideas

1. Describe what some scientists propose Earth was like before life arose.
2. Why are most fossils found in sedimentary rocks?
3. Using fossils, identify evidence showing that species have changed over geologic time.
4. Explain the difference between relative dating and radiometric dating.

Thinking Critically

5. Suppose you are examining layers of sedimentary rock. In one layer, you discover the remains of an extinct relative of the polar bear. In a deeper layer, you discover the fossil of an extinct alligator. What can you hypothesize about changes over time in this area's environment?

Skill Review

6. **Make and Use Tables** Make a table listing the four major divisions of the geologic time scale, their time spans, and the major life forms that appeared during each interval. Use the information to construct a time line based on a clock face. For more help, refer to *Make and Use Tables* in the **Skill Handbook.**

Section
14.2

The Origin of Life

California Standards Standard 1b Students will identify and communicate sources of unavoidable experimental error.

SECTION PREVIEW

Objectives

Analyze early experiments that support the concept of biogenesis.

Review, analyze, and critique modern theories of the origin of life.

Relate hypotheses about the origin of cells to the environmental conditions of early Earth.

Review Vocabulary

prokaryotes: unicellular organisms that lack internal membrane-bound structures (p. 173)

New Vocabulary

spontaneous generation
biogenesis
protocell
archaebacteria

Mold and Mudskippers

Using Prior Knowledge You've probably opened your refrigerator and found some leftovers with an unpleasant surprise—mold. Where did the mold come from? Was it in the air or in the food originally? Did these mudskippers come from the mud or from the air?

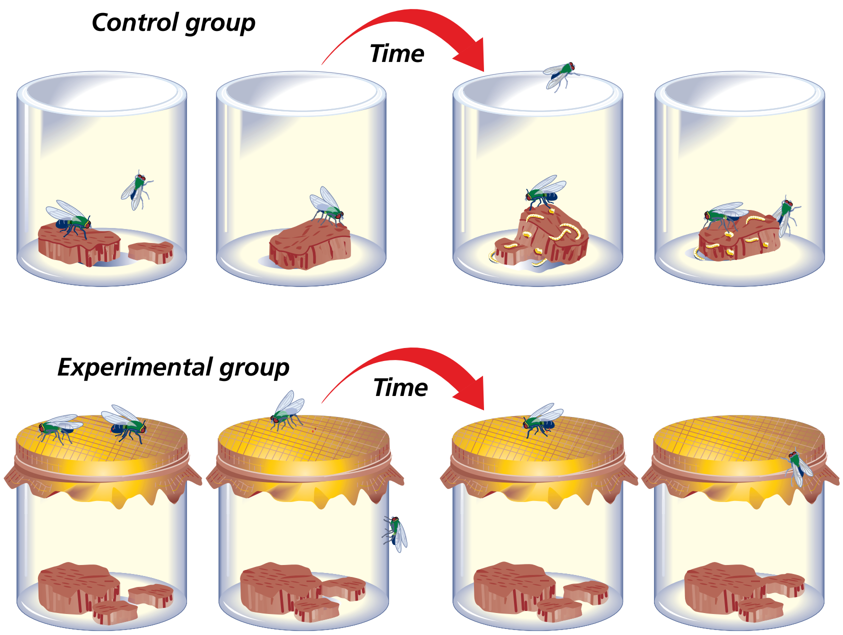
Mudskippers

Experiment *Cut a hot dog in half. Cook one half and place it in an airtight, sealable plastic bag. Place the uncooked half in another airtight, sealable plastic bag. Leave both bags out at room temperature until a change is observed. How did each hot dog sample change? Which sample changed faster? Hypothesize why the changes you observed occurred.*

Origins: The Early Ideas

In the past, the ideas that decaying meat produced maggots, mud produced fishes, and grain produced mice were reasonable explanations for what people observed occurring in their environment. After all, they saw maggots appear on meat and young mice appear in sacks of grain. Such observations led people to believe in **spontaneous generation**—the idea that nonliving material can produce life.

Figure 14.10
Francesco Redi's controlled experiment tested the spontaneous generation of maggots from decaying meat.



A Redi placed decaying meat in several uncovered control jars and in covered experimental jars. The covers prevented flies from landing on the meat.

B In time, maggots and flies filled the open jars, but not the covered jars, showing that only flies produce flies.

Fletcher & Baylis/Photo Researchers

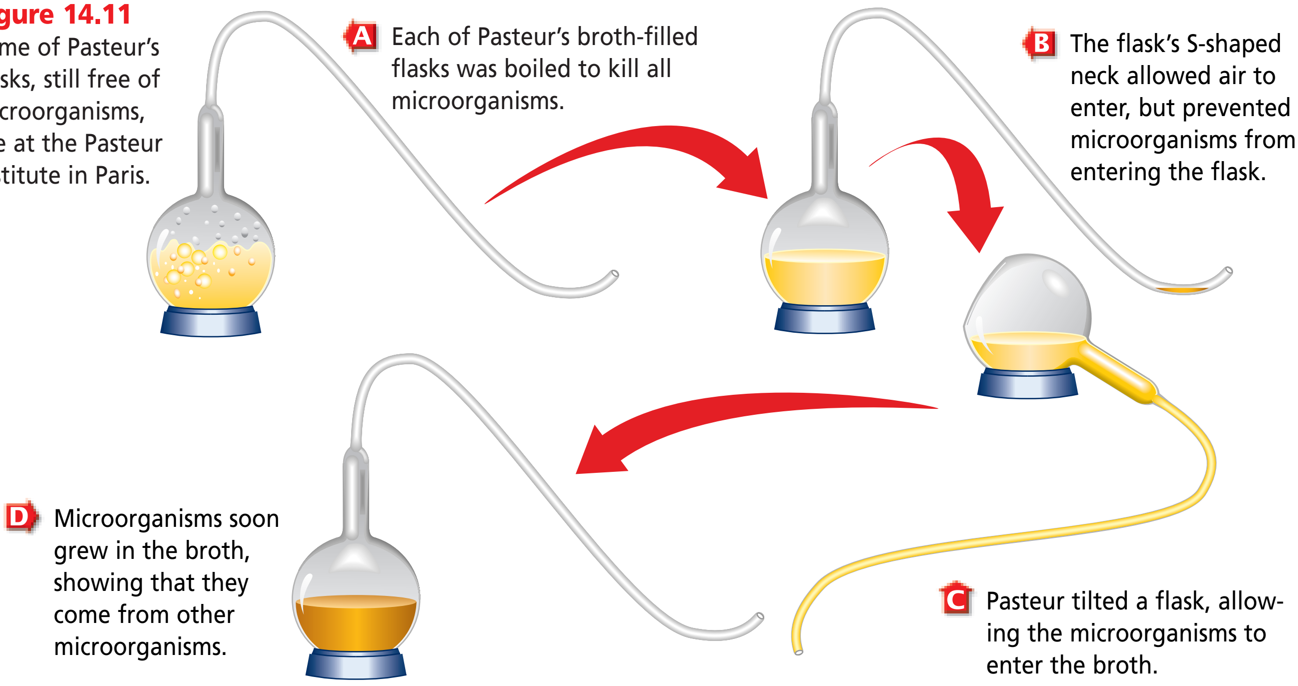


Figure 14.11 Some of Pasteur's flasks, still free of microorganisms, are at the Pasteur Institute in Paris.

Spontaneous generation is disproved

In 1668, an Italian physician, Francesco Redi, disproved a commonly held belief at the time—the idea that decaying meat produced maggots, which are immature flies. You can follow the steps of Redi's experiment in ***Figure 14.10.*** Redi's well-designed, controlled experiment successfully convinced many scientists that maggots, and probably most large organisms, did not arise by spontaneous generation.

However, during Redi's time, scientists began to use the latest tool in biology—the microscope. With the microscope, they saw that microorganisms live everywhere. Although Redi had disproved the spontaneous generation of large organisms, many scientists thought that microorganisms were so numerous and widespread that they must arise spontaneously—probably from a vital force in the air.

Pasteur's experiments

Disproving the existence of a vital force in air proved difficult. Finally, in the mid-1800s, Louis Pasteur designed an experiment that disproved the spontaneous generation of microorganisms. Pasteur set up an experiment in which air, but no microorganisms, was allowed to contact a broth that contained nutrients. You can see how Pasteur carried out his experiment in ***Figure 14.11.***

Pasteur's experiment showed that microorganisms do not simply arise in broth, even in the presence of air. From that time on, **biogenesis** (bi oh JEN uh sus), the idea that living organisms come only from other living organisms, became a cornerstone of biology.

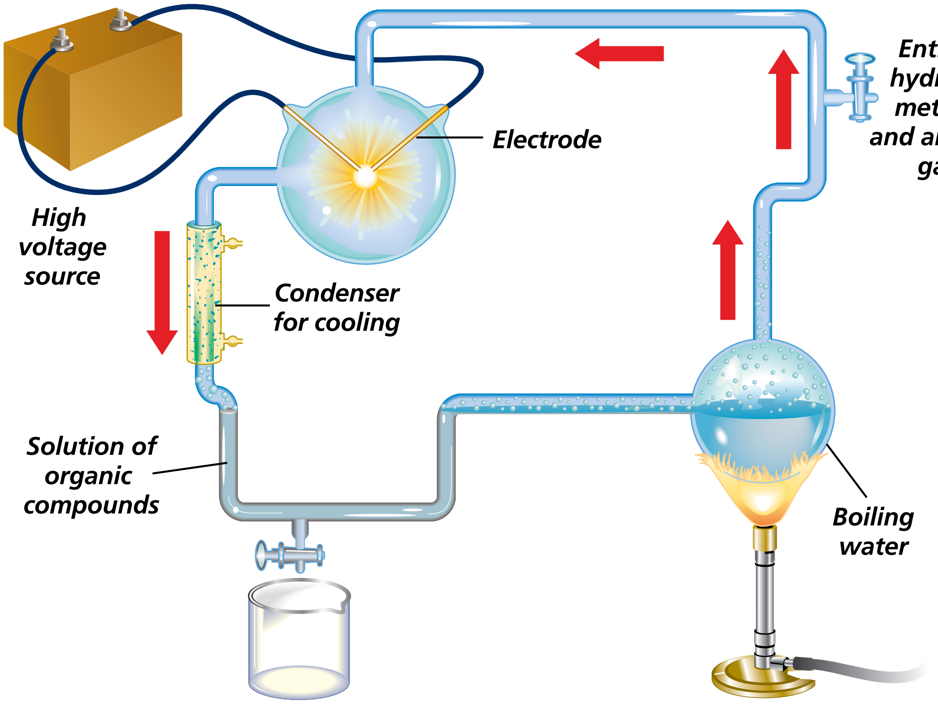
Origins: The Modern Ideas

Biologists have accepted the concept of biogenesis for more than 100 years. However, biogenesis does not answer the question: How did life begin on Earth? No one has yet proven scientifically how life on Earth began. However, scientists have developed theories about the origin of life

Word Origin

biogenesis from the Greek word *bios,* meaning "life," and the Latin word *genesis,* meaning "birth"; Biogenesis proposes that living organisms come only from other living organisms.

Figure 14.12
Miller and Urey's experiments showed that under the proposed conditions on early Earth, small organic molecules, such as amino acids, could form.



on Earth from testing scientific hypotheses about conditions on early Earth. The *Biology and Society* at the end of this chapter summarizes some important viewpoints about the origin of life on Earth.

Simple organic molecules formed

Scientists hypothesize that two developments must have preceded the appearance of life on Earth. First, simple organic molecules, or molecules that contain carbon, must have formed. Then these molecules must have become organized into complex organic molecules such as proteins, carbohydrates, and nucleic acids that are essential to life.

Remember that Earth's early atmosphere probably contained no free oxygen. Instead, the atmosphere was probably composed of water vapor, carbon dioxide, nitrogen, and perhaps methane and ammonia. Many scientists have tried to explain how these substances could have joined together and formed the simple organic molecules that are found in all organisms today.

In the 1930s, a Russian scientist, Alexander Oparin, hypothesized that life began in the oceans that formed on early Earth. He suggested that energy from the sun, lightning, and Earth's heat triggered chemical reactions to produce small organic molecules from the substances present in the atmosphere. Then, rain probably washed the molecules into the oceans to form what is often called a primordial soup.

In 1953, two American scientists, Stanley Miller and Harold Urey, tested Oparin's hypothesis by simulating the conditions of early Earth in the laboratory. In an experiment similar to the one shown in ***Figure 14.12,*** Miller and Urey mixed water vapor (steam) with ammonia, methane, and hydrogen gases. They then sent an electric current that simulated lightning through the mixture. Then, they cooled the mixture of gases, produced a liquid that simulated rain, and collected the liquid in a flask. After a week, they analyzed the chemicals in the flask and found several kinds of amino acids, sugars, and other small organic molecules, providing evidence that supported Oparin's hypothesis.

Word Origin

primordial from the Latin word *primordium,* meaning "origin"; The origin of life may have been in the primordial soup.

The formation of protocells

The next step in the origin of life, as proposed by some scientists, was the formation of complex organic compounds. In the 1950s, various experiments were performed and showed that if the amino acids are heated without oxygen, they link and form complex molecules called proteins. A similar process produces ATP and nucleic acids from small molecules. These experiments convinced many scientists that complex organic molecules might have originated in pools of water where small molecules had concentrated and been warmed.

How did these complex chemicals combine to form the first cells? The work of American biochemist Sidney Fox in 1992 showed how the first cells may have occurred. As you can see in ***Figure 14.13,*** Fox produced protocells by heating solutions of amino acids. A **protocell** is a large, ordered structure, enclosed by a membrane, that carries out some life activities, such as growth and division.

Reading Check **Summarize** the theories for how organic molecules were first formed on Earth.

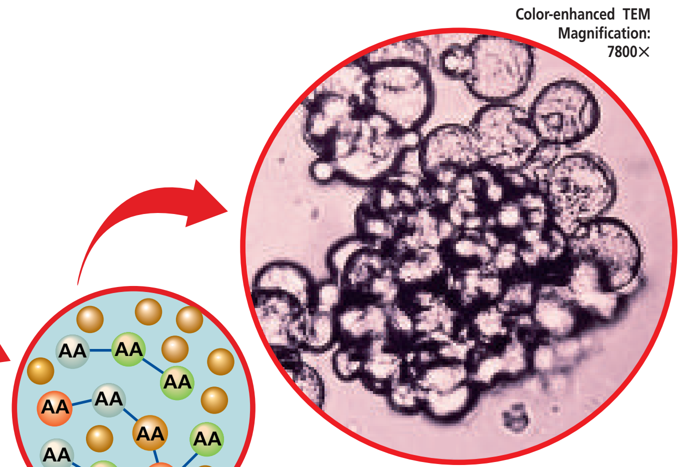
The Evolution of Cells

Fossils indicate that by about 3.4 billion years ago, photosynthetic prokaryotic cells existed on Earth. But these were probably not the earliest cells. What were the earliest cells like, and how did they evolve?

The first true cells

The first forms of life may have been prokaryotic forms that evolved from a protocell. Because Earth's atmosphere lacked oxygen, scientists have proposed that these organisms were most likely anaerobic. For food, the first prokaryotes probably used some of the organic molecules that were abundant in Earth's early oceans. Because they obtained food rather than making it themselves, they would have been heterotrophs.

Over time, these heterotrophs would have used up the food supply. However, organisms that could make food had probably evolved by the time the food was gone. These first autotrophs were probably similar to present-day archaebacteria.



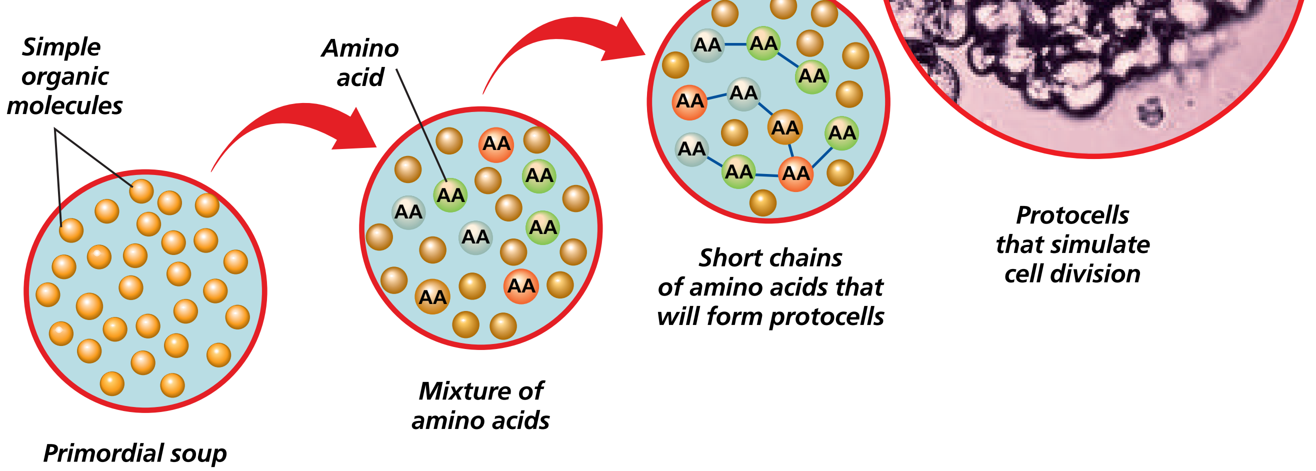


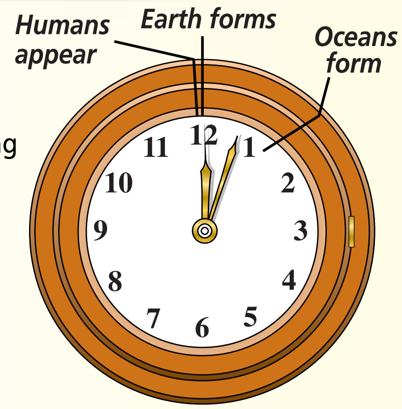
Figure 14.13
Sidney Fox showed how short chains of amino acids could cluster to form protocells.

Sidney Fox/Visuals Unlimited

Problem-Solving Lab 14.2

Interpret Data

Can a clock model Earth's history? As a result of studying fossils and analyzing geological events, scientists have been able to construct the geologic time scale, a timetable that shows the appearance of organisms during the history of Earth.



Solve the Problem

The diagram shown here compresses the history of Earth into a 12-hour clock face. On the clock, assume that the formation of Earth occurred at midnight. The oceans formed at 1:00 A.M. Use this information to help you answer the following questions.

Thinking Critically

Use Models Based on fossil evidence, at what time on the face of the clock did prokaryotes evolve? At what time did the first eukaryotes appear?

Figure 14.14
Present-day archaebacteria live in places like this hot spring in Yellowstone National Park. **Infer** ***What adaptations would an organism need to survive in this environment?***

Comstock/George Gerster

Archaebacteria (ar kee bac TEER ee uh) are prokaryotic and live in harsh environments, such as deep-sea vents and hot springs like the one shown in ***Figure 14.14.*** Some early autotrophs may have made glucose by chemosynthesis rather than by photosynthesis, which requires light-trapping pigments. These autotrophs released the energy of inorganic compounds, such as sulfur compounds, in their environment to make their food.

Photosynthesizing prokaryotes

Eventually, photosynthesizing prokaryotes capable of releasing oxygen from water evolve. Recall that the process of photosynthesis produces oxygen. As the first photosynthetic organisms increased in number, the concentration of oxygen in Earth's atmosphere began to increase. Organisms that could respire aerobically would have evolved and thrived. In fact, the fossil record indicates that there was a large increase in the diversity of prokaryotic life about 2.8 billion years ago.

The presence of oxygen in Earth's atmosphere probably affected life on Earth in another important way. The sun's rays would have converted much of the oxygen into ozone molecules that would then have formed a layer that contained more ozone than the rest of the atmosphere. The ozone layer, that now exists 10 to 15 miles (16–24 km) above Earth's surface, probably shielded organisms from the harmful effects of ultraviolet radiation and enabled the evolution of more complex organisms, the eukaryotes.

The endosymbiont theory

Complex eukaryotic cells probably evolved from prokaryotic cells. Use the *Problem-Solving Lab* on this page to determine how long the event might have taken. The endosymbiont theory,

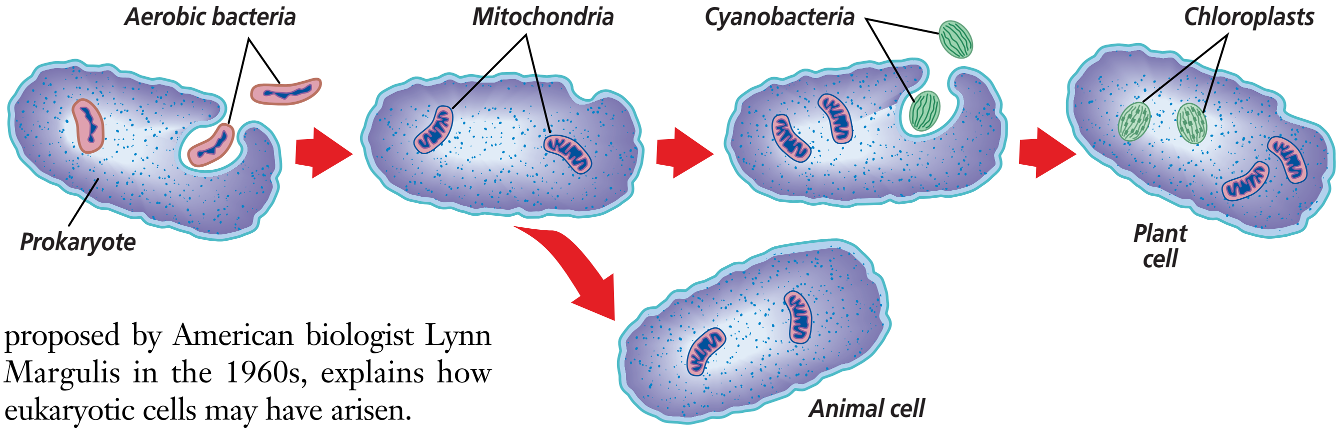
Figure 14.15
The eukaryotic cells of plants and animals probably evolved by endosymbiosis.

A A prokaryote ingested some aerobic bacteria. The aerobes were protected and produced energy for the prokaryote.

B Over a long time, the aerobes become mitochondria, no longer able to live on their own.

C Some primitive prokaryotes also ingested cyanobacteria, which contain photosynthetic pigments.

D The cyanobacteria become chloroplasts, no longer able to live on their own.



proposed by American biologist Lynn Margulis in the 1960s, explains how eukaryotic cells may have arisen.

The endosymbiont (en doh SIHM bee ont) theory as shown in ***Figure 14.15***, proposes that eukaryotes evolved through a symbiotic relationship between ancient prokaryotes. Margulis based her hypothesis on observations and experimental evidence of present-day unicellular organisms. For example, some bacteria that are similar to cyanobacteria and chloroplasts resemble each other in size and in the ability to photosynthesize. Likewise, mitochondria and some bacteria look similar. Experimental evidence revealed that both chloroplasts and mitochondria contain DNA that is similar to the DNA in prokaryotes and unlike the DNA in eukaryotic nuclei.

New evidence from scientific research supports this theory and has shown that chloroplasts and mitochondria have their own ribosomes that are similar to the ribosomes in prokaryotes. In addition, both chloroplasts and mitochondria reproduce independently of the cells that contain them. The fact that some modern prokaryotes live in close association with eukaryotes also supports the theory.

Section Assessment

Understanding Main Ideas

1. How did Pasteur's experiment finally disprove spontaneous generation?
2. Review Oparin's hypothesis and explain how it was tested experimentally.
3. Why do scientists think the first living cells to appear on Earth were probably anaerobic heterotrophs?
4. How would the increasing number of photosynthesizing organisms on Earth have affected both Earth and its other organisms?

Thinking Critically

5. Some scientists speculate that lightning was not present on early Earth. How could you modify the Miller-Urey experiment to reflect this new idea? What energy source would you use to replace lightning?

Skill Review

6. **Sequence** Make a flowchart sequencing the evolution of life from protocells to eukaryotes. For more help, refer to *Sequence* in the **Skill Handbook.**

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INVESTIGATE

BioLab

Determining a Rock's Age

Before You Begin

To date a rock using a radioactive isotope, the half-life of the radioactive isotope and the isotope formed when the radioactive isotope decays must be known. Also, the amount of the radioactive isotope in the rock when it formed and the amount of radioactive isotope currently in the rock must be measured. For example, the half-life of K-40 to decay to Ar-40 is 1.3 billion years. When rocks form, they contain no Ar-40, so measuring the amounts of K-40 and Ar-40 currently in a rock gives the inital amount of K-40 in the rock. Then the age of the rock can be calculated.

PREPARATION

Problem

How can you simulate radioactive half-life?

Objectives

In this BioLab you will:

- **Formulate Models** Simulate the radioactive decay of K-40 into Ar-40 with pennies.
- **Collect Data** Collect data to determine the amount of K-40 present after several half-lives.
- **Make and Use Graphs** Graph your data and use its values to determine the age of rocks.

Materials

shoe box with lid
100 pennies
graph paper

Skill Handbook

If you need help with this lab, refer to the **Skill Handbook.**

PROCEDURE

1. Copy the data table.
2. Place 100 pennies in a shoe box.
3. Arrange the pennies so that their "head" sides are facing up. Each "head" represent an atom of K-40, and each "tail" an atom of Ar-40.
4. Record the number of "heads" and "tails" present at the start of the experiment. Use the row marked "0" in the data table.
5. Cover the box. Then shake the box well. Let the shake represent one half-life of K-40, which is 1.3 billion years.
6. Remove the lid and record the number of "heads" you see facing up. Remove all the "tail" pennies.
7. To complete the first trial, repeat steps 5 and 6 four more times.
8. Run two more trials and determine an average for the number of "heads" present at each half-life.

(l)file photo, (r)Matt Meadows

Data Table

Number of Shakes (half-lives)	Number of Heads (K-40 atoms left)				
	Trial 1	Trial 2	Trial 3	Totals	Average
0					
1					
2					
3					
4					
5					

9. Draw a full-page graph. Plot your average values on the graph. Plot the number of half-lives for K-40 on the *x* axis and the number of "heads" on the *y* axis. Connect the points with a line. Remember, each half-life mark on the graph axis for K-40 represents 1.3 billion years.
10. **CLEANUP AND DISPOSAL** Return everything to its proper place for reuse. Wash hands thoroughly.

ANALYZE AND CONCLUDE

1. **Apply Concepts** What symbol represented an atom of K-40 in this experiment? What symbol represented an atom of Ar-40?
2. **Think Critically** Compare the numbers of protons and neutrons of K-40 and Ar-40. (Consult the Periodic Table on page 1112 for help.) Can Ar-40 change back to K-40? Explain your answer, pointing out what procedural part of the experiment supports your answer.
3. **Define Operationally** Define the term half-life. What procedural part of the simulation represented a half-life period of time in the experiment?
4. **Communicate** Explain how scientists use radioactive dating to approximate a rock's age.
5. **Make and Use Graphs** You are attempting to determine the age of a rock sample. Use your graph to read the rock's age if it has:
   a. 70% of its original K-40 amount.
   b. 35% of its original K-40 amount.
   c. 10% of its original K-40 amount.
6. **ERROR ANALYSIS** Could the size of the box and how vigorously the box was shaken introduce errors into the data? Explain.

Apply Your Skill

Graph Suppose you had calculated the same data for an element with a half-life of 5000 years rather than 1.3 billion years. Plot a graph for the hypothetical isotope. How do the graphs compare?

Web Links To find out more about radioactive dating, visit ca.bdol.glencoe.com/radioactive_dating

The Origin of Life

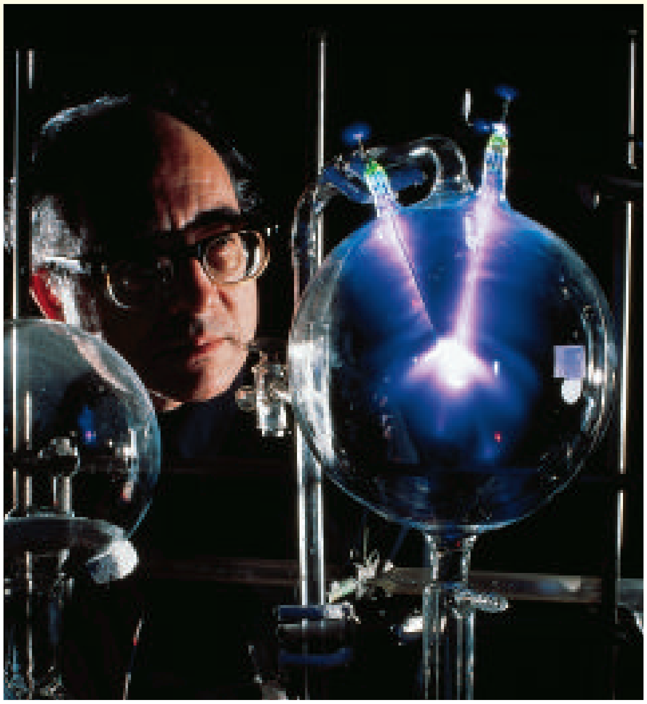
How life originated on Earth is a fascinating and challenging question. Many have proposed answers, but the mystery remains unsolved. Because it is impossible to travel in time, the question of how life originated on Earth might never be answered. However, a number of beliefs and hypotheses exist. Some of these are described below.

Divine origins Common to human cultures throughout history is the belief that life on Earth did not arise spontaneously. Many of the world's major religions teach that life was created on Earth by a supreme being. The followers of these religions believe that life could only have arisen through the direct action of a divine force.

A variation of this belief is that organisms are too complex to have developed only by evolution. Instead, some people believe that the complex structures and processes of life could not have formed without some guiding intelligence.

Meteorites One scientific hypothesis about the origin of life on Earth is that the molecules necessary for life arrived here on meteorites, rocks from space that collide with Earth's surface. Many meteorites contain some organic matter. These organic molecules, which are necessary for the formation of cells, might have arrived on Earth and entered its oceans.

Primordial soup Another hypothesis was proposed by A. I. Oparin. It states that Earth's ancient atmosphere contained the gases nitrogen, methane, and ammonia, but no free oxygen. Energy from the sun, volcanoes, and lightning caused chemical reactions among these gases, which eventually combined into small organic molecules such as amino acids. Rain trapped and then carried these molecules into the oceans, making a primordial soup of organic molecules. In this soup, proteins, lipids, and the other complex organic molecules found in present-day cells formed. Harold Urey and Stanley Miller



Stanley Miller

provided the first experimental evidence to support this idea. They produced organic molecules in the laboratory by creating a spark in a gas mixture similar to Earth's early atmosphere.

An RNA world Some scientists hypothesize that the formation of self-replicating molecules preceded the formation of cells. Today's self-replicating molecules, DNA and RNA, provide clues about the earliest self-replicating molecules. Scientists hypothesize that RNA, which is central to the functioning of a cell, probably predated DNA on Earth. However, because RNA is a more complex molecule than protein, it is not easy to obtain data that supports the idea that RNA was formed on early Earth.

Forming Your Opinion

Review, analyze, and critique the different ideas about the origin of life presented here. Consider strengths and weaknesses during your review.

To find out more about the origin of life, visit ca.bdol.glencoe.com/biology_society

Roger Ressmeyer/Starlight

Chapter 14 Assessment

Study Guide

Section 14.1

The Record of Life

Key Concepts

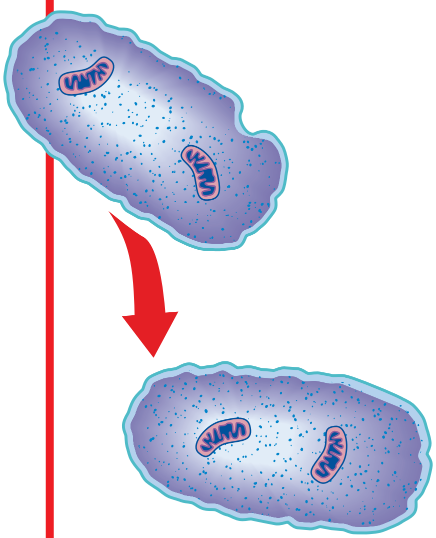
- Fossils provide a record of life on Earth. Fossils come in many forms, such as a leaf imprint, a worm burrow, or a bone.
- By studying fossils, scientists learn about the diversity of life and about the behavior of ancient organisms.
- Fossils can provide information on ancient environments. For example, fossils can help to predict whether an area had been a river environment, terrestrial environment, or a marine environment. In addition, fossils may provide information on ancient climates.
- Earth's history is divided into the geologic time scale, based on evidence in rocks and fossils.
- The four major divisions in the geologic time scale are the Precambrian, Paleozoic Era, Mesozoic Era, and Cenozoic Era. The eras are further divided into periods.

Vocabulary

fossil (p. 370)
plate tectonics (p. 379)

Section 14.2

The Origin of Life



Key Concepts

- Francesco Redi and Louis Pasteur designed controlled experiments to disprove spontaneous generation. Their experiments and others like them convinced scientists to accept biogenesis.
- Small organic molecules might have formed from substances present in Earth's early atmosphere and oceans. Small organic molecules can form complex organic molecules.
- The earliest organisms were probably anaerobic, heterotrophic prokaryotes. Over time, chemosynthetic prokaryotes evolved and then photosynthetic prokaryotes that produced oxygen evolved, changing the atmosphere and triggering the evolution of aerobic cells and eukaryotes.

Vocabulary

archaebacteria (p. 384)
biogenesis (p. 381)
protocell (p. 383)
spontaneous generation (p. 380)

FOLDABLES Study Organizer To help you review the geologic time scale, use the Organizational Study Fold on page 369.

ca.bdol.glencoe.com/vocabulary_puzzlemaker

Jeff J. Daly/Visuals Unlimited

Chapter 14 Assessment

Vocabulary Review

Review the Chapter 14 vocabulary words listed in the Study Guide on page 389. Match the words with the definitions below.

1. prokaryotes that live in harsh environments
2. the idea that nonliving material can produce life
3. evidence of an organism that lived long ago
4. the idea that living organisms come only from other living organisms

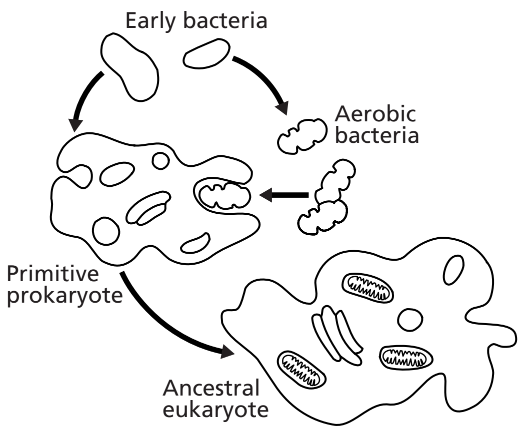
Understanding Key Concepts

5. About how many years ago do scientists suggest that Earth cooled enough for water vapor to condense?
   - **A.** 20 million years
   - **B.** 4.6 billion years
   - **C.** 4.4 billion years
   - **D.** 5.5 billion years
6. Most fossils occur in layers of ________ rocks.
   - **A.** sedimentary
   - **B.** metamorphic
   - **C.** igneous
   - **D.** volcanic
7. Who was the scientist who showed that microscopic life is not produced by spontaneous generation?
   - **A.** Francesco Redi
   - **B.** Stanley Miller
   - **C.** Louis Pasteur
   - **D.** Harold Urey
8. Scientists theorize that oxygen buildup in the atmosphere resulted from ________.
   - **A.** respiration
   - **B.** photosynthesis
   - **C.** chemosynthesis
   - **D.** rock weathering
9. An entire, intact organism may be preserved in ________ and ________.
   - **A.** casts—trace fossils
   - **B.** molds—casts
   - **C.** trace fossils—petrified fossils
   - **D.** amber—ice

Constructed Response

10. **Open Ended** Explain why there might be similar fossils on the east coast of South America and the west coast of Africa.
11. **Open Ended** Why do scientists propose that the 3.4 billion-year-old fossils of cyanobacteria-like prokaryotic cells found in Australia were not the first species to have evolved on Earth?
12. **Open Ended** Explain how fossils might help paleontologists to learn about the important behaviors of different types of animals. Which social behaviors might they provide information about?

Thinking Critically



13. **Interpret Scientific Illustrations** Use the illustration above to explain the endosymbiont hypothesis.
14. **REAL WORLD BIOCHALLENGE** Recent scientific evidence from fossils indicates that feathered dinosaurs may have been a direct ancestor of birds. Visit ca.bdol.glencoe.com to investigate these finds. How do such finds impact our understanding of evolution? Present your findings to the class in a poster or other visual format.
15. **Infer** How might the way organisms obtain energy have evolved over time?
16. **Writing About Biology** Why is knowledge of geology important to paleontologists?
17. **Writing About Biology** Explain why Francesco Redi's experiment with flies did not completely disprove spontaneous generation.

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Chapter 14 Assessment

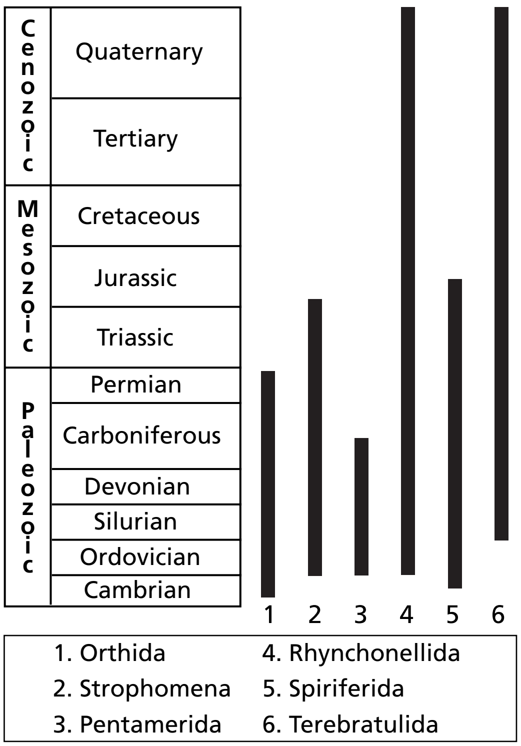
California Standards Practice

All questions aligned and verified by The Princeton Review

Part 1 Multiple Choice

Use the graph to answer questions 18 and 19.

Ranges of Brachiopod (Lamp Shell) Orders



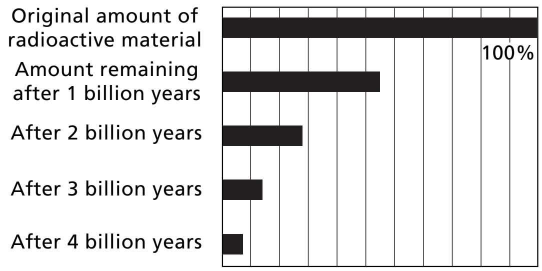
18. Which group of organisms had the shortest history?
A. Orthida
B. Rhynchonellida
C. Terebratulida
D. Pentamerida

19. Which group of organisms evolved first?
A. Orthida
B. Rhynchonellida
C. Terebratulida
D. Pentamerida

20. Which of the following rock types would most likely contain fossils?
A. sedimentary rock composed of limestone
B. igneous rock ejected from a volcano
C. metamorphic rock
D. hardened lava

Study the graph and answer questions 21–24.

Decay Rate of a Radioactive Element



21. How long does it take for half of the element to decay?
A. 1 billion years
B. 2 billion years
C. 3 billion years
D. 4 billion years

22. How much of the original material is left after 4 billion years?
A. 50%
B. 25%
C. 12.5%
D. less than 10%

23. This element would best be used to date fossils that are ________ years old.
A. a few thousand
B. less than a million
C. a few million
D. a billion

Part 2 Constructed Response/Grid In

Record your answers on your answer document.

24. Open Ended The element in the graph above would best be used to date rocks from what era? Explain why.

25. Open Ended What kinds of clues can fossils provide about the past, including climate, what organisms ate, and the environment in which they lived?

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