15 min

Logical Order

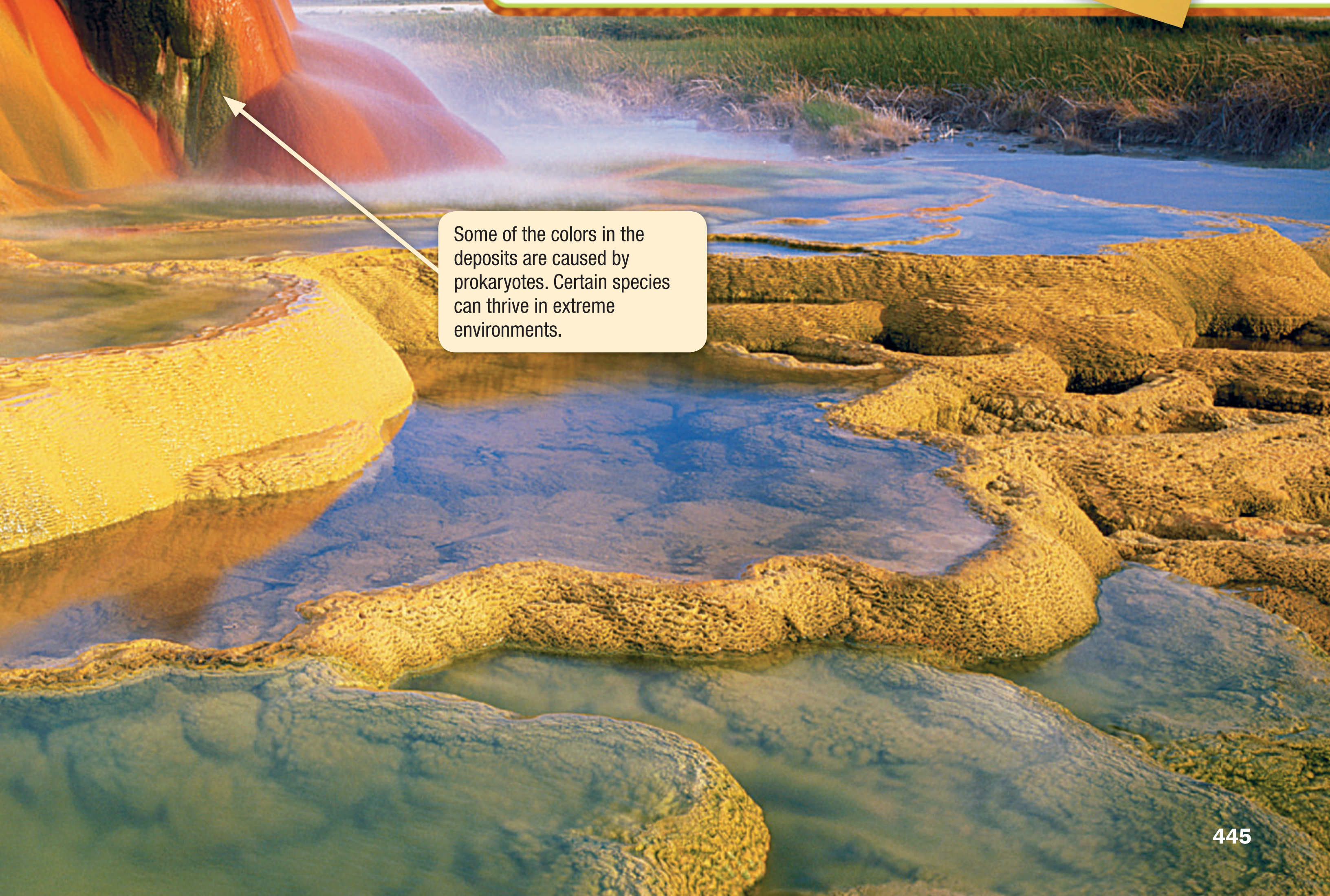
By analyzing overlap in layers of sedimentary rock, scientists reassemble the relative order of much longer sequences of layers.

Procedure

1. Write the following sequence of letters on **six individual index cards** with a **marker:** WXQ, PNB, NBSF, RTK, SFVW, and TKLPN.
2. Look for overlaps in the sequences between individual cards. You can use this overlap to infer the order of the entire series.

Analysis

1. **Sequence** the most likely order of letters in the complete series.
2. **Debate** how the amount of overlap affected how you established this order.
3. **Estimate** how a newly discovered rock sample that had the sequence PNAPN would affect the assembled series.



Some of the colors in the deposits are caused by prokaryotes. Certain species can thrive in extreme environments.

READING TOOLBOX

These reading tools can help you learn the material in this chapter. For more information on how to use these and other tools, see **Appendix: Reading and Study Skills.**

Using Words

Word Parts You can tell a lot about a word by taking it apart and examining its prefix and root.

Your Turn Use the information in the table to write your own definition for the following terms.

1. *microsphere*
2. *lithosphere*
3. *paleolithic*

Word Parts

Word part	Type	Meaning
micro-	prefix	small
paleo-	prefix	ancient
lith	root	rock, stone
sphere	root	ball-shaped object

Using Language

Describing Time Certain words and phrases can help you get an idea of when something happened and for how long it happened. These phrases are called *specific time markers*. Specific time markers include phrases such as 1 hour, yesterday, the 20th century, and 30 years later.

Your Turn Read the sentences below, and write the specific time markers.

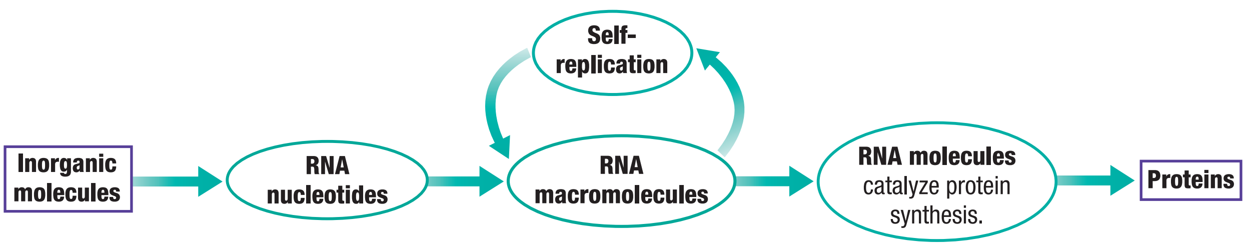
1. Jennifer celebrated her 16th birthday on Saturday two weeks ago.
2. Dinosaurs became extinct about 65 million years ago, at the end of the Cretaceous Period.

Using Science Graphics

Process Chart Process charts show the steps that a process takes to get from one point to another point. Events in a process happen in a certain order. There are many words that can be used to describe the order in which things happen. Some of these words include *first, next, then,* and *last*.

Your Turn Use the diagram to answer the following questions.

1. Which event happens second?
2. Which event follows RNA self-replication?
3. Describe the process illustrated in this chart in paragraph form. Use sequence words to indicate in what order things happen.



Section 1 How Did Life Begin?

Key Ideas	Key Terms	Why It Matters
❯ What did the Miller-Urey experiment show about the formation of the basic molecules of life? ❯ What are two theories that propose where the building blocks of life originated on early Earth? ❯ How could molecules have become packaged into cells that contain heritable cellular instructions?	microsphere ribozyme	Studying the origin of life on Earth allows scientists to discover key biological and chemical processes.

Most scientists think that life on Earth evolved through natural processes. The point when life started likely involved simple chemicals.

The Basic Chemicals of Life

In the 1920s, Russian scientist Aleksandr I. Oparin and British scientist John B. S. Haldane suggested that Earth's early oceans contained large amounts of organic molecules. They proposed that these molecules formed spontaneously in chemical reactions that were activated by energy from the sun, volcanic eruptions, and lightning.

Oparin and American scientist Harold Urey, along with other scientists, hypothesized that the early atmosphere was rich in hydrogen gas, H_2, and hydrogen-containing gases, such as water vapor, H_2O, ammonia, NH_3, and methane, CH_4. They thought that if the atmosphere lacked oxygen gas, a variety of organic compounds made up of the elements found in these gases could form. This hypothesis was tested in the 1950s by Urey and American scientist Stanley Miller.

The Miller-Urey Experiment Urey and Miller placed the gases into a device like the one in **Figure 1.** To simulate lightning, they used electrical sparks. After a few days, they found organic molecules in the device, which included some of life's basic building blocks: amino acids, fatty acids, and other hydrocarbons (molecules made of carbon and hydrogen). ❯ **The Miller-Urey experiment showed that, under certain conditions, organic compounds could form from inorganic molecules.**

We now know that the molecules used in the Miller-Urey experiment could not have existed in abundance on early Earth. Four billion years ago, shortly after Earth formed, it did not have a protective layer of ozone gas. Ultraviolet radiation from the sun would have destroyed any ammonia and methane in the atmosphere when the ozone layer did not exist. When ammonia and methane gases are absent from the Miller-Urey experiment, key biological molecules are not made. However, the Miller-Urey experiment clearly shows that complex biological compounds can form from simple building blocks.

❯ **Reading Check** *What compounds were formed in the Miller-Urey experiment? (See the Appendix for answers to the Reading Checks.)*

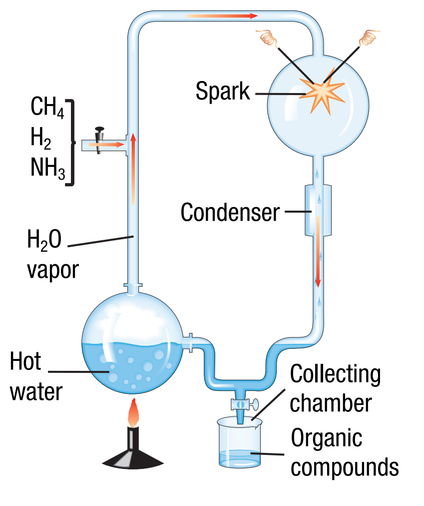


Figure 1 Urey and Miller simulated an atmosphere that Oparin and others incorrectly hypothesized as the atmosphere of early Earth. The experiment produced several organic compounds.

Life's Building Blocks

Scientists agree that the building blocks of life formed under special conditions. They research environments that could have made these molecules. **Among the hypotheses that address the origin of life, one states that early biological molecules formed close to hydrothermal vents. Organic molecules may also have arrived on early Earth in meteorites.**

Hydrothermal Vents Some scientists think that the chemical reactions that produced the first biological molecules occurred in the oceans of early Earth. The heat from hydrothermal vents, shown in **Figure 2,** could have provided energy for chemical reactions. Within the sea, biological molecules also would have been protected from potentially harmful solar radiation.

SCILINKS.
www.scilinks.org
Topic: Origin of Life
Code: HX81083

Space Some scientists think that organic molecules could have arrived on Earth on meteorites or comets. For example, the meteorite shown in **Figure 2** contains amino acids. Organic molecules likely arrived on early Earth from outside of our atmosphere. It is unknown, however, whether these chemicals influenced the history of life on Earth. But we know that such impacts were more frequent in the early history of Earth than they are now.

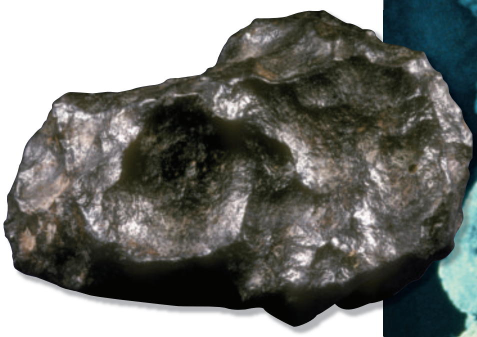
ACADEMIC VOCABULARY

impact collision

The First Cells

Research continues that might provide clues to how biological molecules first began to group together and become packaged into cells. For example, how did amino acids link to form proteins? There are major differences between simple organic molecules and the large organic molecules found in living cells. Research has shown that amino acids can form proteins under certain conditions.

Forming a Cell How did molecules become packaged together inside a cell membrane? To answer this question, scientists have studied the behavior of organic molecules in water. Lipids, which make up cell membranes, tend to combine in water. Certain lipids, when combined with other molecules, can form a tiny droplet that has a surface that resembles a cell membrane.



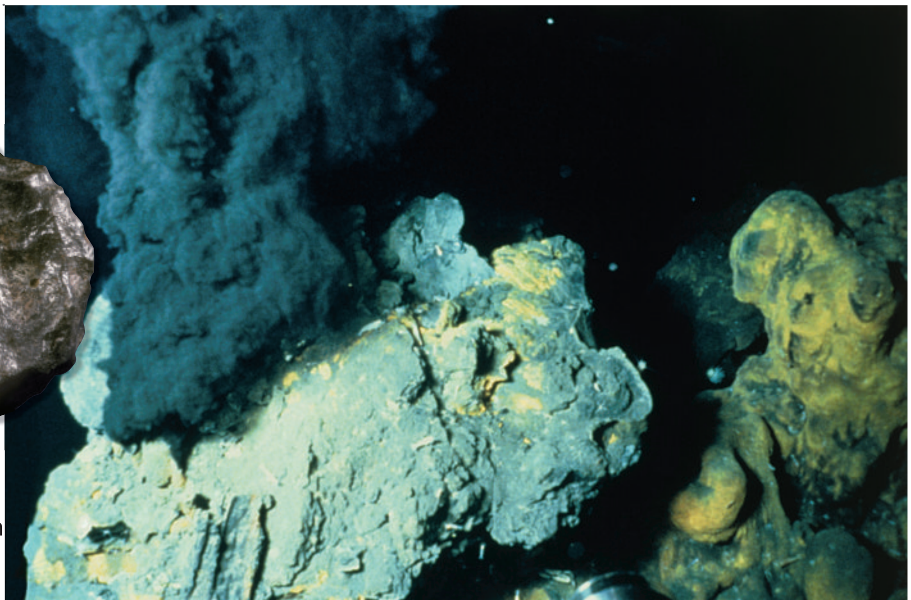


Figure 2 Scientists have suggested that the basic chemicals of life could have originated in deep-sea vents or from outside our atmosphere. **Why do scientists study the conditions around hydrothermal vents?**

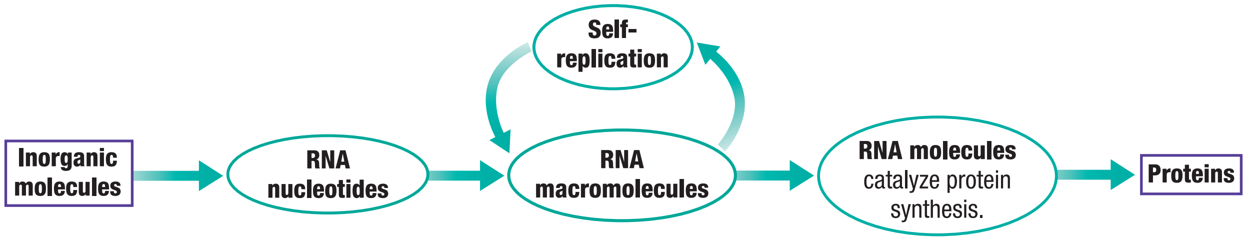


Figure 3 In this proposed model of protein formation, chemical reactions between inorganic molecules formed RNA nucleotides. The nucleotides assembled into large RNA molecules which were able to replicate and to catalyze the formation of proteins.

Further research has shown that, in water, lipids can form tiny spherical structures called **microspheres** that act like a membrane. **Many scientists think that the formation of microspheres may have been the first step toward cellular organization.** Microspheres could not be considered cells, however, unless they had characteristics of living things, including heredity.

Origin of Heredity How did heredity begin? Recall that our DNA contains instructions for making proteins. DNA is also passed on from one generation to the next. In the laboratory, scientists have not been able to make most proteins or DNA form spontaneously in water. However, scientists have been able to form short chains of RNA, the nucleic acid that helps carry out the instructions of DNA, in water.

Scientists now know that RNA molecules perform many tasks in a cell. There are several types of RNA that accomplish these tasks. Each type of RNA has a unique structure that relates to its function. In the 1980s, American scientists Thomas Cech and Sidney Altman found that a certain type of RNA molecule, called a **ribozyme,** can act like an enzyme. Also, they showed that RNA can form spontaneously in water, without DNA. Other scientists have hypothesized that RNA was the first self-replicating molecule that stored information and that catalyzed the formation of the first proteins. One idea of how RNA could have been involved in protein synthesis is shown in **Figure 3.** It was further hypothesized that RNA could have changed—evolved—from one generation to the next. Scientists hypothesize that DNA and proteins eventually took over these roles in the cell.

Reading Check *Explain how RNA could have existed before DNA.*

READING TOOLBOX

Process Chart Use the process chart in **Figure 3** to understand the hypothesis about how proteins were created. What is the significance of the loop at the self-replication step?

microsphere (MIE kroh SFIR) a hollow microscopic spherical structure that is usually composed of proteins or a synthetic polymer

ribozyme (RIE buh ZIEM) a type of RNA that can act as an enzyme

Section 1 Review

KEY IDEAS

1. **State** what the Miller-Urey experiment demonstrated.
2. **Describe** two theories that address where the building blocks of life evolved.
3. **Explain** a prevailing theory of how cells evolved.

CRITICAL THINKING

4. **Evaluating Conclusions** People once believed fish could form from the mud in a pond that sometimes dried up. How could you demonstrate that this conclusion is false?
5. **Inferring Conclusions** How might the hypothesis about the origin of heredity change if DNA could form spontaneously in water?

USING SCIENCE GRAPHICS

6. **Analyzing Models** Using **Figure 1,** determine what changes to the apparatus used by Miller and Urey would be necessary to model the production of amino acids and other organic compounds near hydrothermal vents.

Section 2

The Age of Earth

Key Ideas	Key Terms	Why It Matters
How is the fossil record used to chronicle the history of life? How do paleontologists date fossils? What evidence was used to make the geologic time scale?	fossil record relative dating radiometric dating half-life geologic time scale mass extinction	The fossil record is used to understand the diversity of life on Earth.

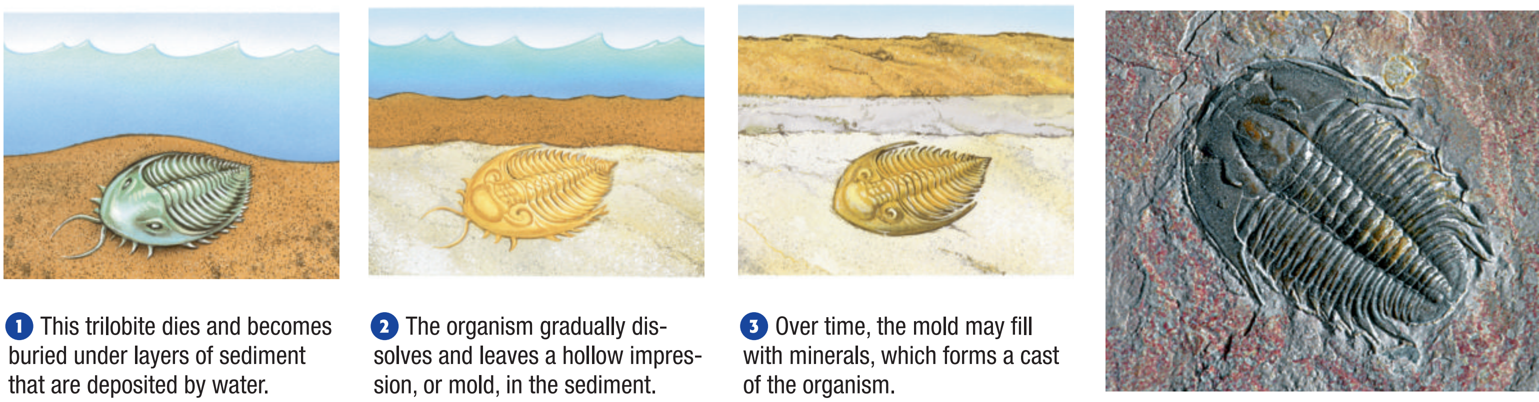
Scientists think Earth formed more than 4.5 billion years ago. Fossil evidence indicates that for much of that long history, Earth has been the home of living things.

The Fossil Record

The **fossil record** includes all fossil remains of living things on Earth. **Both the geographical distribution of organisms and when they lived on Earth can be inferred from the fossil record. It chronicles the diversity of life on Earth.** The fossil record also provides evidence of intermediate forms of life and suggests how organisms are related to each other. Although our examination of the fossil record will never be complete, it presents strong evidence that evolution has taken place.

How Fossils Form Most fossils are found in sedimentary rock. These fossils form when organisms and traces of organisms are rapidly buried in fine sediments that are deposited by water, wind, or volcanic eruptions. The formation of one kind of fossil from a marine animal is shown in **Figure 4.** Environments that often cause fossil formation are wet lowlands, slow-moving streams, lakes, shallow seas, and areas near volcanoes that spew volcanic ash. However, many species have lived in environments where fossils do not form. Even if an organism lives in an environment where fossils can form, its dead body might not be buried in sediment before it decays or is eaten.

Figure 4 Fossils can form in several ways. The most common way is when an organism dies and is buried in sediment. **What happens when an organism is covered by sediment?**



1 This trilobite dies and becomes buried under layers of sediment that are deposited by water.

2 The organism gradually dissolves and leaves a hollow impression, or mold, in the sediment.

3 Over time, the mold may fill with minerals, which forms a cast of the organism.

Analyzing Fossil Evidence

Earth's surface changes constantly. Rocks are eroding and are laid down as sediment. This sediment forms layers of sedimentary rock called *strata,* shown in **Figure 5.** According to the *principle of superposition,* older strata are covered by younger strata. However, geologic events such as earthquakes can affect how the strata are arranged. **In order to analyze fossil evidence, paleontologists use both relative and absolute dating methods to date fossils.**

Types of Fossils The most common types of fossils are little-altered mineral shells of animals. In some cases, as shown in **Figure 4,** an organism breaks down, leaving a hollow space. This mold may fill with minerals. In other cases, the pores of the organism are filled with minerals, preserving the shape of the organism. An example of a mineralized fossil is shown in **Figure 5.** In rare cases, fossils are preserved in hardened plant sap, or amber. In these fossils, soft parts of the tissue are preserved in detail.

Relative Age A process called **relative dating** is used to estimate ages of fossils found within strata. Relative dating cannot reveal a fossil's age, in years. But it can reveal the order that strata and the fossils within them were laid down over time. Paleontologists organize fossils into a sequence based on the relative age of the strata in which the fossil was found.

Index Fossils An *index fossil* is a fossil of an organism that was common and had widespread geographical distribution during a certain time in Earth's history. Index fossils are used to estimate the age of other strata that contain the same type of fossil. Scientists have compared patterns of strata and the index fossils within them to make the geologic time scale.

Reading Check ***What is the principle of superposition?***

fossil record the history of life in the geologic past as indicated by the traces or remains of living things

relative dating a method of determining whether an event or object, such as a fossil, is older or younger than other events or objects

READING TOOLBOX

Word Parts The suffix *-ologist* means "one who studies." What do you think a paleontologist does?

Figure 5 Rock strata are easily visible in the Grand Canyon. Gastropod fossils like this one have been found in the region.

Hands-On

QuickLab

15 min

Radioactive Decay

You can use pennies to model radioactive decay.

Procedure

1. Work in pairs. Make a data table like the one shown.
2. Place **100 pennies** into a **box that has a lid.**
3. Shake the box gently. Remove the pennies showing heads. This process models one half-life. Record the number of coins remaining in the box.
4. Repeat step 3 until every coin has been removed.
5. Make a line graph of your data. Label "Half-life" on the *x*-axis and "Coins remaining" on the *y*-axis.

Half-life	Number of coins remaining
1	
2	
3	

Analysis

1. **Identify** what "Number of coins remaining" represents.
2. **Calculate** the age of your sample if 25 coins remained. Assume that each half-life equals 5,730 years.
3. CRITICAL THINKING **Evaluating Models** Describe how this model illustrates radioactive decay.

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

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

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

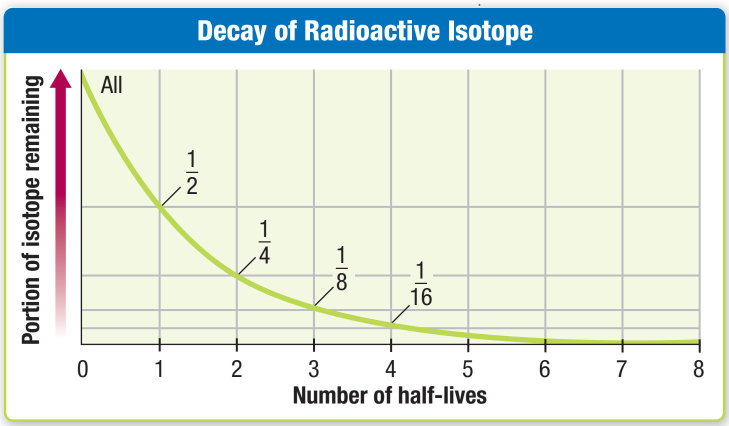
mass extinction an episode during which large numbers of species become extinct

Absolute Age Relative dating can show only whether an object is older or younger than another object. **Radiometric dating** estimates the age in years of an object by measuring certain radioactive isotopes that the igneous rock that surrounds the object contains. An *isotope* is a form of an element whose atomic mass differs from that of other atoms of the same element. Radioactive isotopes, or *radioisotopes,* are unstable isotopes that break down and give off energy in the form of charged particles, or radiation. This breakdown is called *radioactive decay.*

When the radioactive isotope, called a "parent," decays, it produces new isotopes—*daughter* isotopes—that are smaller and more stable. The time required for half of a sample of parent radioisotope to decay into a daughter isotope is the isotope's **half-life. Figure 6** shows this concept. Each radioisotope has a specific half-life, and the rate at which a radioisotope decays is not affected by external factors.

Measuring Age As the parent radioisotope decays, the amount of the daughter radioisotope increases. By comparing the amounts of certain radioisotopes and their daughter isotopes, scientists can calculate how many half-lives have passed since a material formed. One radioisotope that is widely used to date organic materials, such as mummified remains, is carbon-14. The half-life of carbon-14 is relatively short—5,730 years. Carbon-14 is used to measure the age of carbon-containing materials that are younger than 75,000 years old. Older materials have too little isotope remaining for scientists to accurately measure the age of the materials. To find the age of the older materials, scientists have to measure other radioisotopes.

Figure 6 This graph shows the rate of decay of a radioactive isotope.



Describing Geologic Time

The **geologic time scale** organizes geologic and evolutionary events. **The geologic time scale is based on evidence in the fossil record and has been shaped by mass extinctions.** A shortened geologic time scale is shown in **Figure 7.**

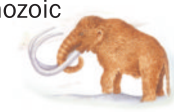
Divisions of Geologic Time Earth has existed for more than 4 billion years. From the beginning of Earth to about 542 million years ago is often referred to as Precambrian time. From the end of Precambrian time to the present, Earth's history is divided into three *eras*—the Paleozoic Era, the Mesozoic Era, and the Cenozoic Era. These three eras are further divided into periods. Humans appeared during the Quaternary Period.

Mass Extinction Recall that the extinction of a species is the death of all members of that species. When large numbers of species become extinct, the event is called a **mass extinction.** The fossil record indicates that many mass extinctions have occurred during Earth's history. Evidence indicates that world-wide geologic and climate changes are common factors that contribute to mass extinctions. Mass extinctions may have contributed to overall biodiversity on Earth. After a mass extinction, opportunities open for new life-forms to emerge.

Mass extinctions have been used to mark the divisions of geologic time. Large mass extinctions mark the boundaries between eras, as shown on **Figure 7.** For example, mass extinctions occurred at the end of Precambrian time, at the end of the Paleozoic Era, and at the boundary between the Mesozoic Era and Cenozoic Era. Smaller mass extinctions mark the divisions between periods.

Reading Check ***What evidence shows that mass extinctions occur?***

Geologic Time Scale

Era	Period	Time*
Cenozoic 	Quaternary	1.8
	Tertiary	65.5
	MASS EXTINCTION	
Mesozoic 	Cretaceous	146
	Jurassic	200
	Triassic	251
	MASS EXTINCTION	
Paleozoic 	Permian	299
	Carboniferous	359
	Devonian	416
	Silurian	444
	Ordovician	488
	Cambrian	542
	MASS EXTINCTION	
Precambrian time 		>4,500

*indicates how many millions of years ago the period began

Figure 7 The geologic time scale is based on fossil evidence. The time in the scale refers to the number of years ago that the time period started. **How long did the Permian period last?**

Section 2 Review

KEY IDEAS

1. **Describe** how the fossil record chronicles the history of life.
2. **Explain** how dating methods are used to analyze fossil evidence.
3. **State** the evidence that scientists have used to create the geologic time scale.

CRITICAL THINKING

4. **Constructing Explanations** Why might the fossil record give an inaccurate picture of the history of biodiversity? Explain your answer.
5. **Explaining Relationships** How could index fossils in two different rock strata in a series help a paleontologist to estimate the absolute age of fossils in a layer of rock between them? Explain your reasoning.

METHODS OF SCIENCE

6. **Describing Methods** You are a paleontologist who is digging for fossils in a remote area. Describe the methods you would use on the dig to make sure that you could estimate the age of the fossils.

Section 3

Evolution of Life

Key Ideas	Key Terms	Why It Matters
What major evolutionary developments occurred during Precambrian time? What dominant organisms evolved during the Paleozoic Era? What dominant organisms evolved during the Mesozoic Era and the Cenozoic Era?	cyanobacteria endosymbiosis	Knowing the order in which life-forms evolved helps scientists form new hypotheses of how life forms are related.

When did life first evolve on Earth? To find out, scientists study fossils and other evidence of early life, such as "signatures" of certain isotopes in rock. These isotopes are associated with living things.

Precambrian Time

Precambrian time spanned between about 4.5 billion and 542 million years ago. Many critical events occurred during this long period of Earth's history. **Single-celled prokaryotes and later, eukaryotes, evolved and flourished in Precambrian time. The evolution of multicellular organisms set the stage for the evolution of modern organisms. The accumulation of atmospheric oxygen allowed organisms to become larger and live on land.**

Early Earth was a dangerous place. Meteors bombarded the planet in large numbers. This activity heated Earth's surface repeatedly and made our planet a hostile place for living things. Eventually, fewer meteor impacts occurred, which allowed early cells to evolve.

Prokaryotic Life Recall that organisms on Earth are divided into three groups: eukaryotes and Archaea and bacteria, the prokaryotes. Living examples from these two groups are shown in **Figure 8.** The close relationship of some eukaryotic genes to those of archaeans suggests that archaea played a role in eukaryote evolution.

cyanobacteria
(SIE uh noh bak TIR ee uh) bacteria that carry out photosynthesis; blue-green algae

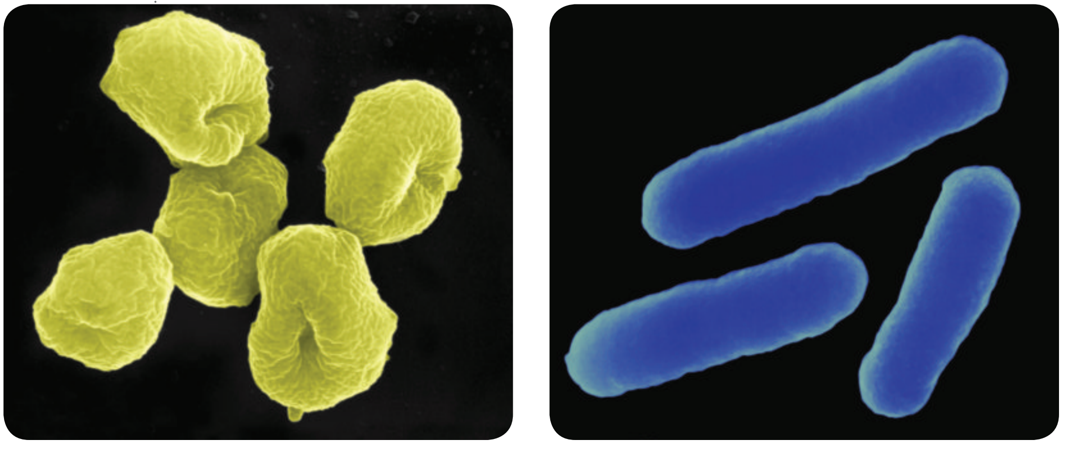


Figure 8 *Sulfolobus* (left) is a living example of archaea. *Escherichia coli* (right) is a living example of bacteria. Both archaea and bacteria are groups of organisms that have existed since ancient times.

Figure 9 Fossilized mats of cyanobacteria, called *stromatolites,* are the most common Precambrian fossils. These modern stromatolites are similar to stromatolites that existed during Precambrian time.

Recall that most prokaryotes are single-celled organisms that lack membrane-bound organelles. The oldest presumed fossils, which are microscopic fossils of prokaryotes, come from rock that is about 3.5 billion years old. The earliest common fossils are those of marine cyanobacteria. **Cyanobacteria** are photosynthetic prokaryotes. Modern cyanobacteria, clustered in layered structures called *stromatolites* are shown in **Figure 9.**

Formation of Oxygen About 2.4 billion years ago, the chemistry of rock layers changed markedly. Because of this, scientists think that cyanbacteria began adding oxygen to the atmosphere at this time. Before cyanobacteria appeared, oxygen gas was scarce on Earth. But as ancient cyanobacteria carried out photosynthesis, they released oxygen gas into Earth's oceans. This oxygen eventually escaped into the air. The increase of oxygen in the ocean destroyed many marine prokaryotes. These organisms had evolved to live without oxygen, which was a poison to them.

As oxygen reached Earth's upper atmosphere, the sun's rays caused some of the oxygen gas, O_2, to chemically react and form molecules of ozone, O_3. In the upper atmosphere, the ozone layer blocks some of the ultraviolet radiation of the sun. The sun provides life-giving light, but overexposure to ultraviolet radiation is dangerous to living things. Organisms on the very early Earth could not survive on land because ultraviolet radiation damaged their DNA. After millions of years however, enough ozone had accumulated to make land a safe place for organisms to live. The first organisms to live on land were prokaryotes.

Eukaryotic Life Later in Precambrian time, the first eukaryotes appeared. Most eukaryotic cells are much larger than prokaryotic cells are. Eukaryotes have a complex system of internal membranes, and their DNA is enclosed within a nucleus. Most eukaryotes have mitochondria. Plants and some protists also have chloroplasts, which carry out photosynthesis. Mitochondria and chloroplasts are the size of prokaryotes, and they contain their own DNA, which is similar to that of prokaryotes.

READING TOOLBOX

Describing Time Scientists describe events in Earth's history in terms of geologic time. Look for references to time in this section, and construct a table of their meanings.

ACADEMIC VOCABULARY

accumulate to collect, especially over a period of time

endosymbiosis (EN doh SIM bie OH ses) a mutually beneficial relationship in which one organism lives within another

SCILINKS
www.scilinks.org
Topic: Endosymbiosis
Code: HX80506

Origin of Energy-Releasing Organelles Mitochondria and chloroplasts likely originated as described by the endosymbiotic theory proposed by Lynn Margulis, which is illustrated in **Figure 10.** **Endosymbiosis** is a mutually beneficial relationship in which one organism lives within another. Endosymbiotic theory proposes that larger cells engulfed smaller cells, which then began to live inside larger cells. According to this theory, mitochondria are the descendants of symbiotic, aerobic (oxygen-requiring) bacteria. Likewise, scientists think that chloroplasts are thought to be the descendants of symbiotic, photosynthetic bacteria. The following observations support the theory that mitochondria and chloroplasts descended from bacteria:

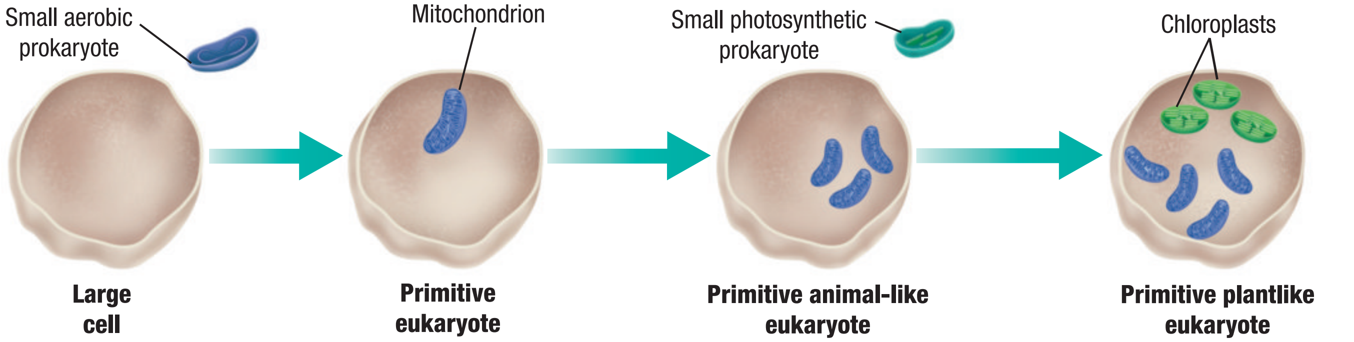
- **Size and Structure** Mitochondria are the same size as most bacteria. Chloroplasts are the same size as some cyanobacteria.
- **Genetic Material** Both chloroplasts and mitochondria contain genes that are different from those found in the nucleus of the host cell and that are closely related to bacterial genes.
- **Ribosomes** Mitochondrial and chloroplast ribosomes are similar in size and structure to bacterial ribosomes.
- **Reproduction** Like bacteria, chloroplasts and mitochondria reproduce by simple fission. This replication takes place independently of the cell cycle of the host cell.

Multicellularity *Volvox,* a colonial protist, is shown in **Figure 11.** Colonies differ from true multicellular organisms. In true multicellularity, cells communicate with one another and differentiate to form different cell types. The development of multicellular organisms marked an important step in the evolution of life-forms that are familiar to us. Multicellularity first developed in protists in Precambrian time. Scientists think that the first multicellular organisms began as clusters of single-celled organisms. Eventually these cells took on specialized functions.

Figure 10 The theory of endosymbiosis states that energy-releasing organelles evolved from ancestors of bacteria.
What genetic evidence supports the theory of endosymbiosis?

go.hrw.com
interact online
Keyword: HX8LIFF10

Endosymbiotic Theory



1. Large prokaryotes and small aerobic or photosynthetic prokaryotes exist as separate cells.
2. Aerobic prokaryotes enter the large prokaryotic cell either as parasites or as undigested prey.
3. Instead of being digested, the small prokaryotes survived and began to live inside the host cell.
4. The internalized prokaryotes eventually performed either cellular respiration (mitochondria) or photosynthesis (chloroplasts).

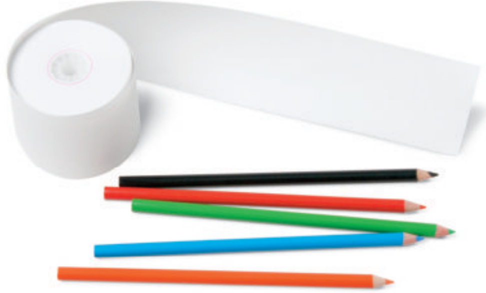
Hands-On

QuickLab

15 min

Timeline of Earth

Using some calculations, you can create your own timeline of Earth's history.



Procedure

1. Copy the table shown onto a **piece of paper.**
2. Complete the table by using this scale: 1 cm is equal to 10 million years.
3. Lay a **5 m strip of adding-machine paper** flat on a hard surface. Use a **meterstick,** a **metric ruler,** and a **pencil** to mark off the beginning and end of Precambrian time according to the time scale that you calculated. Do the same for the three eras. Label each division of time, and make each a different color with **colored pencils.**

Era	Length of time (years)	Scale length
Precambrian	4,058,000,000	
Palezoic	291,000,000	
Mesozoic	185,500,000	
Cenozoic	65,500,000 (to present)	

4. Refer to the geologic time scale shown in **Figure 7.** Using the same scale as in step 2, calculate the scale length for each period listed. Mark the boundaries of each period on the paper strip, and label them.
5. Decorate your strip by adding names or drawings of the organisms that lived in each division of time.

Analysis

1. **Identify** in which period humans appeared.
2. **Calculate** the length from the period in which humans appeared to the present.
3. CRITICAL THINKING **Interpreting Graphics** What percentage of the geologic time scale do these eras combined represent? What percentage of the geologic time scale does Precambrian time represent?

Dominant Life For most of Precambrian time, life probably was limited to prokaryotes and protists, which are eukaryotes. Recent evidence suggests that the oldest known fossils of multicellular eukaryotes have been found in rock that is about 1 billion years old. The first known fossils of true multicellular animals are about 632 million years old. Very early animal fossils are scarce because most animals at that time had soft body parts that did not fossilize well. Fossils of marine animals similar to modern sea anemones and snail-like animals are dated to late Precambrian time.

Mass Extinctions The first known mass extinction in Precambrian time killed many microorganisms, including cyanobacteria and other types of bacteria. A second mass extinction, late in Precambrian time, killed off many animals that had recently evolved. This mass extinction opened up new ecological niches, and preceded a burst of diversification in animals. The animals, with their hard exoskeletons and shells, that evolved after this extinction have left a rich fossil record as evidence of evolution.

› **Reading Check** ***Why is the evolution of colonial organisms an important step in evolution?***

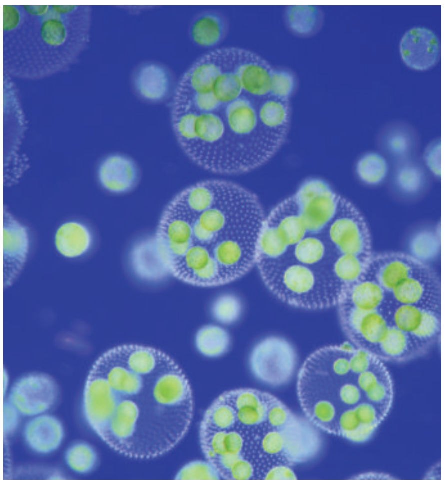


Figure 11 *Volvox* is a colonial protist. Cells in a colony remain attached after dividing. But they are not truly multicellular.

Paleozoic Era

The Cambrian Period, the first period in the Paleozoic Era, was a time of great evolutionary expansion. The rapid diversification of animals that appeared in the fossil record is sometimes referred to as the "Cambrian explosion," though it occurred over several million years.

Dominant Life The Paleozoic Era was a time of great evolutionary expansion. **During the Paleozoic Era, marine invertebrates diversified, and marine vertebrates evolved. The first land plants evolved. Some arthropods, and then some vertebrates, left the oceans to colonize land.**

Plants and Fungi on Land The first multicellular organisms to live on land may have been fungi living together with plants or algae. Plants and fungi began living together on the surface of the land about 475 million years ago. Eventually, great forests, illustrated in **Figure 12,** covered much of Earth's landscape.

Plant life from the Paleozoic Era still has an impact on our lives. In the great coal swamps of the Carboniferous Period, organic materials were subjected to pressure from overlying earth. Over millions of years this produced fossil fuels—beds of coal and reservoirs of oil. Humans now burn both oil and coal to release stored energy.

Arthropods An arthropod is an animal that has a hard outer skeleton, a segmented body, and paired, jointed limbs. Although many arthropods continued to live in the oceans, the first animals to successfully live on land were also arthropods. An important terrestrial arthropod—the insect—evolved in the late Devonian.

Vertebrates A vertebrate is an animal with a backbone. According to the fossil record, the first vertebrates were small, jawless fishes that evolved in the oceans about 530 million years ago. Fishes that have jaws appeared about 430 million years ago. For over one hundred million years, vertebrates lived only in the sea. The first land vertebrates, amphibians, came out of the sea about 370 million years ago. Reptiles evolved from amphibian ancestors about 340 million years ago.

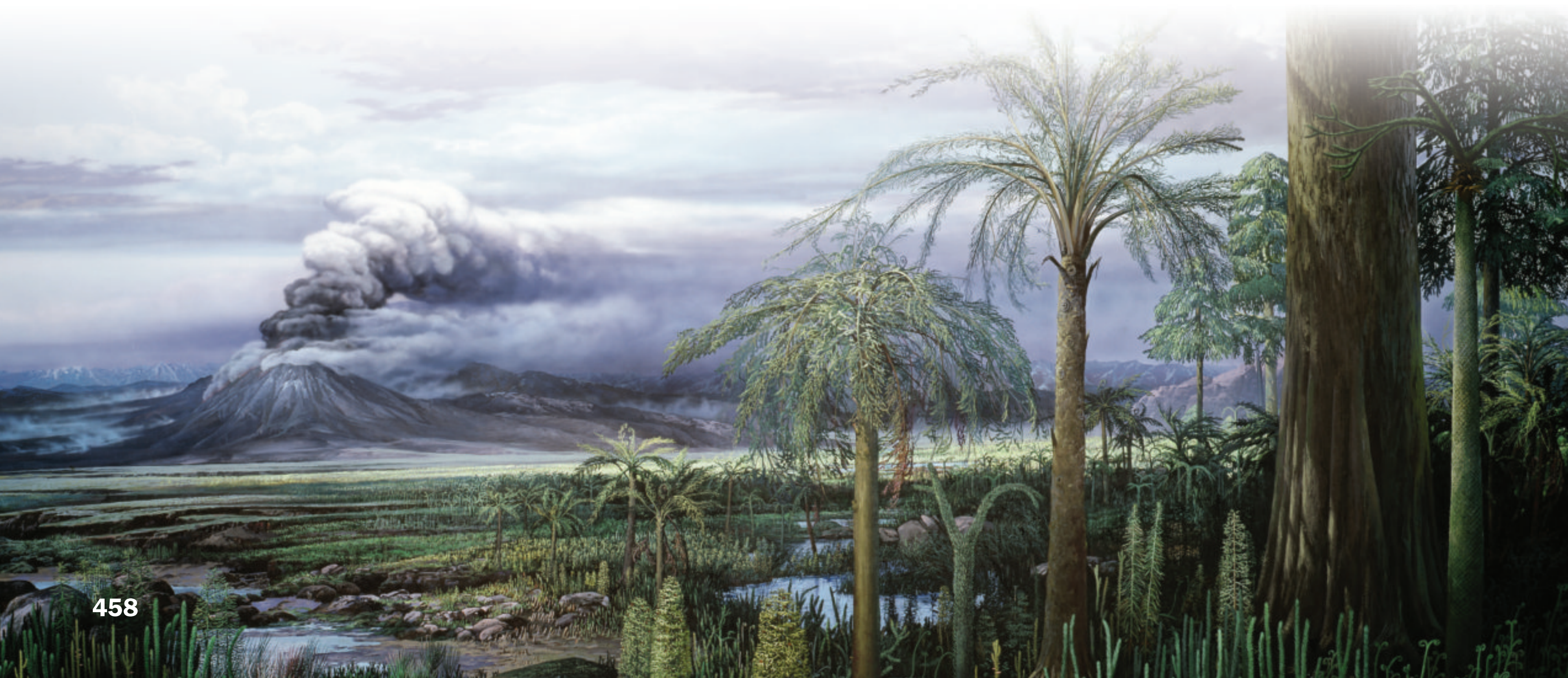


Figure 12 The Devonian Period, which began about 416 million years ago, was dominated by large forests, such as the one shown in this illustration.

Mass Extinctions The fossil record indicates that mass extinctions occurred both at the end of the Ordovician Period (440 million years ago) and just before the end of the Devonian Period (375 million years ago). These events eliminated about 70% of all of the species on Earth. The most devastating of all mass extinctions occurred at the end of the Permian Period, about 252 million years ago. More than 90% of all animals species living at the time became extinct.

Mesozoic and Cenozoic Eras

Many of the dominant life-forms on our planet diverged during the Mesozoic and Cenozoic Eras. **Reptiles, dinosaurs, and birds were the dominant animals during the Mesozoic Era, and mammalian animals dominated the Cenozoic Era.**

Figure 13 This woolly mammoth is an example of an animal that lived during the Quaternary Period. **Did woolly mammoths live before or after the K-T extinction?**

Dominant Life During the Mesozoic Era, dinosaurs and other reptiles evolved to be the dominant life-forms. Therapsids, which were mammal-like reptiles, gave rise to modern mammals at about the same time that dinosaurs evolved, during the Triassic Period. Scientists think that birds evolved from feathered dinosaurs during the Jurassic Period. Flowering plants evolved during the Cretaceous Period of the Mesozoic Era. The Cenozoic Era is the current era. During this era, mammals, such as the woolly mammoth shown in **Figure 13,** became the dominant life-form on land. The first hominids (early human ancestors) evolved during the Tertiary Period. Modern humans did not appear until the Quaternary Period.

Mass Extinction A mass extinction 65 million years ago included about two-thirds of all land species, including the dinosaurs. This mass extinction is often called the K-T extinction, because it marks the boundary between the Cretaceous Period (K) of the Mesozoic Era and the Tertiary Period (T) of the Cenozoic Era. Scientists think that this mass extinction was caused by a catastrophic event that had widespread effects.

Section 3 Review

KEY IDEAS

1. **Describe** the major events that occurred during Precambrian time.
2. **Name** the types of life-forms that evolved during the Paleozoic Era.
3. **Describe** the dominant life-forms that evolved during the Mesozoic and Cenozoic eras.

CRITICAL THINKING

4. **Justifying Conclusions** A classmate states that mitochondria and chloroplasts descended from the same type of bacteria. Does the evidence support this? Explain your reasoning.
5. **Evaluating an Argument** Defend the argument that fossil fuels are *not* a renewable resource.

CONNECTING KEY IDEAS

6. **Evaluating Viewpoints** Several scientists have said that if a large asteroid struck Earth, the impact could result in a mass extinction. If an asteroid impact did not kill all organisms, would evolution continue or stop? Explain your reasoning.

Why It Matters

Nearing the End

Sixty-five million years ago a mass extinction occurred on Earth. The dinosaurs and more than 50% of other species became extinct. What could have caused this worldwide extinction? In 1980, a group of scientists reported evidence that suggested that a huge asteroid 10 km in diameter struck Earth and triggered the mass extinction.

Effects of Impact

A 10 km asteroid would hit Earth with the force of 100,000 billion metric tons of TNT. This impact would generate an earthquake 1,000 times stronger than the strongest recorded earthquake and winds of more than 400 km/h. Long-term effects would be more deadly. Debris blasted upward would reenter the atmosphere at high speeds, heating it and igniting forest fires across the globe.

What Died? The most affected organisms were in the oceans, where 90% of the plankton was killed, which led to the collapse of the oceanic food chain. On land, dinosaurs became extinct but mammals and most non-dinosaur reptiles did not go extinct.

Research Conduct research on the Internet to discover why mammals and most non-dinosaur reptiles survived the KT extinction.

Skills Practice

Chapter 19 Lab

30 min

Objectives

- Model the formation and analysis of strata.
- Apply the criteria used to identify index fossils to the strata model.
- Evaluate the effectiveness of the model to illustrate relative fossil age.

Materials

- graduated cylinder, 100 mL
- water, tap
- aquarium gravel, four distinct colors
- dish, small (8 per group)
- tablespoon
- beans, dried (navy, black, pinto)

Safety

Model of Rock Strata

Sedimentary strata are arranged so that, if they remain undisturbed, any layer is older than the strata on top of it but younger than the strata beneath it. One way to study strata and the fossils within them is to take core samples through the earth and compare them to samples taken at different locations. Paleontologists can determine the original order of strata by comparing multiple samples from many locations. In this lab, you will model how strata are formed and how they can be used to construct a record of Earth's geologic and biologic history.

Procedure

1. Work in groups of three or four. Each student in the group should make a separate model. You will build up a series of layers in a column. You will model eight periods of time using different colors of gravel and different beans. The gravel represents sediment and the beans represent fossils. One tablespoon represents deposition that occurs over a 10,000-year period.
2. **CAUTION: Glass items such as graduated cylinders are fragile and may break.** Add 30 mL of tap water to the graduated cylinder.
3. For the first time period, choose a color. Have each member of the group add 1 Tbsp of that gravel color to their column. Randomly choose one member of the group to omit this layer.
4. Repeat step 3 using another color of your choice until you have modeled eight time periods. At the third time period, insert some navy beans; at the fifth time period, insert pinto beans; at the seventh time period, insert black beans. Record the strata order used by your group. Keep this record as a key to your models.
5. Exchange the models from your group with those of another group. Try to determine the order of strata used by that group.
6. Clean up your lab materials according to your teacher's instructions. Wash your hands before leaving the lab.

Analyze and Conclude

1. **Recognizing Relationships** Explain how this model relates to how sedimentary strata are formed.
2. SCIENTIFIC METHODS **Analyzing Conclusions** Describe your success at inferring the other group's strata order.
3. SCIENTIFIC METHODS **Inferring Conclusions** Compare the occurrence of the three types of "fossils" across the models from each group. What is the significance of these fossils? Explain your reasoning.
4. **Analyzing Models** If the same fossils are contained within different kinds of strata, can they be classified as index fossils? Explain.

Chapter 19 Summary

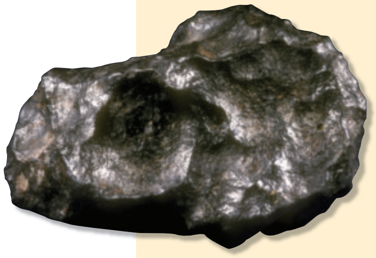
go.hrw.com
SUPER SUMMARY
Keyword: HX8LIFS

Key Ideas	Key Terms

1 How Did Life Begin?

- The Miller-Urey experiment showed that, under certain conditions, organic compounds could form from inorganic molecules.
- Among the scientific theories that address the origin of life, one suggests that life began close to hydrothermal vents, and another proposes that organic molecules arrived on early Earth from a meteorite.
- The formation of microspheres might have been the first step toward cellular organization.

Key Terms:
microsphere (449)
ribozyme (449)



2 The Age of Earth

- Both the geographical distribution of organisms and when organisms lived on Earth can be inferred by examining the fossil record.
- In order to analyze fossil evidence, paleontologists use both relative and absolute dating methods to date fossils.
- The geologic time scale is based on evidence in the fossil record and has been shaped by mass extinctions.

Key Terms:
fossil record (450)
relative dating (451)
radiometric dating (452)
half-life (452)
geologic time scale (453)
mass extinction (453)

3 Evolution of Life

- Prokaryotes and later, eukaryotes, evolved in the Precambrian. The evolution of multicellular life preceded the evolution of modern life-forms. Atmospheric oxygen allowed life to survive on land.
- During the Paleozoic Era, marine invertebrates diversified, and marine vertebrates evolved. The first land plants evolved. Some arthropods, and then some vertebrates, colonized the land.
- Reptiles, dinosaurs, and birds were the dominant animals in the Mesozoic Era, and mammalian animals were dominant in the Cenozoic Era.

Key Terms:
cyanobacteria (455)
endosymbiosis (456)

Chapter 19 Review

READING TOOLBOX

1. **Describing Time** Describing time is an important skill when discussing historical events. Use this skill to organize the events of this chapter into a timeline.

2. **Concept Map** Construct a concept map that shows how life began based on information in the chapter. Include the following items in your map: *Miller-Urey experiment, hydrothermal vents, RNA, microspheres, strata,* and *radioactive isotopes.*

Using Key Terms

In your own words, write a definition for each of the following terms:

3. *microsphere*
4. *ribozyme*
5. *strata*

Use each of the following terms in a separate sentence.

6. *mass extinction*
7. *endosymbiosis*
8. *radiometric dating*

Understanding Key Ideas

9. Which gases did Oparin and Urey think were in the atmosphere of early Earth?
   a. water vapor, ammonia, and ozone
   b. oxygen gas, ozone, and water vapor
   c. hydrogen gas, ammonia, and methane
   d. methane, oxygen gas, and hydrogen gas

10. Which of the following can form spontaneously in water?
    a. DNA
    b. proteins
    c. lipids
    d. RNA

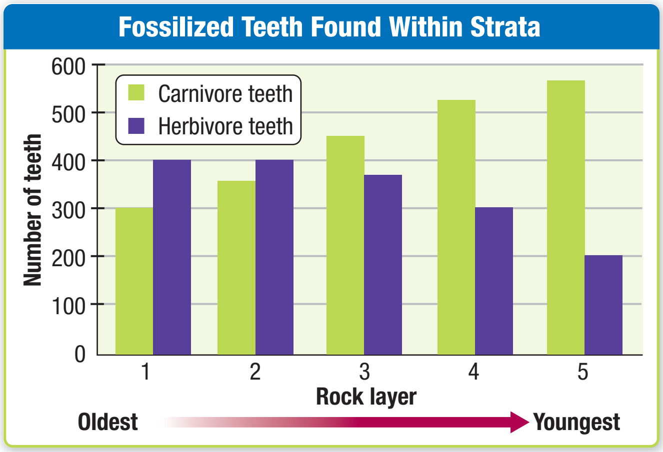
11. Where in the oceans do scientists think that life could have originated?
    a. in shallow bays
    b. near hydrothermal vents
    c. in areas filled with sediment
    d. in surface waters away from shore

12. The first multicellular organisms to invade land were
    a. reptiles.
    b. mammals.
    c. amphibians.
    d. fungi and plants.

13. A paleontologist can estimate the absolute age of an object by measuring the concentration of
    a. radioisotopes in the object.
    b. stable isotopes in the object.
    c. radioisotopes in rock surrounding the object.
    d. stable isotopes in rock surrounding the object.

14. Which ancient organisms were most likely responsible for the development of the ozone layer?
    a. protists
    b. sulfur bacteria
    c. cyanobacteria
    d. plantlike eukaryotes

Use the diagram to answer the following question.



15. At what point did carnivore teeth begin to outnumber herbivore teeth?
    a. between layer 1 and layer 2
    b. between layer 2 and layer 3
    c. between layer 3 and layer 4
    d. between layer 4 and layer 5

Explaining Key Ideas

16. **Distinguish** between microspheres and cells.
17. **Describe** how fossils are formed in a lake.
18. **Explain** the law of superposition.
19. **Name** the dominant types of organisms that evolved during the Mesozoic and Cenozoic eras.

Using Science Graphics

Suppose the mass of a radioactive isotope is 100 kg, or 100,000 g. Use the table to answer the following questions.

Radioactive Isotope Half-Life

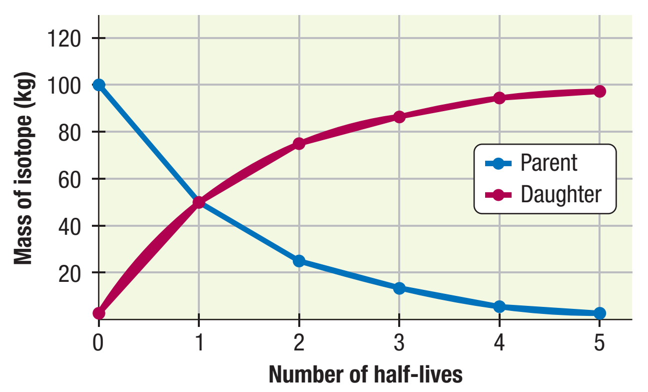
Number of half-lives	Parent isotope	Daughter isotope
0	100,000 g	0 g
1	50,000 g	50,000 g
2	25,000 g	75,000 g
3	12,500 g	87,500 g
4	6,250 g	93,750 g
5	3,125 g	96,875 g

20. How many half-lives have passed when there is three times more daughter isotope than parent isotope?

21. How many grams of the parent isotope are left in the sample after three half-lives?

The data from the table can be plotted in a line graph. Use the line graph to answer the following questions.

Radioactive Decay of Sample Isotope



22. Why is the line graph a curve instead of a straight line?

23. If a sample contained 94,000 g of the daughter isotope, where on the line graph would the sample be shown?

Critical Thinking

24. Making Inferences If the building blocks for life came to Earth on a meteorite, under what conditions might those building blocks have formed in space?

25. Judging Validity A classmate states that birds are living dinosaurs. Is the classmate correct? Explain.

26. Predicting Consequences Some forms of air pollution reduce the thickness of Earth's ozone layer. How might this change affect modern life?

27. Recognizing Relationships Propose a hypothesis for the appearance of all animal phyla on Earth within a relatively short period during late Precambrian time and the early Cambrian Period.

28. Justifying Conclusions Justify the argument that today's organisms would not exist if mass extinctions had not occurred.

Methods of Science

29. Forming Hypotheses State the hypothesis that was tested in the Miller-Urey experiment.

Alternative Assessment

30. Life Timeline Create a timeline or visual display that shows the major events of life from Precambrian time to the Mesozoic and Cenozoic eras.

31. Oral Report Thomas Cech and Sidney Altman shared a Nobel prize in 1989 for their work on RNA. Research their work and the rewards associated with winning a Nobel prize. Present your findings in an oral report.

Math Skills

32. Create a Graph The half-life of the radioisotope lead-210 is about 22.3 years. Construct a line graph that shows how lead-210 decays over 120 years.

Chapter 19 Standardized Test Prep

TEST TIP If time permits, take short mental breaks to improve your concentration during a test.

Science Concepts

1. In the Miller-Urey experiment, which of the following substances were formed after electricity activated chemical reactions?
A ozone
B methane
C hydrocarbons
D inorganic molecules

2. What is the function of a ribozyme?
F to form microspheres
G to catalyze protein assembly
H to catalyze RNA formation
J to store genetic information

3. Which of the following environments is least likely to cause fossil formation?
A stream
B desert plain
C wet lowland
D area near a volcano

4. In an area that has not been disturbed, which rock layer is the oldest?
F the layer closest to Earth's surface
G the layer right above Earth's crust
H the layer deepest within Earth's crust
J the layer that contains fossils

5. Most scientists believe that mitochondria are formed from
A aerobic bacteria.
B photosynthetic bacteria.
C aerobic eukaryotes.
D anaerobic archaea.

6. What were the first vertebrates?
F reptiles
G jawed fishes
H amphibians
J jawless fishes

7. What percentage of land species was eliminated during the mass extinction that occurred 65 million years ago?
A about 45%
B about 67%
C about 70%
D about 96%

Using Science Graphics

The table depicts the estimated abundance of certain elements on Earth and in meteorites. Use the table to answer the following questions.

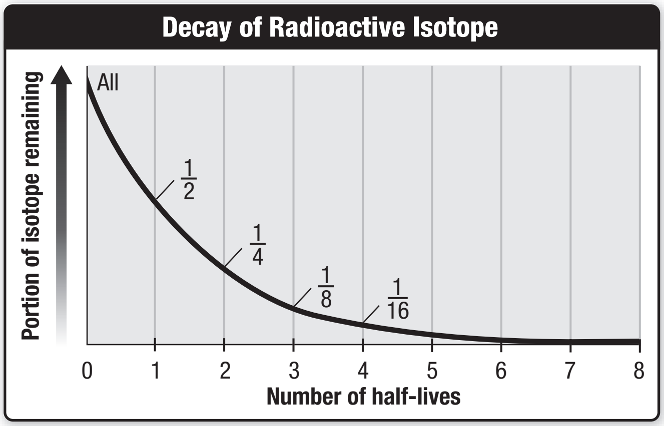
Estimated Abundance of Elements

Element	Percentage of total mass of Earth	Percentage of total mass of meteorites
Iron	36.0	27.2
Oxygen	28.7	33.2
Magnesium	13.6	17.1
Silicon	14.8	14.3
Sulfur	1.7	1.9

8. Which element is found in a greater abundance on Earth than in meteorites?
F iron
G sulfur
H oxygen
J magnesium

9. If this table is typical of the abundance of all elements on Earth, in meteorites, and on other planets, which statement would be supported?
A Earth and meteorites have similar origins.
B Earth and meteorites have different origins.
C All meteorites formed from parts of Earth.
D All elements on Earth come from meteorites.

Use the graph to answer the following question.

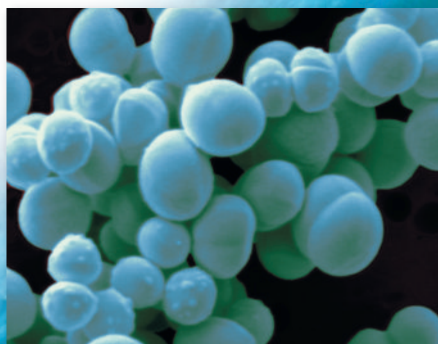


10. If the half-life of carbon-14 is 5,730 years, how many years would it take for 7/8 of the original amount of carbon-14 in the sample to decay?
F 5,014 years
G 11,460 years
H 17,190 years
J 22,920 years

UNIT 6

Microbes

Giant kelp



Staphylococcus xylosus