CHAPTER

12 History of Life on Earth

Quick Review

Answer the following without referring to earlier sections of your book.

1. **Compare** the structure of proteins, lipids, and nucleic acids. *(Chapter 2, Section 3)*
2. **Describe** the role of enzymes in catalyzing chemical reactions. *(Chapter 2, Section 4)*
3. **Contrast** prokaryotes and eukaryotes. *(Chapter 3, Section 2)*
4. **Identify** the structure and function of chloroplasts and mitochondria. *(Chapter 3, Section 3)*
5. **Summarize** the role of DNA in heredity. *(Chapter 9, Section 1)*

Did you have difficulty? *For help, review the sections indicated.*

Reading Activity

Before you begin to read this chapter, write down all of the key words for each section of the chapter. Then, write a definition next to each word that you have heard of. As you read the chapter, write definitions next to the words that you did not previously know, and modify as needed your original definitions of words familiar to you.

Billions of years ago, the combination of simple molecules and energy from sources such as lightning may have given rise to the complex organic molecules necessary for life.

Looking Ahead

internet connect

www.scilinks.org
National Teachers Association *sci*LINKS Internet resources are located throughout this chapter.

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Opening Activity — GENERAL

To help students visualize the enormity of one billion of anything, ask students if they could physically carry one million dollars. One million dollars would be a stack of $100 bills approximately 1 m in height (10,000 bills). A billion dollars would be a stack of the same bills to a height of the Washington Monument (one million bills). Now relate this image to the first billion years of our planet's existence without any form of life.

Quick Review Answers

1. Proteins are polymers of amino acids. Lipids are mostly or completely nonpolar substances containing either chains or rings of primarily carbon and hydrogen atoms. Nucleic acids are polymers of nucleotides.
2. Enzymes interact with molecules to place strain on a chemical bond so that it breaks easily, or to place substances in close proximity so that a small amount of energy input results in a bond being formed between the substances.
3. Prokaryotes are single-celled organisms that lack membrane-bounded organelles. Eukaryotes are single or multicellular organisms that have membrane-bounded organelles, including a nucleus.
4. Chloroplasts and mitochondria are oval and have a complex system of internal membranes. Chloroplasts carry out all of the reactions of photosynthesis. Mitochondria carry out all of the reactions of cellular respiration.
5. The DNA of an organism makes up its genetic information. When a new organism is formed from two parents, it contains its own genetic information, half of which came from each parent.

Chapter Resource File

- Vocabulary Worksheets
- Concept Mapping

Reading Activity Answers

Student lists will likely indicate some understanding of the Earth's beginnings and the origin of life. Few will likely show an understanding of how the complexity and diversity of life on Earth today could have evolved from the earliest organisms that appeared on Earth.

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Section 1

Focus

Overview

Before beginning this section review with your students the objectives listed in the Student Edition. They will learn about how scientists measure the age of the Earth. They will also learn about several models scientists have developed to explain how the first life forms originated on the early Earth. Finally, they will learn how scientists think the complex chemicals found in living things could have arisen from the chemicals present on Earth at the time.

Bellringer

Ask students to draw a picture of what they think Earth's first life form looked like, and have them label the parts of the organism.

Motivate

Using the Figure — GENERAL

Direct students' attention to **Figure 1.** Ask students to explain why the graph of the rate of decay shown in this figure is not a straight line. (The rate of radioactive decay is based on the half-life of a radioactive material. The amount of material that decays in one half-life is one-half of the undecayed portion of the sample present at the beginning of the time period. With each successive half-life, the total amount of material decayed increases. LS Visual

Section 1 How Did Life Begin?

Objectives

- **Summarize** how radioisotopes can be used in determining Earth's age.
- **Compare** two models that describe how the chemicals of life originated.
- **Describe** how cellular organization might have begun.
- **Recognize** the importance that a mechanism for heredity has to the development of life.

Key Terms

radiometric dating
radioisotope
half-life
microsphere

The Age of Earth

When Earth formed, about 4.5 billion years ago, it was a fiery ball of molten rock. Eventually, the planet's surface cooled and formed a rocky crust. Water vapor in the atmosphere condensed to form vast oceans. Most scientists think life first evolved in these oceans and that the evolution of life occurred over hundreds of millions of years. Evidence that Earth has existed long enough for this evolution to have taken place can be found by measuring the age of rocks found on Earth.

Measuring Earth's Age

Scientists have estimated the age of Earth using a technique called radiometric dating. **Radiometric dating** is the estimation of the age of an object by measuring its content of certain radioactive isotopes *(IE soh tohps)*. An isotope is a form of an element whose atomic mass (the mass of each individual atom) 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 (radiation). This breakdown, called radioactive decay, results in other isotopes that are smaller and more stable.

For example, certain rocks contain traces of potassium-40, an isotope of the element potassium. As **Figure 1** shows, the decay of potassium-40 produces two other isotopes, argon-40 and calcium-40. The time it takes for one-half of a given amount of a radioisotope to decay is called the radioisotope's **half-life.** By measuring the proportions of certain radioisotopes and their products of decay, scientists can compute how many half-lives have passed since a rock was formed.

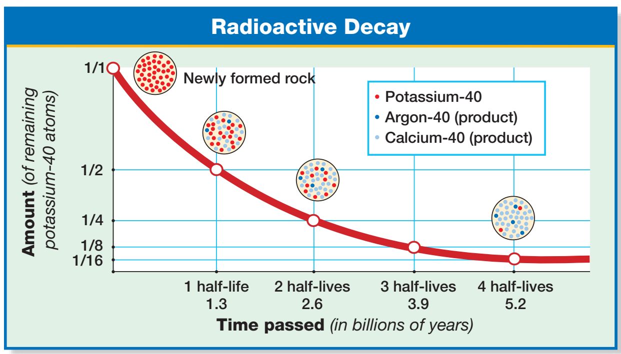

Figure 1 Rate of decay for potassium-40. This graph shows the rate of decay for the radioisotope potassium-40. After one *half-life* has passed, half of the original amount of the radioisotope remains.

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Chapter Resource File

- Directed Reading BASIC
- Active Reading GENERAL
- Data Sheet for Quick Lab GENERAL

One-Stop Planner CD-ROM

- Reading Organizers BASIC
- Reading Strategies BASIC
- Basic Skills Worksheet Mass and Density BASIC

INCLUSION Strategies

- *Attention Deficit Disorder*
- *Developmental Delay*
- *Learning Disability*

Ask students to draw illustrations of their interpretation of the Earth's formation 4.5 billion years ago. The illustrations should show their idea of at least four stages of the evolution of the Earth's surface. The stages should reflect information in the opening paragraphs of Section 1. Students should narrate their drawings through a tape-recorded description of the events shown in their drawings.

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Formation of the Basic Chemicals of Life

Most scientists think that life on Earth developed through natural chemical and physical processes. It is thought that the path to the development of living things began when molecules of nonliving matter reacted chemically during the first billion years of Earth's history. These chemical reactions produced many different simple, organic molecules. Energized by the sun and volcanic heat, these simple, organic molecules formed more-complex molecules that eventually became the building blocks of the first cells. The hypothesis that many of the organic molecules necessary for life can be made from molecules of nonliving matter has been tested and supported by results of laboratory experiments.

internet connect
www.scilinks.org
Topic: Radioactive Decay
Keyword: HX4154
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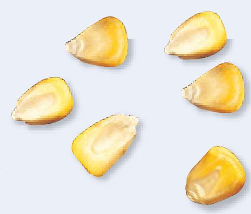
QUICK LAB

Modeling Radioactive Decay

You can use some dried corn, a box, and a watch to make a model of radioactive decay that will show you how scientists measure the age of objects.



Materials

approximately 100 dry corn kernels per group, cardboard box, clock or watch with a second hand

Procedure

1. On a separate sheet of paper, make a data table like the one below.
2. Assign one member of your team to keep time.
3. Place 100 dry corn kernels into a box.
4. Shake the box gently from side to side for 10 seconds.
5. Keep the box still and remove and count the kernels that "point" to the left side of the box, as shown below. Record in your data table the number of kernels you removed.
6. Repeat steps 4 and 5 until all kernels have been counted and removed.
7. Calculate the number of kernels remaining for each time interval.
8. Make a graph using your group's data. Plot "Total shake time (seconds)" on the *x*-axis. Plot "Number of kernels remaining" on the *y*-axis.

Analysis

1. **Identify** what the removed kernels represent in each step.
2. **Calculate** the half-life of your sample, in seconds, that is represented in this activity.
3. **Calculate** the age of your sample, in years, if each 10-second interval represents 5,700 years.
4. **Evaluate** the ability of this model to demonstrate radioactive decay.

DATA TABLE

Total shake time (seconds)	Number of kernels removed	Number of kernels remaining
10		
20		
30		

Teach

SKILL BUILDER —ADVANCED

Writing Skills Have students research radioactive decay using the Web site in the Internet Connect box. Have students write a report summarizing their findings.

QUICK LAB

Modeling Radioactive Decay

Skills Acquired
Forming a model, inferring, calculating

Teacher's Notes
Have kernels precounted and placed in paper or plastic cups. If time allows, multiple trials (two or three) would provide a better set of data. Make sure all kernels are accounted for; they can be slippery if stepped on.

Analysis Answers:

1. The kernels that are removed with each step represent the molecules that decayed.
2. The half-life of the sample is the number of trials it took to remove 50 kernels multiplied by 10 sec/trial.
3. Age of the sample = (number of trials) × (5,730 years/trial)
4. Answers will vary, but should be supported by the data.

Transparencies

- **TR** Bellringer
- **TR D4** Radioactive Decay
- **TR D5** Miller-Urey Experiment
- **TR D6** Lerman's Bubble Model

Trends in Particle Physics

Trace Analysis A new ultrasensitive trace analysis technique—able to detect single atoms in a large sample—has been developed by Argonne National Laboratory researchers. The technology, called Atom Trap Trace Analysis, or ATTA for short, holds promise for advancing the state of the art in many fields, from groundwater studies to environmental monitoring. One of its first applications may be dating ancient Greenland ice cores. While carbon-14 dating has been used to date ice up to about 50,000 years old, ages of older samples have to be inferred from other evidence, such as their depth. Trace analysis of krypton-81, which lasts 40 times longer than carbon-14, can be used to date samples up to one million years old.

ATTA could be applied to other isotopes for applications in a range of scientific disciplines. One possibility is using calcium-41 as a medical tracer to monitor bone loss from osteoporosis. A patient could ingest a small, non-harmful amount of the isotope, which would be taken up into the bones. Over the following years, ATTA could be used to detect the miniscule amounts of calcium-41 in urine samples, which would signal the loss of calcium from bones.

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Teach, *continued*

Real Life — GENERAL

Answers

Scientists are working on technology to eventually examine (by remote telescopes) the planets in and beyond our solar system whose spectral "signatures" indicate the presence of oxygen, water, and carbon dioxide. NASA plans a sample recovery mission to Mars for 2008.

Teaching Tip — GENERAL

Skin Health Remind students that ultraviolet (UV) radiation in sunlight can be very damaging to their health. Sunburn indicates that skin has been damaged by UV radiation. The American Cancer Society reminds us that people who have been seriously sunburned, even once, have an increased risk of developing skin cancer. Remind students that if they are going to be exposed to the sun, they should wear a high SPF sunscreen or protective clothing to reduce UV damage. Explain that the "peeling" that occurs after sunburn is the body's way of getting rid of cells that are too damaged to repair.

Real Life

Is there life on other planets?

Many scientists think life could have arisen on other planets the same way it did on Earth.

Analyzing Information

Find out about research on extraterrestrial life, and compare scientists' predictions about possible life-forms on other planets.

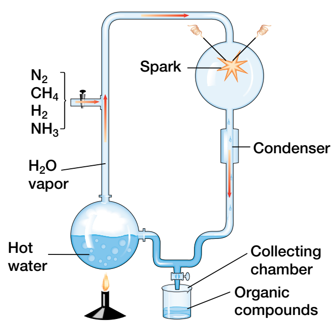
The "Primordial Soup" Model

In the 1920s, the Russian scientist A. I. Oparin and the British scientist J.B.S. Haldane both suggested that the early Earth's oceans contained large amounts of organic molecules. This hypothesis became known as the primordial *(prie MAWR dee uhl)* soup model. Earth's vast oceans were thought to be filled with many different organic molecules, like a soup that is filled with many different vegetables and meats. Oparin and Haldane hypothesized that these molecules formed spontaneously in chemical reactions activated by energy from solar radiation, volcanic eruptions, and lightning.

Oparin, together with the American scientist Harold Urey, and other scientists also proposed that Earth's early atmosphere lacked oxygen. They hypothesized that the early atmosphere was instead rich in nitrogen gas, N_2; hydrogen gas, H_2; and hydrogen-containing gases such as water vapor, H_2O; ammonia, NH_3; and methane, CH_4. They reasoned that electrons in these gases would have been frequently pushed to higher energy levels by light particles from the sun or by electrical energy in lightning. Today, high-energy electrons are quickly soaked up by the oxygen in Earth's atmosphere because oxygen atoms have a great "thirst" for such electrons. But without oxygen, high-energy electrons would have been free to react with hydrogen-rich molecules, forming a variety of organic compounds.

In 1953, the primordial soup model was tested by Stanley Miller, who was then working with Urey. Miller placed the gases that he and Urey proposed had existed on early Earth into a device like the one seen in **Figure 2.** To simulate lightning, he provided electrical sparks. After a few days, Miller found a complex collection of organic molecules in his apparatus. These chemicals included some of life's basic building blocks: amino acids, fatty acids, and other hydrocarbons (molecules made of carbon and hydrogen). These results support the hypothesis that some basic chemicals of life could have formed spontaneously under conditions like those in the experiment.

Figure 2 Miller-Urey experiment. Miller simulated an atmospheric composition that Oparin and other scientists incorrectly hypothesized existed on early Earth. His experiment produced several different organic compounds.



Reevaluating the Miller-Urey Model

Recent discoveries have caused scientists to reevaluate the Miller-Urey experiment. We now know that the reductant molecules used in Miller's experiment could not have existed in abundance on the early Earth. Four billion years ago, Earth did not have a protective layer of ozone gas, O_3. Today ozone protects Earth's surface from most of the sun's damaging ultraviolet radiation. Without ozone, ultraviolet radiation would have destroyed any ammonia and methane present in the atmosphere. When these gases are absent from the Miller-Urey experiment, key biological molecules are not made. This raises a very important question: If the chemicals needed to form life were not in the atmosphere, where did they come from? Some scientists argue that the chemicals were produced within ocean bubbles. Others say that the chemicals arose in deep sea vents. The correct answer has not been determined yet.

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did you know?

The Light of Life Experiments similar to Miller and Urey's that used UV light instead of electrical sparks as an energy source also produced amino acids.

Integrating Physics and Chemistry

Remind students that electrons occur in regions around atoms called orbitals which exist within each of several discrete energy levels surrounding the atom's nucleus. Excited electrons pushed into higher energy levels are more reactive, since interactions between the outermost electrons cause chemical bonding. Ask students to identify the number of valence electrons for nitrogen, carbon, and hydrogen (the component elements found in the "primordial soup" of the Miller-Urey experiment), and then relate this information to their bonding pattern.

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The Bubble Model

In 1986, the geophysicist Louis Lerman suggested that the key processes that formed the chemicals needed for life took place within bubbles on the ocean's surface. Lerman's hypothesis, also known as the bubble model, is summarized in **Figure 3.**

Step 1 Ammonia, methane, and other gases resulting from the numerous eruptions of undersea volcanoes were trapped in underwater bubbles.

Step 2 Inside the bubbles, the methane and ammonia needed to make amino acids might have been protected from damaging ultraviolet radiation. Chemical reactions would take place much faster in bubbles (where reactants would be concentrated) than in the primordial soup proposed by Oparin and Haldane.

Step 3 Bubbles rose to the surface and burst, releasing simple organic molecules into the air.

Step 4 Carried upward by winds, the simple organic molecules were exposed to ultraviolet radiation and lightning, which provided energy for further reactions.

Step 5 More complex organic molecules that formed by further reactions fell into the ocean with rain, starting another cycle.

Thus, the molecules of life could have appeared more quickly than is accounted for by the primordial soup model alone.

Study TIP

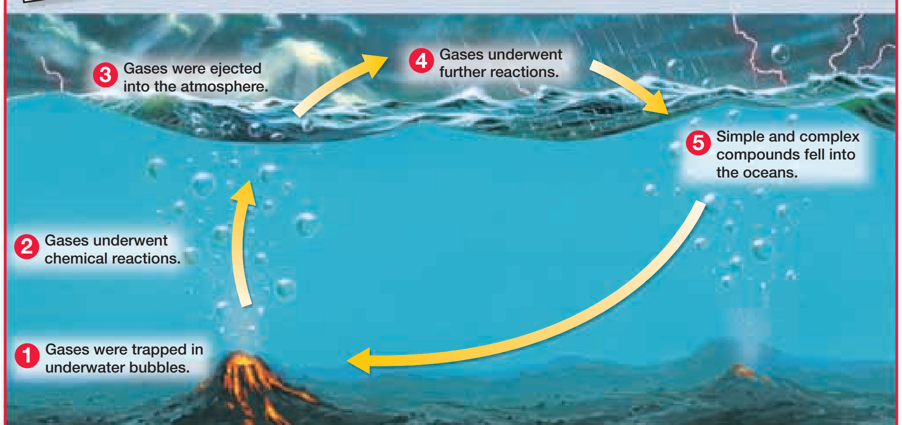
Reading Effectively
Before reading this chapter, write the Objectives for each section on a sheet of paper. Rewrite each Objective as a question, and answer these questions as you read the section.

BIO graphic

Figure 3

Lerman's Bubble Model

Lerman proposed that gases formed simple organic molecules.



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READING SKILL BUILDER — GENERAL

Interactive Reading Assign Chapter 12 of the *Holt Biology* Guided Audio CD Program to help students achieve greater success in reading the chapter.

Teaching Tip — GENERAL

Space Science The origin of life on this planet is of interest to scientists in many fields. Investigators in the fields of biology, chemistry, physics, geology, and astrophysics are all working together to learn more about other planets in the quest to learn more about our own. Indeed, whole new fields of study, such as planetary geology, were unheard of a few years ago. Ask students to discuss new fields of study that might arise from exploration of the planets in our solar system. (Answers will vary, but might include planetary mining and refining, and mass transit between planets.)
LS Verbal

Teaching Tip — ADVANCED

Earth's Changing Atmosphere
Students may think that the atmosphere is an infinite resource that will always be present as it is today. Challenge this misconception by having students compare the changes in the atmosphere of early Earth with the changes that are occurring in our present atmosphere. Begin by describing how oxygen levels steadily increased in the ancient atmosphere due to the activity of photosynthetic bacteria. Then ask students what kind of gaseous products human activity is producing today. (Carbon dioxide, methane, sulfur dioxide, nitrous oxide, and others) Ask which gas of particular importance is increasing worldwide and which is decreasing worldwide. (Carbon dioxide is increasing, and upper atmospheric ozone is decreasing.)

ASTRONOMY CONNECTION

In the late 1890's, telescopic studies of Mars spawned theories about vegetative and possibly intelligent life on Mars. These ideas had great popular appeal and, given the poor quality of the data available, possibly even a modicum of scientific credibility. There was no question that the Martian poles were ice-locked and so Mars indeed seemed to possess one of the essential ingredients for life—water. At issue, then as now, was whether this water was ever in liquid form. Even as late as 1962, respected astronomers continued to interpret data gleaned from fifty years of telescopic observation of Mars as supportive of theories of life there. The high-quality images returned by the Mariner flybys showed Mars to be heavily cratered, more akin to the Earth's moon than to the Earth.

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Teach, *continued*

Teaching Tip — GENERAL

The First Hereditary Molecule
Armed with the knowledge of the function of RNA in protein synthesis, many students may not be able to understand immediately how RNA, which relies on a template provided by DNA, could have developed before DNA. Explain to students that today certain viruses (called retroviruses), including HIV, contain only RNA as their genetic material. Their viral RNA, when released into a host cell, is used as a template to then make DNA.

QUICK LAB

Modeling Coacervates

Skills Acquired
Forming a model, predicting outcomes

Teacher's Notes
Solutions must be fresh and prepared accurately. Always wear safety goggles and lab aprons when mixing chemicals. Tell students to notify you in case of an accident. Supervise the cleanup of all spills.

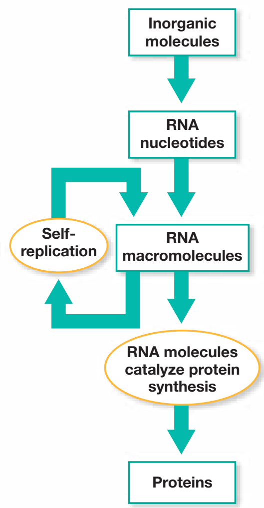
Analysis Answers:

1. The solution became cloudy.
2. Coacervates are spherical and membrane-bound but have no internal structures.
3. Answers may vary but may include that coacervates might break up.
4. Answers will vary. Students might state that coacervates are discrete structures that resemble cells and that arise in certain chemical environments.

Precursors of the First Cells

Scientists disagree about the details of the process that led to the origin of life. Most scientists, however, accept that under certain conditions, the basic molecules of life could have formed spontaneously through simple chemistry. But there are enormous differences between simple organic molecules and large organic molecules found in living cells. How did amino acids link to form proteins? How did nucleotides form the long chains of DNA that store the instructions for making proteins? In the laboratory, scientists have not been able to make either proteins or DNA form spontaneously in water. However, short chains of RNA, the nucleic acid that helps carry out DNA's instructions, have been made to form on their own in water.

Figure 4 **Proposed stages leading to RNA self-replication and protein synthesis.** Chemical reactions between inorganic molecules formed RNA nucleotides. The nucleotides assembled into RNA macromolecules. These molecules were able to self-replicate and to catalyze the formation of proteins.



A Possible Role As Catalysts

In the 1980s, American scientists Thomas Cech of the University of Colorado and Sidney Altman of Yale University found that certain RNA molecules can act like enzymes. RNA's three-dimensional structure provides a surface on which chemical reactions can be catalyzed. Messenger RNA acts as an information-storing molecule. As a result of Cech's and Altman's work and other experiments showing that RNA molecules can form spontaneously in water, a simple hypothesis was formed: RNA was the first self-replicating information-storage molecule and it catalyzed the assembly of the first proteins. More important, such a molecule would have been capable of changing from one generation to the next. This hypothesis is illustrated in **Figure 4.**

Microspheres and Coacervates

Observations show that lipids, which make up cell membranes, tend to gather together in water. By shaking up a bottle of oil and vinegar, you can see something similar happen—small spheres of oil form in the vinegar. Certain lipids, when combined with other molecules, can form a tiny droplet whose surface resembles a cell membrane. Similarly, laboratory experiments have shown that, in water, short chains of amino acids can gather into tiny droplets called **microspheres.** Another type of droplet, called a *coacervate (koh AS suhr VAYT),* is composed of molecules of different types, including linked amino acids and sugars.

Scientists think that formation of microspheres might have been the first step toward cellular organization. According to this hypothesis, microspheres formed, persisted for a while, and then dispersed. Over millions of years, those microspheres that could persist longer by incorporating molecules and energy would have become more common than shorter lasting microspheres were. Microspheres could not be considered true cells, however, unless they had the characteristics of living things, including heredity.

did you know?

Ancient Oceans Early oceans were probably similar in salt content to modern freshwater lakes. The salinity of today's oceans is the result of millions of years of water running over rocks, picking up mineral salts, and flowing to the sea.

CHEMISTRY CONNECTION

Carbon atoms can form an almost infinite number of compounds by combining with each other in long chains and in other types of large, complex molecules. They not only form a total of four bonds, they can also join other atoms in single, double, and triple bonds. The structure of silicon, however, is far more rigid. Their differences can be seen by comparing carbon-based plastics to silicon-based ceramics.

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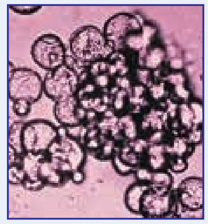
Origin of Heredity

Although scientists disagree about the details of the origin of heredity, many agree that double-stranded DNA evolved after RNA and that RNA "enzymes" catalyzed the assembly of the earliest proteins. Many scientists also tentatively accept the hypothesis that some microspheres or similar structures that contained RNA developed a means of transferring their characteristics to offspring. But researchers do not yet understand how DNA, RNA and hereditary mechanisms first developed. Therefore, the subject of how life might have originated naturally and spontaneously remains a subject of intense interest, research, and discussion.

QUICK LAB

Modeling Coacervates



By using simple chemistry, you will see that some properties of coacervates resemble the properties of cells.

Materials

safety goggles, protective gloves and lab apron, graduated cylinder, 1 percent gelatin solution, 1 percent gum arabic solution, test tube, 0.1 M HCl, pipet, microscope slide and coverslip, microscope

Procedure

1. **CAUTION: Hydrochloric acid is corrosive. Put on safety goggles, gloves, and apron. Avoid contact with skin and eyes. Avoid breathing vapors. If any of this solution should spill on you, immediately flush the area with water, and notify your teacher.**
2. Mix 5 mL of a 1 percent gelatin solution with 3 mL of a 1 percent gum arabic solution in a test tube.
3. Add 0.1 M HCl to the gelatin–gum arabic solution one drop at a time until the solution turns cloudy.
4. Prepare a wet mount of the cloudy solution, and examine it under a microscope at high power.
5. Prepare a drawing of the structures that you see. They should resemble the structures in the micrograph above.

Analysis

1. **Describe** what happened to the solutions after the acid was added.
2. **Compare** the appearance of coacervates with that of cells.
3. **Predict** what would happen to the coacervates if a base were added to the solution.
4. **Critical Thinking** **Evaluating Hypotheses** Based on the evidence you obtained, defend the hypothesis that coacervates could have been the basis of life on Earth.

Section 1 Review

1. **Explain** how radioisotopes are used to determine the age of a rock.
2. **Critique** two scientific models that explain the origin of life.
3. **Describe** the first step that may have led toward cellular organization.
4. **Explain** how heredity may have arisen.
5. Standardized Test Prep Miller and Urey's model is inconsistent with the finding that Earth's early atmosphere lacked
   A nitrogen. **C** water.
   B hydrogen. **D** ozone.

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Answers to Section Review

1. The amount of the radioisotope in the rock is compared to the amounts of isotope species that resulted from decay. An older rock would have less of the original radioisotope.
2. In the "primordial soup" model, the early atmosphere contained large amounts of nitrogen and hydrogen-containing gases. Recent discoveries indicate that without ozone, any ammonia and methane would have been destroyed. In the bubble model, ammonia, methane, and other gases from underwater volcanoes were trapped in bubbles in the seas. Chemical reactions took place faster in the bubbles, and the underwater bubbles were protected from UV radiation. This model relies on the assumption that bubbles remained intact for a significant time.
3. The formation of microspheres might have led to cellular organization.
4. Microspheres that contained replicating RNA might have transferred both their structure and their RNA to offspring.
5. **A.** Incorrect. Nitrogen is believed to have been present. **B.** Incorrect. Hydrogen is believed to have been present. **C.** Incorrect. Water is believed to have been present. **D.** Correct. The Earth's early atmosphere did not have a protective layer of ozone. Without ozone, the ammonia and methane in Miller and Urey's model would have been destroyed by ultraviolet radiation.

Close

Reteaching — Basic

Ask students to draw a rough diagram of the Miller-Urey apparatus. Be sure to have them label all components of the diagram. (Students should include in their sketch an area for holding water, an area where water and gases can combine and be subjected to electrical sparks, an area where any by-products can cool, and an area where the by-products can be collected.)

Quiz — General

1. What is a "half-life"? (It is the amount of time that it takes for half of an amount of material to break down.)
2. What does "spontaneous" mean, in reference to the origin of life? (It means that life originated from nonliving things.)
3. Every theory about the origin of life has a source of energy for the transformation. What are some of these sources? (Possible sources include ultraviolet or other light energy from the sun, an electrical spark as from lightning, and volcanic eruption.)
4. What molecule is thought to be the first hereditary molecule? (RNA)

Alternative Assessment — General

Ask students to write an answer to this question: Were the first cells that evolved on Earth prokaryotes or eukaryotes? Have them justify their choice. (The first cells were prokaryotes. At this point in the chapter, students should conclude that, since prokaryotes are single-celled organisms lacking a nucleus, they probably evolved earlier than more complex eukaryotes.)

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Section 2

Focus

Overview

Before beginning this section review with your students the objectives listed in the Student Edition. Tell students that the purpose of this lesson is to teach them how the first eukaryotic cells and their organelles might have evolved and how multicellular organisms likely evolved. How explosions of new species of organisms occurred in several different periods of Earth's history and how mass extinctions have also played an important role in the diversity of life on Earth are also discussed.

Bellringer

Ask students to write down the names of all the kingdoms of living things, writing them in the order in which they appeared on Earth.

Motivate

Demonstration — GENERAL

Some students may have difficulty understanding the timeline of Earth's history. This analogy should provide some perspective. Draw a large circle on the board to represent a clock. Place an arrow at 12:01 to indicate when Earth was formed. Place additional arrows at 1:15 (the first bacteria appeared), 8:00 (the first eukaryotes), 11:00 (the first life on land), 11:50 (dinosaurs became extinct), and 11:59 (first humans appeared). Students will be able to relate more life-on-Earth "milestones" to a 24-hour day when they complete the Exploration Lab. LS Visual

Section 2 The Evolution of Cellular Life

Objectives

- **Distinguish** between the two groups of prokaryotes.
- **Describe** the evolution of eukaryotes.
- **Recognize** an evolutionary advance first seen in protists.
- **Summarize** how mass extinctions have affected the evolution of life on Earth.

Key Terms

fossil
cyanobacteria
eubacteria
archaebacteria
endosymbiosis
protist
extinction
mass extinction

The Evolution of Prokaryotes

When did the first organisms form? To find out, scientists study the best evidence of early life that we have, fossils. A **fossil** is the preserved or mineralized remains (bone, tooth, or shell) or imprint of an organism that lived long ago. The oldest known fossils, which are microscopic fossils of prokaryotes, come from rock that is 2.5 billion years old.

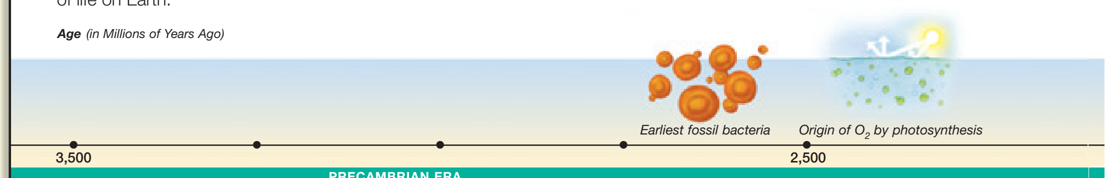
Recall that prokaryotes are single-celled organisms that lack internal membrane-bound organelles. Among the first prokaryotes to appear were marine cyanobacteria. **Cyanobacteria** *(SIE an oh bak TIR ee ah)* are photosynthetic prokaryotes. Before cyanobacteria appeared, oxygen gas was scarce on Earth. But as ancient cyanobacteria carried out photosynthesis, they released oxygen gas into Earth's oceans. After hundreds of millions of years, the oxygen produced by cyanobacteria began to escape into the air, as shown in **Figure 5.** Over time, more oxygen was added to the air. Today oxygen gas makes up 21 percent of the Earth's atmosphere.

Two Groups of Prokaryotes

Early in the history of life, two different groups of prokaryotes evolved—eubacteria (which are commonly called *bacteria*) and archaebacteria. Living examples include *Escherichia coli,* a species of eubacteria, and *Sulfolobus,* a group of archaebacteria. **Eubacteria** are prokaryotes that contain a chemical called peptidoglycan *(PEP tih doh GLIE kan)* in their cell walls. Eubacteria include many bacteria that cause disease and decay.

Archaebacteria are prokaryotes that lack peptidoglycan in their cell walls and have unique lipids in their cell membranes. Modern archaebacteria are thought to closely resemble early archaebacteria. Chemical evidence indicates that archaebacteria and eubacteria diverged very early.

Figure 5 Evolutionary timeline. This timeline shows some of the major events that occurred during the evolution of life on Earth.



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Chapter Resource File

- Directed Reading BASIC
- Active Reading GENERAL
- Data Sheet for Data Lab GENERAL

One-Stop Planner CD-ROM

- Reading Organizers BASIC
- Reading Strategies BASIC

Transparencies

TR Bellringer
TR D8 Evolution of Eukaryotes

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The Evolution of Eukaryotes

About 1.5 billion years ago, the first eukaryotes appeared. A eukaryotic cell is much larger than a prokaryote is. Eukaryotic cells have a complex system of internal membranes. Eukaryotic DNA is enclosed within a nucleus. Almost all eukaryotes have mitochondria. Chloroplasts, which carry out photosynthesis, are found only in protists and plants. Mitochondria and chloroplasts are the size of prokaryotes, and they contain their own DNA.

The Origins of Mitochondria and Chloroplasts

Most biologists think that mitochondria and chloroplasts originated as described by the theory of **endosymbiosis** that was proposed in 1966 by the American biologist Lynn Margulis. This theory proposes that mitochondria are the descendants of symbiotic, aerobic (oxygen-requiring) eubacteria and cholorplasts are the descendants of symbiotic, photosynthetic eubacteria.

DATA LAB

Analyzing Signs of Endosymbiosis

Magnification: 6930x

Background

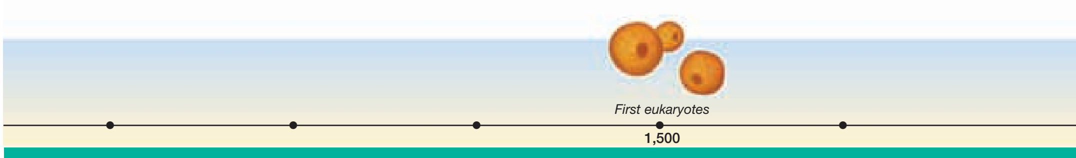
You may recall that mitochondria have their own DNA and produce their own proteins. The data below were collected by scientists studying the proteins produced by mitochondrial DNA. The scientists found that the three-nucleotide sequences (codons) in the nucleus of an organism's cells can code for different amino acids than those coded for in the cell's mitochondria. Examine the data below, and answer the questions that follow.

Analysis

1. **Defend** the theory of endosymbiosis using these data.
2. **Infer** what these data indicate about the evolution of plant cells.
3. **Describe** how these data can be used to support the idea that more than one type of cell evolved early in the history of life.

Amino Acids Made in the Nucleus and Mitochondria

	Amino acids or other instructions coded for in the nucleus	Amino acids or other instructions coded for in mitochondria	
Codon	**Plants and mammals**	**Plants**	**Mammals**
UGA	Stop	Stop	Tryptophan
AGA	Arginine	Arginine	Stop
AUA	Isoleucine	Isoleucine	Methionine
AUU	Isoleucine	Isoleucine	Methionine
CUA	Leucine	Leucine	Leucine



Teach

Teaching Tip

Remembering What Came from What Use a Graphic Organizer similar to the one at the bottom of this page to help students grasp the progression of the complexity of life. Reproduce the diagram, without the eight terms, on the board or overhead. Next, write an alphabetical list of the eight terms beside the graphic organizer. Ask students to insert the terms into their correct rectangles.

DATA LAB

Analyzing Signs of Endosymbiosis

Skills Acquired
Analyzing data, relating conclusions

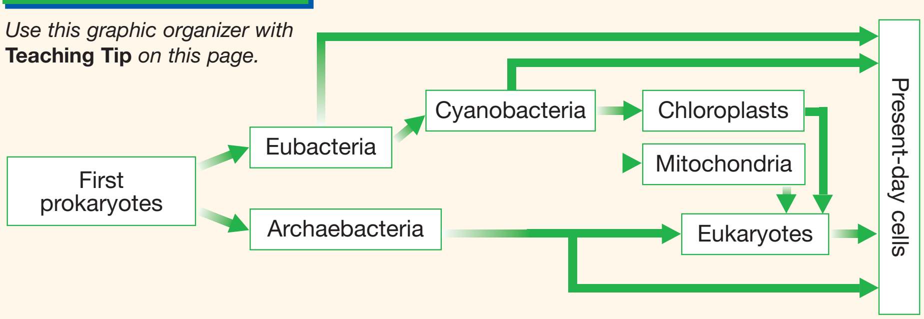
Teacher's Notes
Point out to students that they are looking at a "doubled double" set of data. That is, they are considering the nucleus with respect to mitochondria and plants with respect to mammals.

Answers to Analysis

1. The fact that in mammals the genetic code of nuclear DNA differs from that of mitochondrial DNA suggests that mitochondria have evolved separately from the animal cells that contain them.
2. We can infer that plant mitochondria and plant cells together have been subjected to selective pressures different from those that acted on mammalian cells and on mammalian mitochondria.
3. We can infer that the prokaryotic ancestors of mammalian mitochondria probably diverged very early from the prokaryotic ancestors of plant mitochondria because the genetic codes are quite different in the two types.

Graphic Organizer

Use this graphic organizer with **Teaching Tip** *on this page.*



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Teach, *continued*

Teaching Tip — GENERAL

Endosymbiosis The term endosymbiosis refers to any symbiotic relationship in which one organism lives inside another. Help students understand Margulis's hypothesis for the endosymbiotic origin of mitochondria and chloroplasts by reviewing other examples of endosymbiosis. Examples include wood-digesting bacteria that live within the digestive tracts of termites, bacteria that break down plant cell walls within the digestive tract of cows, and bacteria in the human digestive tract that break down otherwise undigested materials and synthesize vitamin K as a by-product. English Language Learners
LS Verbal

Group Activity — GENERAL

Models of Endosymbionts and Bacteria Have students work in small groups to create models or posters of chloroplasts, mitochondria, non-photosynthetic bacteria cells, and photosynthetic bacterial cells. Students should use reference materials for their models or posters to ensure that they accurately depict these organelles and cells. Tell students that their models or poster pictures should have clearly labeled internal structures and the colors should be realistic (i.e., green for chloroplasts or photosynthetic bacteria). They should also identify the names of the bacteria used for these models or pictures. Display the models and posters where all students can observe them. Co-op Learning

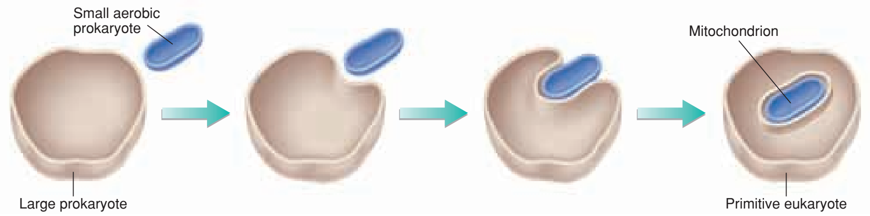

Figure 6 **Endosymbiosis**

Mitochondria are thought to have evolved from small, aerobic prokaryotes that began to live inside larger prokaryotes.

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Keyword: HX4068
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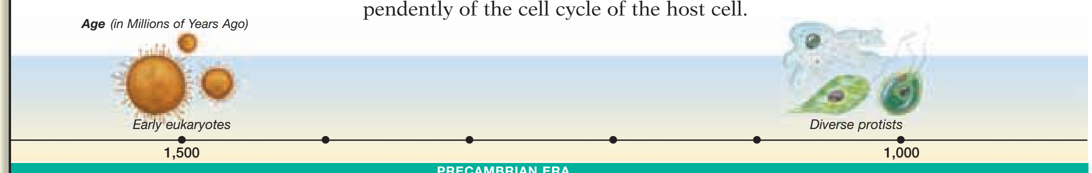
According to Lynn Margulis's theory of endosymbiosis, bacteria entered large cells either as parasites or as undigested prey as illustrated in **Figure 6.** Instead of being digested, the bacteria began to live inside the host cell, where they performed either cellular respiration (mitochondria) or photosynthesis (chloroplasts). The invading bacteria that became chloroplasts were probably closely related to cyanobacteria. Both mitochondria and chloroplasts have characteristics that are similar to those of bacteria. The following observations support the idea that mitochondria and chloroplasts descended from bacteria:

1. **Size and structure.** Mitochondria are about the same size as most eubacteria, and chloroplasts are the same size as some cyanobacteria. Both mitochondria and chloroplasts are surrounded by two membranes. The smooth outer membrane of mitochondria is thought to be derived from the endoplasmic reticulum of the larger host cell. The inner membrane of mitochondria is folded into many layers, so it looks like the cell membranes of aerobic eubacteria. Inside this membrane are proteins that carry out cellular respiration. Both chloroplasts and cyanobacteria contain thylakoids, structures in which photosynthesis takes place.
2. **Genetic material.** Mitochondria and chloroplasts have circular DNA similar to the chromosomes found in bacteria. Both chloroplasts and mitochondria contain genes that are different from those found in the nucleus of the host cell.
3. **Ribosomes.** Mitochondrial and chloroplast ribosomes have a size and structure similar to the size and structure of bacterial ribosomes.
4. **Reproduction.** Like bacteria, chloroplasts and mitochondria reproduce by simple fission. This replication takes place independently of the cell cycle of the host cell.



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MEDICINE CONNECTION

Inside nearly every cell are mitochondria, the tiny structures that provide the cell with energy. Each mitochondrion contains a circular chromosome. Several rare diseases are caused by abnormal genes carried by the chromosome inside a mitochondrion. Mitochondrial genes code primarily for proteins in the electron transport chain and for ATP synthase. Defects in one or more of these proteins thus reduce the amount of ATP the cell can make. One disease, mitochondrial myopathy, causes weakness, exercise intolerance, and muscle deterioration. In addition, at least some cases of diabetes and heart disease, as well as other disorders such as Alzheimer's disease, have been linked to mitochondrial genes.

When an egg is fertilized, only mitochondria from the egg become part of the developing fetus; all mitochondria from the sperm are discarded. Therefore, diseases caused by abnormal mitochondrial genes are transmitted by the mother. A father with abnormal mitochondrial genes can't transmit any such diseases to his children.

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Multicellularity

Many biologists group all living things into six broad categories called kingdoms. The two oldest kingdoms, Eubacteria and Archaebacteria, are made up of single-celled prokaryotes. The first eukaryotic kingdom was the kingdom Protista. **Protists** make up a large, varied group that includes both multicellular and unicellular organisms. The other three kingdoms (fungi, plants, and animals) evolved later and also consist of eukaryotes.

The unicellular body plan has been tremendously successful, with unicellular organisms today constituting about half the biomass (the total weight of all living things) on Earth. But a single cell must carry out all of the activities of the organism. Distinct types of cells in one body can have specialized functions. For example, some organisms may have specific cells that help the organism protect itself from predators or disease. Other cells may help the organism resist drying out. Other examples of specialized cells include cells that help a multicellular organism move about in order to find a mate or food. With all these advantages, it is not surprising that multicellularity has arisen independently many times.

Almost every organism large enough to see with the naked eye is multicellular. Most protists, such as those shown in **Figure 7,** are single celled, but there are many multicellular forms. The development of multicellular organisms of the kingdom Protista marked an important step in the evolution of life on Earth. The oldest known fossils of multicellular organisms were found in 700 million year-old rocks.

Some of the multicellular lines that resulted did not produce diverse groups of organisms. Among those groups of organisms that survive today are plantlike red, green, and brown algae, shown in **Figure 8.** You may know these algae as seaweed. Three of the multicellular groups that evolved from the protists were very successful, producing three separate kingdoms—Fungi, Plantae, and Animalia. Each of these three kingdoms evolved from a protistan ancestor.

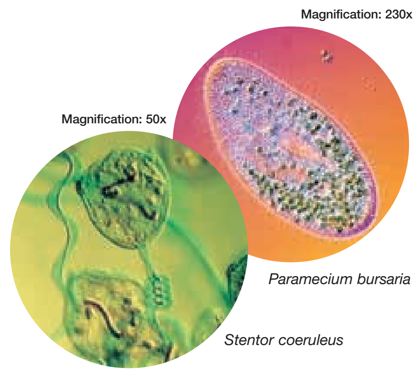
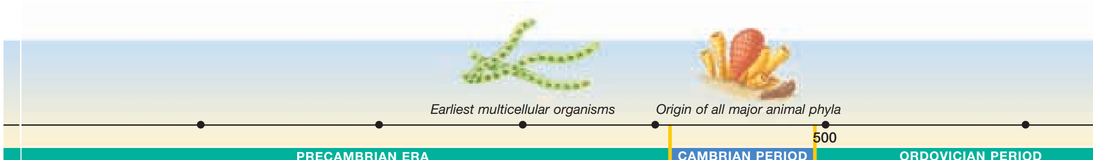


Figure 7 Single-celled protists. Single-celled protists occur in many shapes and can live in many different types of environments, including water and land.

Figure 8 Brown algae. Brown algae, called kelps, are multicellular protists that form vast underwater "forests" in some coastal waters.



Teaching Tip — General

Multicellularity and Cellular Specialization It is important that students recognize the relationship between multicellularity and the division of labor among different types of cells. Illustrate these concepts with the following analogy. Modern industry uses individual workers' skills and abilities to perform different tasks. Use as an example a local industry (such as an automotive plant, steel mill, canning company, or meat packing plant) to show how more is produced, both in quantity and complexity, by breaking the total task into smaller parts that are accomplished by workers trained to do that specific task. Point out that cells exhibit the same type of departmentalizing.

Activity — Advanced

Favorite Fossils Have students pick an extinct species that interests them and write a short report about it. Ask students to address the following questions: When, where, and how did the species live? What evidence do we have that the species lived at all? Why might it have become extinct? Do you see a relationship between this species and a modern species? Have students include with their reports an artist's rendition of their species or a picture of a fossil of the species.
LS Verbal

Demonstration — General

Bring to class a variety of fossils. Petrified wood, diatomaceous earth, trilobites, casts and molds of small fish, mollusks, and coprolites (petrified feces) usually are inexpensive and easy to obtain. Fossils are also available through biological supply houses or other retail dealers. Assign identification or classification activities using the specimens.
LS Visual

OCEANOGRAPHY CONNECTION

Sponges have a variety of sexual and asexual reproductive modes. They are best known for their quite remarkable regenerative powers. This is illustrated by the classic experiment of forcing a piece of sponge through a sieve, which separates the cells of the organism. Within a short period of time the dissociated cells aggregate and reform a multicellular organism. This cannot be achieved by all sponge species.

The ability to regenerate is related to asexual reproduction. A bud or small fragment broken from the parent sponge can generate a new sponge. Some sponges produce specialized asexual reproductive bodies called gemmules. These consist of food-filled archeocytes and amoebocytes. The amoebocytes are capable of giving rise to any other type of cell. Gemmules remain viable for extended periods of time. When suitable conditions are found, a gemmule can grow to form a new sponge that is genetically identical to the parent. Gemmules provide a means of dispersal and are a way of maintaining local distribution and abundance.

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Teach, *continued*

Teaching Tip — GENERAL

Cambrian Explosion Point out to students that the diversity of multicellular organisms expanded rapidly during the period known as the Cambrian explosion. Changing geological and atmospheric conditions during this time period are thought to have increased the number of available habitats for animals. Primitive multicellular organisms could then specialize differently, become more complex, and take advantage of the newly available resources. This first explosion of biological diversity was the foundation from which most complex life existing today evolved.

Activity — ADVANCED

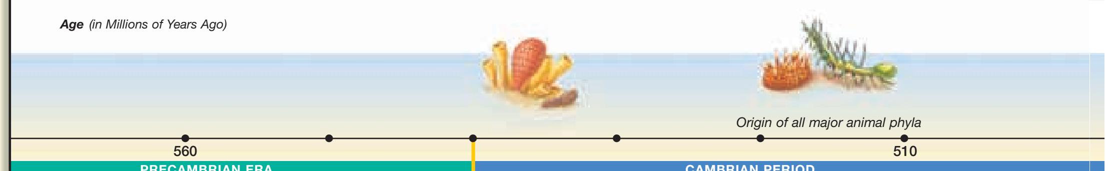
Burgess Shale Have students use library or Internet resources to research the Burgess Shale. Fossil evidence from the shale suggests that animals with a wide variety of body plans existed very early in evolutionary history. Have students search for organisms that would be considered unusual (even bizarre) today, and make simple sketches of them.

Origins of Modern Organisms

Most animal phyla that exist today probably originated during a relatively short time (most estimates range from 10 to 100 million years) during the late Precambrian and early Cambrian periods. This rapid diversification of animals is sometimes known as the "Cambrian explosion." The Cambrian period was a time of great evolutionary expansion, as shown in **Figure 9.** Many unusual marine animals also appeared at this time, animals for which there are no close living relatives. A very rich collection of Cambrian fossils was uncovered in 1909 in a geological formation in Canada called the Burgess Shale. The fossils in the Burgess Shale include those of strange animals that are not like anything alive today.

The Ordovician period, which followed the Cambrian period, lasted from about 505 million to 438 million years ago. During this time, many different animals continued to abound in the seas. Among them were trilobites, marine arthropods that became extinct about 250 million years ago, shown in Figure 9.

Figure 9 Appearance of a Cambrian sea. By studying fossils from the Cambrian period, such as the trilobite fossil below, artists re-create a scene from the shallow seas of the Cambrian period.



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Trends in Astrophysics

Cause of Mass Extinction Earth's most severe mass extinction, which happened 250 million years ago, may have been triggered by a collision with a comet or asteroid. Over 90 percent of all marine species and 70 percent of land vertebrates perished as a result. Some scientists hypothesize that the collision wasn't directly responsible for the extinction, but rather triggered a series of events, such as massive volcanism and changes in ocean oxygen, sea level, and climate. That in turn led to wholesale loss of species.

Scientists don't know the site of the impact 250 million years ago, when all Earth's land formed a supercontinent called Pangaea. There is strong evidence suggesting the extinction happened very rapidly, on the order of 8,000 to 100,000 years.

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Mass Extinctions

The fossil record indicates that a sudden change occurred at the end of the Ordovician period. About 440 million years ago, a large percentage of the organisms on Earth suddenly became extinct. **Extinction** is the death of all members of a species. This was the first of five major mass extinctions that have occurred on Earth. A **mass extinction** is an episode during which large numbers of species become extinct.

Another mass extinction of about the same size happened about 360 million years ago. The third and most devastating of all mass extinctions occurred at the end of the Permian period, about 245 million years ago. About 96 percent of all species of animals living at the time became extinct. About 35 million years later, a fourth, less devastating mass extinction occurred. Although the specific causes of these extinctions are unknown, evidence indicates that worldwide geological and weather changes were likely factors. The fifth mass extinction will be discussed in more detail in a later chapter. It occurred 65 million years ago and brought about the extinction of about two-thirds of all land species, including most of the dinosaurs.

Some scientists think that another mass extinction is occurring today. These scientists reason that this new extinction is taking place because the Earth's ecosystems, especially tropical rain forests, are being destroyed by human activity, as shown in **Figure 10.** The world has already lost half its tropical rain forests. If the current rate of destruction continues, from 22 percent to 47 percent of Earth's plant species will be lost, along with 2,000 of the world's 9,000 species of birds and countless insect species. This would be an astonishing loss of biodiversity.

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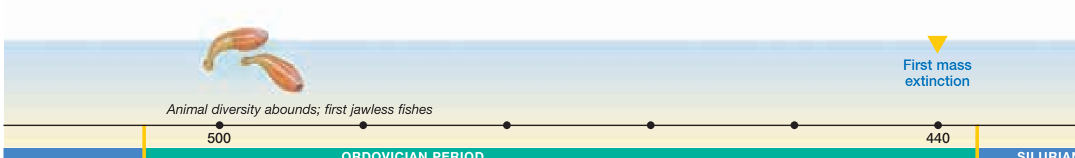
Figure 10 Rain forests are being destroyed at an alarming rate. Although tropical rain forests cover only 7 percent of the Earth's land surface, they contain more than one-half of all the world's animal and plant species.

Section 2 Review

1. **Contrast** the two major groups of prokaryotes.
2. **Analyze** Margulis's theory of endosymbiosis, citing its strengths and weaknesses.
3. **Compare** bacteria with eukaryotes.
4. **Summarize** how multicellularity advanced the evolution of protists.
5. **Critical Thinking Justify** the argument that today's organisms would not exist if mass extinctions had not occurred.
6. **Standardized Test Prep** The kingdom that includes both multicellular and unicellular eukaryotes is called
   A Plantae.
   B Protista.
   C Eubacteria.
   D Archaebacteria.



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Close

Reteaching — Basic

Have students write a one-page summary of this section. Ask them to be sure to include a timeline indicating all of the evolutionary advancements they describe.

Quiz — General

1. When did the first life form appear on Earth? (Over 2.5 billion years ago)
2. What cellular organelles are thought to have derived from bacterial cells? (Mitochondria and chloroplasts were probably bacteria that became endosymbionts with pre-eukaryotic organisms.)
3. During what geologic time period did multicellular life forms on Earth significantly increase in diversity? (The Cambrian period)

Alternative Assessment — General

Divide the class into two teams. Have each team write ten true or false questions about the material in this section. A spokesperson for one team should pose the questions to the other team. Give two points for each correct answer. Give students one point for each of their own questions that was answered correctly. Tally the scores, and declare a winning team.

Answers to Section Review

1. Eubacteria contain peptidoglycan in their cell walls. Archaebacteria lack peptidoglycan and their cell membrane lipids differ from eukaryotes.
2. Eukaryotes probably evolved through endosymbiosis. Refer to the text to check students' answers.
3. Unlike eukaryotes, bacteria have no membrane-bounded cellular inclusions; bacterial DNA is in a single loop, unlike the chromosomal DNA of eukaryotes; and bacteria have cell walls, unlike eukaryotic protists.
4. The development of multicellularity in protists allowed for cell specialization.
5. The ancestors of many living species filled niches vacated by organisms that died in mass extinctions.
6. **A.** Incorrect. The organisms in kingdom Plantae are all multicellular eukaryotes. **B.** Correct. Organisms in the kingdom Protista may be unicellular or multicellular eukaryotes. **C.** Incorrect. Eubacteria are single-celled prokaryotes. **D.** Incorrect. Archaebacteria are single-celled prokaryotes.

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Section 3

Focus

Overview

Before beginning this section review with your students the objectives listed in the Student Edition. Tell students that the purpose of this section is to teach them about how the conditions of Earth's atmosphere make it possible for organisms to live on land. They will learn about the challenges of living on land and about the succession of organisms that moved from the oceans onto land.

Bellringer

Have students write down some of the differences they recognize between ocean-dwelling and land-dwelling organisms. (You might suggest that they consider how organisms support themselves and move around, how they obtain food, how they protect themselves from dangers, and how they reproduce.) Ask them to consider all kinds of organisms, not just animals.

Motivate

Discussion/Question — GENERAL

Ask students if ozone is a desirable part of our atmosphere. (Most will answer yes.) Then ask if ozone is always a desirable part of our atmosphere. (At lower elevations, ozone contributes to pollution; at higher elevations, however, ozone absorbs much of the damaging ultraviolet radiation that would otherwise reach Earth where it could harm living things.) LS Verbal

Section 3 Life Invaded the Land

Objectives

- **Relate** the development of ozone to the adaptation of life to the land.
- **Identify** the first multicellular organisms to live on land.
- **Name** the first animals to live on land.
- **List** the first vertebrates to leave the oceans.

Key Terms

mycorrhizae
mutualism
arthropod
vertebrate
continental drift

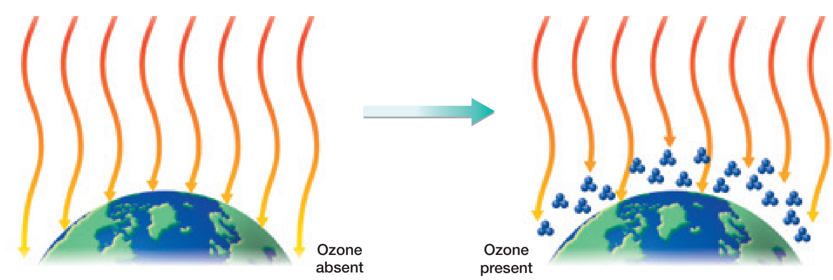
The Ozone Layer

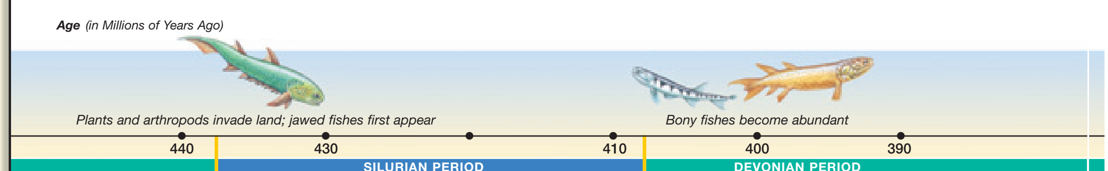
The sun provides both life-giving light and dangerous ultraviolet radiation. Early in Earth's history, life formed in the seas, where early organisms were protected from ultraviolet radiation. These organisms could not leave the water because ultraviolet radiation made life on dry ground unsafe. What enabled life-forms to leave the protection of the seas and live on the land?

Formation of the Ozone Layer

During the Cambrian period and for millions of years afterward, organisms did not live on the dry, rocky surface of Earth. However, a slow change was taking place. About 2.5 billion years ago, photosynthesis by cyanobacteria began adding oxygen to Earth's atmosphere. As oxygen began to reach the upper atmosphere, the sun's rays caused some of the molecules of oxygen, O_2, to chemically react and form molecules of ozone, O_3. In the upper atmosphere, ozone blocks the ultraviolet radiation of the sun, as shown in **Figure 11.** After millions of years, enough ozone had accumulated to make the Earth's land a safe place to live.

Figure 11 Ozone shields the Earth
As ancient cyanobacteria added oxygen to the atmosphere, ozone began to form.





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Chapter Resource File
- Directed Reading BASIC
- Active Reading GENERAL

Transparencies
TR Bellringer
TR D7 Ozone Shields the Earth

One-Stop Planner CD-ROM
- Reading Organizers BASIC
- Reading Strategies BASIC
- Supplemental Reading Guide *The Dinosaur Heresies* ADVANCED

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Plants and Fungi on Land

The first multicellular organisms to live on land may have been fungi living together with plants or algae. Such paired organisms were able to live on land because each group possessed a quality needed by the other.

Plants, which likely evolved from photosynthetic protists, could carry out photosynthesis. In photosynthesis, plants use the energy from sunlight to make carbohydrates. Plants cannot, however, harvest needed minerals from bare rock. In contrast, fungi cannot make nutrients from sunlight but can absorb minerals—even from bare rock.

Early plants and fungi formed biological partnerships called mycorrhizae *(MIE koh RIE zee)*, which enabled them to live on the harsh habitat of bare rock. **Mycorrhizae**, which exist today, are symbiotic associations between fungi and the roots of plants, as shown in **Figure 12.** The fungus provides minerals to the plant, and the plant provides nutrients to the fungus. This kind of partnership is called mutualism. **Mutualism** is a relationship between two species in which both species benefit. Plants and fungi began living together on the surface of the land about 430 million years ago.

Fossilized *Cooksonia*

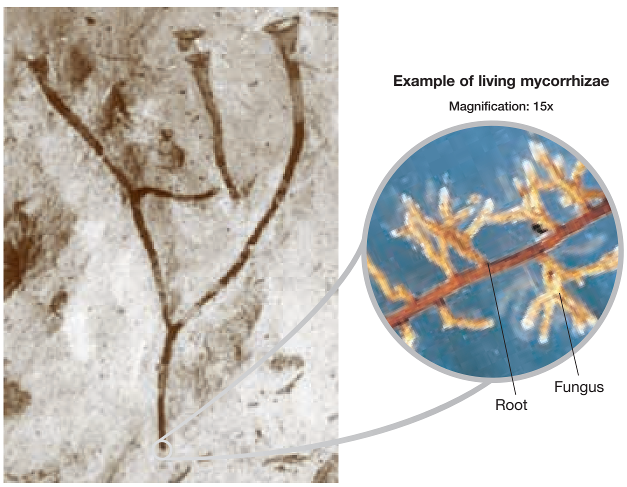
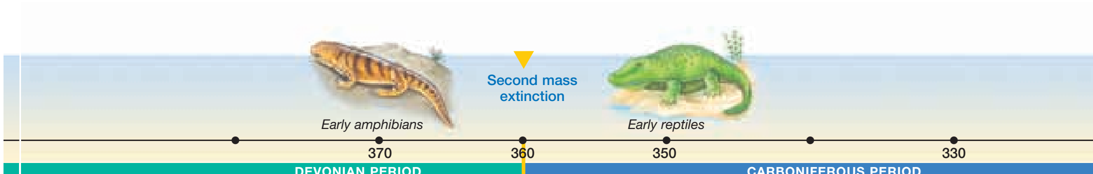


Figure 12 Mycorrhizae formed on the roots of the first plants. This fossil is of *Cooksonia*, the first known vascular plant, which lived 410 million year ago. *Cooksonia* was only a few centimeters tall. *Cooksonia*'s roots formed mycorrhizae similar to the living mycorrhizae shown in color to the left.



Teach

Teaching Tip — GENERAL

Hard As a Rock Ask students: what kinds of organisms could survive on bare rock? What would it take to be successful? (Students may suggest an association similar to lichen, in which a fungus and a cyanobacterium or alga coexist in a symbiotic relationship.) Remind students that as life emerged from the oceans, living things were confronted with this kind of problem. **LS Verbal**

SKILL BUILDER — ADVANCED

Math Skills Tell students that an experiment was conducted in which pine seedlings were grown from seed in soil with or without mycorrhizae. After several months of growth, the plants were harvested and dried, and their weights and contents of certain nutrients were measured. The following averaged data were obtained:

Plant Composition

	Without Mycorrhizae	With Mycorrhizae
Dry weight (g)	321	405
Nitrogen (g)	0.85	1.24
Phosphorus (g)	0.07	0.20
Potassium (g)	0.43	0.74

Have students calculate the percent increase in dry weight, nitrogen content, phosphorus content, and potassium content for the plants grown in soil with mycorrhizae, compared with plants grown in soil without mycorrhizae. (Dry weight: 26.2% higher with mycorrhizae; nitrogen content: 45.9% higher; phosphorus content: 185.7% higher; potassium: 72.1% higher) Have students prepare an appropriate graph of these results and write a paragraph of conclusions about them. **LS Logical**

Trends in Paleobotany

Closest Living Relative of First Land Plants
Some 470 million years ago, the first land plants emerged from prehistoric waters, put down roots in soil, and ended up ruling the plant world. But scientists haven't been certain about the family history of those pioneer plants.

By studying gene sequences of common freshwater algae, a team of University of Maryland researchers, funded by the National Science Foundation (NSF), has traced this family tree and identified the closest living relatives of the first land plants. Charales, a group of green algae which survives today in freshwater around the world, was confirmed to be the descendant. Data show that land plants and the Charales both evolved from a common ancestor that was a fairly complex organism. Among its characteristics were branching threads and reproduction with eggs and sperm.

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Teach, *continued*

Activity — ADVANCED

Coevolution of Insects and Plants Have students conduct library or Internet research on an example of an insect species and a plant species that have coevolved. Some examples that students could investigate are yucca plants and their moth pollinators, and various orchid species and their bee or wasp pollinators. Have students write a brief report on their findings that includes a description of the structural and functional adaptations of both members of the partnership, the "costs" and "benefits" to both species, and characteristics of the environment in which the two species are found that might influence the partnership.

INCLUSION *Strategies*

- ***Learning Disability***
- ***Developmental Delay***

Have students create their own resource documents of animal classification. The *Arthropod Guide* and the *Vertebrate Guide* would each contain lists, pictures, descriptions, and approximate time of each animal's appearance on Earth. Students can design a cover for each guide and a page for each type of animal they research. The completed guides may be used as tools for students to exchange with each other and study.

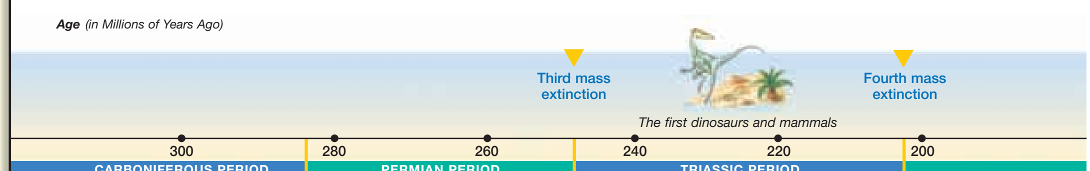
Figure 13 An arthropod. This marbled spider is a member of the phylum Arthropoda, which includes about 1 billion billion (10^{18}) individuals in about 1.5 million described species.

Arthropods

By 100 million years after their first union with fungi, plants had covered the surface of the Earth, forming large forests. These land plants provided a food source for land-dwelling animals. The first animals to successfully invade land from the sea were arthropods. An **arthropod** is a kind of animal with a hard outer skeleton, a segmented body, and paired, jointed limbs. Examples of arthropods include lobsters, crabs, insects, and spiders, like the one in **Figure 13.** Biologists think a type of scorpion was the first arthropod to live on land.

A unique kind of terrestrial arthropod—the insect—evolved from the first land dwellers. Insects have since become the most plentiful and diverse group of animals in Earth's history. The success of the insects is probably connected to their ability to fly. Insects were the first animals to have wings. Flying allowed insects, like the dragonfly shown in **Figure 14,** to efficiently search for food, mates, and nesting sites. It also led to partnerships between insects and flowering plants. The oldest known fossils of flowering plants are from about 127 million years ago, but flowering plants may be much older than that.

Figure 14 Swamp 320 million years ago. Forested swamps were dominated by tall, seedless canopy trees and shorter tree ferns. Dragonflies had wingspans of more than 1 m (about 3.25 ft).



MISCONCEPTION ALERT

Evolution Some students mistakenly view evolution as individuals changing into new forms, rather than populations changing over periods of time longer than the lifetime of an individual organism. An individual organism begins life with a particular set of genes. This organism may take on different characteristics depending on the kind of environment it grows in, but its genes are not modified. When the organism reproduces, it passes half of its genes (in sexual reproduction) to each of its offspring. The organisms that reproduce are those that have a combination of genes that make them well adapted to their environment. The process of natural selection operates on every generation. Over many generations, the genetic composition of the organisms living in the environment might become different from what it was when their ancestors first lived in that environment. It is this change that constitutes evolution.

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Vertebrates

A **vertebrate** is an animal with a backbone—vertebrates are the animals most familiar to us. Humans are vertebrates, and almost all other land animals bigger than our fist are vertebrates as well.

Fishes

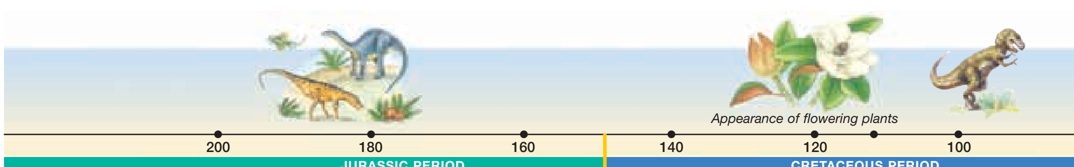
According to the fossil record, the first vertebrates were small, jawless fishes that evolved in the oceans about 530 million years ago. Jawed fishes first appeared about 430 million years ago. Jaws enabled fishes to bite and chew their food instead of sucking up their food. As a result, jawed fishes were efficient predators. A fossilized example of a jawed fish is shown in **Figure 15.** Fishes soon came to be among the most abundant animals in the seas, and for hundreds of millions of years the sea is where vertebrates stayed. Fishes are the most successful living vertebrates—they make up more than half of all modern vertebrate species. After nearly 200 million years of living in the sea, fishes have become uniquely adapted for success in water. Major changes had to occur in fish body organization, however, before some descendants of fishes became capable of living on land.

Figure 15 Fossilized fish skeleton. This fish skeleton clearly shows the backbone, the structure that is characteristic of all vertebrate animals.

Amphibians

The first vertebrates to inhabit the land did not come out of the sea until 370 million years ago. Those first land vertebrates were early amphibians. Amphibians are smooth-skinned, four-legged animals that today include frogs, toads, and salamanders.

Several structural changes in the bodies of amphibians occurred as they adapted to life on land. Amphibians had moist breathing sacs—lungs—which allowed the animals to absorb oxygen from air. The limbs of amphibians are thought to have derived from the bones of fish fins. The evolution of a strong support system of bones in the region just behind the head made walking possible. This system of bones provided a rigid base for the limbs to work against. Because of their strong, flexible internal skeleton, the bodies of vertebrates can be much larger than those of insects. While amphibians were well adapted to their environment, a new group of animals more suited to a drier environment evolved from them.



did you know?

Mammals of the Sea Mammals that live in the ocean range in size from the furry, five-foot-long sea otter to the hundred foot long blue whale. Like us, these creatures are warm-blooded animals that breathe air and nurse their young. The cetaceans (whales, dolphins, porpoises) descended from a cow-like ancestor that returned to ocean life about 65 million years ago. The streamlined, fishlike whale doesn't resemble its ancestor. With one or two nostrils on the top of its head, a whale can easily breathe at the surface without lifting its head. Its tail is powerful enough to push the whale through the water. The pinnipeds (seals and sea lions) are agile swimmers with tapering bodies and strong flippers, but they still retain many ties to the land. Most return to shore to mate and give birth. The sea otter adapted to life in the ocean over the past four million years. It still resembles the weasel, its relative on land. Sea otters live close to shore; they are not as well equipped for the open ocean as the streamlined, deep-diving seals and whales.

Teaching Tip — BASIC

Clamping Down Advantages
The lamprey, a jawless fish alive today, is a parasite. Without jaws, it can merely attach to a host and try to gain nutrition by sucking. Help students appreciate the importance of jaws by having each name a vertebrate predator. (Answers will vary.) How does each predator catch and eat its prey? For every case, direct the discussion to the important role of the predator's jaws in its successful lifestyle. (If not directly involved in capture, jaws are important in ingesting food.)

Demonstration — GENERAL

Distribute soft gelatin-based candy such as "gummy worms" to the class and challenge small groups of students to create an internal skeleton for some worms and an external skeleton for others, using toothpicks and tape. Caution students not to eat the candy. Have the groups share their progress and results with the class. Ask which type of skeleton requires less material and weighs less. (The internal [endo-] skeleton should be smaller and lighter.)
LS Kinesthetic Co-op Learning

Demonstration — BASIC

Crack open an egg in a Petri dish. In another Petri dish, place an intact egg. Weigh each egg-and-dish combination and record the weight, then store the eggs in a refrigerator, if possible. At the end of 2 days, crack open the intact egg and compare it to the exposed egg. Record the similarities and differences between the two, then reweigh both Petri dishes. Have students explain which egg setup showed the greater difference in weight and why. (The opened egg should weigh less, because of evaporation, and may show signs of decomposition. The other egg was protected by a shell that prevents water loss and should be in good condition.) **LS Visual**

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Close

Reteaching — Basic

Draw a table on the board. Across the top of the table, write these four headings: Evolutionary History, Structural Features, Special Adaptations, and Examples. Down the left side of the table write these seven classes: Jawless fishes, Sharks (cartilaginous fishes), Bony fishes, Amphibians, Reptiles, Birds, and Mammals. Have students take turns filling in the information.

Quiz — General

1. In what ways did the evolution of flight and an endoskeleton provide advantages for the organisms that possessed these traits? (Both flight and an endoskeleton aid an animal's movement on land.)
2. What are amphibian legs thought to be derived from? (The fins of bony fishes are thought to be the precursors of amphibian legs.)

Alternative Assessment — General

Tell students to return to the list of things they want to know about how life began. Have them place check marks next to the questions that they are now able to answer. Students should finish by making a list of what they have learned. Ask students the following: Which questions are still unanswered? What new questions do you have? You may wish to assign projects that require students to research their unanswered questions.

Figure 16 Reptiles. Reptiles, such as this crocodile, were the largest group of land-dwelling organisms until the end of the Cretaceous period.

Reptiles

Reptiles evolved from amphibian ancestors about 340 million years ago. Modern reptiles include snakes, lizards, turtles, and crocodiles. Reptiles are better suited to dry land than amphibians because reptiles' watertight skin slows the loss of moisture. Reptiles also have a watertight egg, such as the one shown in **Figure 16.** Unlike amphibians, reptiles can lay their eggs on dry land. Amphibians must lay their eggs in water or in very moist soil because their eggs are unable to retain enough water to remain alive.

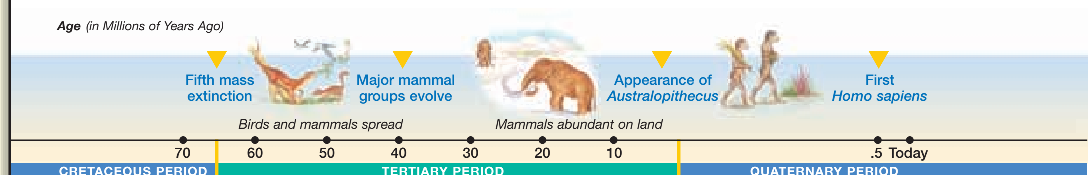
Mammals and Birds

Birds apparently evolved from feathered dinosaurs during or after the Jurassic period. Therapsids, reptiles with complex teeth and legs positioned beneath their body, gave rise to mammals about the same time dinosaurs evolved, during the Triassic period. Sixty-five million years ago, during the fifth mass extinction, most species disappeared forever. All of the dinosaurs except for the ancestors of birds became extinct. The smaller reptiles, mammals, and birds survived. Although many resources were available to the surviving animals, the world's climate was no longer largely dry. Thus the reptiles' advantages in dry climates were not so important. Birds and mammals then became the dominant vertebrates on land.

Both extinctions and continental drift played important roles in evolution. **Continental drift** is the movement of Earth's land masses over Earth's surface through geologic time. Continental drift resulted in the present-day position of the continents. The movement of continents helps explain why there are a large number of marsupial (pouched) mammal species in both Australia and South America, continents that were once connected.

Section 3 Review

1. **Summarize** why ozone was important in enabling organisms to live on land.
2. **Name** the first multicellular organisms that colonized land.
3. **Identify** the first kinds of animals to live on land.
4. **Describe** the first kinds of vertebrates that inhabited land.
5. **Critical Thinking** **Defend** the argument that invasion of land could not have happened until well after the evolution of cyanobacteria.
6. **Standardized Test Prep** Mycorrhizae are mutualistic relationships between the roots of plants and
   A amphibians. **C** cyanobacteria.
   B insects. **D** fungi.



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Answers to Section Review

1. Ozone was essential to protect early land organisms from the sun's ultraviolet rays.
2. Plants and fungi (or mycorrhizae) were the first multicellular land-dwelling organisms.
3. Arthropods were the first animals to live on land.
4. The first land-dwelling vertebrates were amphibians, which had lungs, an endoskeleton, and smooth skin.
5. Cyanobacteria contributed oxygen gas to the atmosphere. Some of this oxygen gas reacted and formed the ozone layer, which was necessary to protect any multicellular organisms from the sun's ultraviolet radiation.
6. **A.** Incorrect. Amphibians and plant roots do not form a mutualistic relationship. **B.** Incorrect. Insects and plant roots may form a relationship, but it is not mycorrhizal. **C.** Incorrect. Cyanobacteria are aquatic organisms that do not form relationships with plant roots. **D.** Correct. Mycorrhizal associations involve plant roots and fungi.

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Study ZONE

CHAPTER HIGHLIGHTS

Key Concepts

1 How Did Life Begin?

- The Earth formed about 4.5 billion years ago according to evidence obtained by radiometric dating.
- The primordial soup model and the bubble model propose explanations of the origin of the chemicals of life.
- Scientists think RNA formed before DNA or proteins formed.
- Scientists think that the first cells may have developed from microspheres.
- The development of heredity made it possible for organisms to pass traits to subsequent generations.

2 Complex Organisms Developed

- Prokaryotes are the oldest organisms and are divided into two groups, archaebacteria and eubacteria.
- Prokaryotes likely gave rise to eukaryotes through the process of endosymbiosis.
- Mitochondria and chloroplasts are thought to have evolved through endosymbiosis.
- Multicellularity arose many times and resulted in many different groups of multicellular organisms.
- Extinctions influenced the evolution of the species alive today.

3 Life Invaded the Land

- Ancient cyanobacteria produced oxygen, some of which became ozone. Ozone enabled organisms to live on land.
- Plants and fungi formed mycorrhizae and were the first multicellular organisms to live on land.
- Arthropods were the first animals to leave the ocean.
- The first vertebrates to invade dry land were amphibians.
- The extinction of many reptile species enabled birds and mammals to become the dominant vertebrates on land.
- The movement of the continents on the surface of the Earth has contributed to the geographic distribution of some species.

Key Terms

Section 1

radiometric dating (252)
radioisotope (252)
half-life (252)
microsphere (256)

Section 2

fossil (258)
cyanobacteria (258)
eubacteria (258)
archaebacteria (258)
endosymbiosis (259)
protist (261)
extinction (263)
mass extinction (263)

Section 3

mycorrhizae (265)
mutualism (265)
arthropod (266)
vertebrate (267)
continental drift (268)

Study ZONE

Alternative Assessment — GENERAL

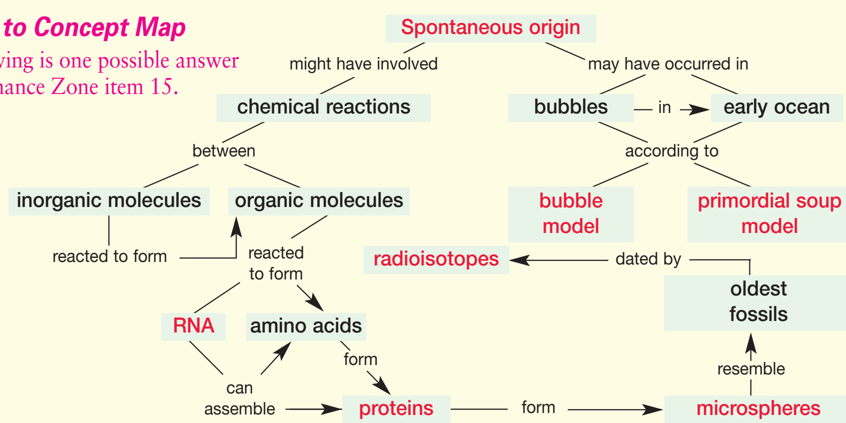
Have students prepare a blank bingo card with 25 squares, and label the center square FREE. Write 24 terms or short phrases on the board. Have students write in each term or phrase in random order, filling all of the squares on their bingo cards. Next, have students cross out the appropriate square each time a definition or clue is provided. Students call out “bingo” whenever a horizontal, vertical, or diagonal line is completed.

Chapter Resource File

- Science Skills Worksheet GENERAL
- Critical Thinking Worksheet ADVANCED
- Test Prep Pretest GENERAL
- Chapter Test GENERAL

Answer to Concept Map

The following is one possible answer to Performance Zone item 15.



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ANSWERS

Understanding Key Ideas

1. d
2. b
3. d
4. d
5. c
6. The theory of endosymbiosis is supported by the observations that mitochondria reproduce by binary fission, and that they have their own genes that are separate and distinct from nuclear genes.
7. After four half-lives, the sample would have 1.625 g of carbon-14.
8. 1 billion years
9. Producers (plants) colonized the land first,
providing food for consumers of plants and,
in turn, consumers of the consumers, or predators. In this way, energy was gathered from the sun by land plants and then passed through the food web, from herbivores to carnivores.
10. One possible answer to Performance Zone item 15 is on the Study Zone page.

Critical Thinking

11. Evolution would continue after a mass extinction. In the remaining organisms, there would be traits that would help ensure some survival to the point of reproduction. These traits would be amplified within populations. New niches would then cause new species to evolve.
12. Answers may vary. Students may propose that changes in the sea environment might have increased selection pressure and resulted in rapid evolution and diversification.

Alternative Assessment

13. Answers will vary.
14. Answers will vary.
15. Students' research may identify a variety of scientific hypotheses for the origin of life. Possibilities include the proposed assembly of complex biological molecules on clay or other mineral substrates, hypotheses of the "RNA world" which holds that RNA acted both as a catalyst and as the first hereditary molecule, and so on."

Performance ZONE

CHAPTER REVIEW

Understanding Key Ideas

1. After three half-lives of a radioisotope have passed, how much of the original radioisotope has decayed?
a. 1/8 **c.** 3/4
b. 1/2 **d.** 7/8

2. Unlike the primordial soup model, Lerman's bubble model takes ______ into account.
a. ozone
b. ultraviolet radiation
c. lightning
d. volcanoes

3. Cells are different from microspheres because cells
a. contain amino acids.
b. have a two-layer outer boundary.
c. grow by taking in molecules from their surroundings.
d. transfer information through heredity.

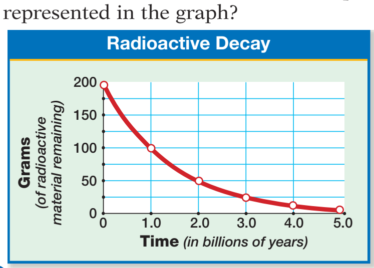
4. Cell specialization came about as a result of
a. endosymbiosis. **c.** the Cambrian period.
b. archaebacteria. **d.** multicellularity.

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

6. Describe the evidence that supports the theory of endosymbiosis.

7. The half-life of carbon-14 is 5,700 years. If a sample originally had 26 g of carbon-14, how much would it contain after 22,800 years?

8. What is the half-life of the radioisotope represented in the graph?



9. Relate the order in which different types of organisms invaded the land to the flow of energy. (**Hint:** See Chapter 5, Section 1.)

10. **Concept Mapping** Construct a concept map that shows how life might have originated by natural forces. Include the following items in your map: *spontaneous origin, primordial soup model, bubble model, RNA, proteins, microspheres,* and *radioisotopes.*

Critical Thinking

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

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

Alternative Assessment

13. Being a Team Member Work together in groups to design a poster to illustrate the different models that describe how life's chemicals may have originated. Show how the compounds on early Earth would have participated in each of these models.

14. Finding and Communicating Information 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. Relate your findings in an oral report.

15. Finding and Communicating Information Use the media center or Internet resources to study scientific hypotheses for the origin of life that are alternatives to the hypotheses proposed by Oparin and Lerman. Analyze either Oparin's or Lerman's hypotheses as presented in your textbook along with one alternative scientific hypotheses that you discover in your research.

Assignment Guide

Section	Questions
1	1, 2, 3, 7, 8, 10, 13, 15
2	4, 6, 11, 12, 14
3	5, 10

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Standardized Test Prep

Understanding Concepts

***Directions (1–3):* For *each* question, write on a separate sheet of paper the letter of the correct answer.**

1 What did the development of heredity allow organisms to store and pass on to their offspring?
- **A.** energy
- **B.** information
- **C.** radioisotopes
- **D.** UV radiation

2 A cell's surface-area-to-volume ratio limits the size that unicellular organisms can achieve. How can multicellularity solve this problem?
- **F.** As a cell grows in size, its surface-area-to-volume ratio increases, which improves the efficiency of the cell.
- **G.** Multicellular organisms tend to have larger cells than unicellular organisms, which makes them stronger.
- **H.** Communication between the nucleus and other parts of the cell is faster in larger cells than in smaller cells.
- **I.** An organism with many small cells has a greater surface-area-to-volume ratio than an organism with one large cell.

3 Photosynthesis in what organisms originally formed the oxygen that became ozone in Earth's atmosphere?
- **A.** archaebacteria
- **B.** arthropods
- **C.** cyanobacteria
- **D.** mycorrhizae

***Directions (4):* For the following question, write a short response.**

4 Identify and describe the event that resulted in the origin of eukaryotes.

Test TIP

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

Reading Skills

***Directions (5):* Read the passage below. Then answer the question.**

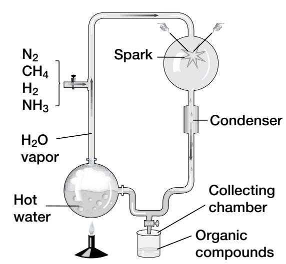
Originally, there were no organisms living on dry land. One factor that contributed to this occurrence was that outside of an aquatic environment, organisms could not get all of the nutrients and minerals they needed to survive. Then, a symbiotic relationship developed between plants and fungi, which provided nutrients for the fungi and minerals for the plants. This allowed them to colonize the bare land. Land plants served as food for insects, which then served as food for amphibians and other organisms.

5 What type of relationship did the plants and fungi have?
- **F.** aquatic
- **G.** microscopic
- **H.** mutualistic
- **I.** predatory

Interpreting Graphics

***Directions (6):* Base your answer to question 6 on the diagram below.**

Experimental Setup



6 What conclusion could be drawn from the results of the experiment shown?
- **A.** Earth's early atmosphere lacked N_2.
- **B.** N_2 and H_2 can be converted into NH_3 when heated.
- **C.** Water can be changed into organic compounds if it is heated vigorously.
- **D.** Organic compounds can form under conditions such as those in the experiment.

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Answers

1. B

2. I

3. C

4. According to the theory of endosymbiosis, bacteria entered large cells and began to live inside host cells. Cyanobacteria likely became chloroplasts and carried out photosynthesis for the host cell. Other bacteria became mitochondria and carried out cellular respiration for the host cell.

5. H

6. D

TEST DOCTOR

Question 2 Answer I is the correct choice. Answer F is incorrect because the opposite is true. As a cell grows in size, its surface-area-to-volume ratio decreases. Answer G is incorrect because multicellular organisms have a variety of cell sizes, and their size does not necessarily make them stronger. Answer H is incorrect because the opposite tends to be true. Communication between the nucleus and other parts of the cell tends to be slower in larger cells than in smaller cells.

Question 4 Endosymbiotic theory proposes that mitochondria are the descendants of symbiotic, aerobic eubacteria, and chloroplasts are the descendants of symbiotic, photosynthetic eubacteria.

Question 5 Answer H is the correct choice. Both plants and fungi benefited from their relationship. Answer F is incorrect because their relationship allowed them to move away from an aquatic environment. Answer G is incorrect because there is no clear indication these organisms were too small to see without a microscope. Answer I is incorrect because their relationship did not involve predation.

Question 6 Answer D is the correct choice. The experiment showed it was possible for organic compounds to form under certain conditions. Answer A is incorrect because Earth's atmosphere was thought to be rich in N_2. Answer B is incorrect because NH_3 is not an organic compound and was not detected in the compound in the collecting chamber. Answer C is incorrect because other compounds besides water were present in the experiment.

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Exploration Lab

Making a Timeline of Life on Earth

Teacher's Notes

Time Required 90 minutes

Ratings

EASY → HARD

Teacher Preparation 2
Student Setup 1
Concept Level 1
Cleanup 1

Skills Required
- Communicating
- Identifying/Recognizing Patterns
- Inferring
- Measuring
- Organizing and Analyzing Data

Scientific Methods

In this lab, students will:
- Make Observations
- Ask Questions
- Draw Conclusions
- Communicate the Results

Materials and Equipment

Materials for this lab can be ordered from WARD'S. See *Master Materials List* at the front of this book for catalog numbers.

Tips and Tricks

Set up stations in various parts of the classroom with specimens, fossils, photographs, or slides of different types of organisms. Provide compound light microscopes if needed. During the first hour (or lab period), have students make their timelines and observe and record data for as many organisms as possible. During the second period, have students complete the investigation.

Exploration Lab

Making a Timeline of Life on Earth

SKILLS
- Observing
- Inferring relationships
- Organizing data

OBJECTIVES
- **Compare** and **contrast** the distinguishing characteristics of representative organisms of the six kingdoms.
- **Organize** the appearance of life on Earth in a timeline.

MATERIALS
- 5 m roll of adding-machine tape
- meterstick
- colored pens or pencils
- photographs or drawings of organisms from ancient Earth to present day

Before You Begin

About 4.5 billion years ago, Earth was a ball of molten rock. As the surface cooled, a rocky crust formed and water vapor in the atmosphere condensed to form rain. By 3.9 billion years ago, oceans covered much of the Earth's surface. Rocks formed in these oceans contain **fossils** of bacterial cells that lived about 3.5 billion years ago. The **fossil record** shows a progression of life-forms and contains evidence of many changes in Earth's surface and atmosphere.

In this lab, you will make a **timeline** showing the major events in Earth's history and in the history of life on Earth, such as the evolution of new groups of organisms and the mass extinctions. This timeline can be used to study how living things have changed over time.

1. Write a definition for each boldface term in the paragraphs above.
2. Make a data table similar to the one at right.
3. Based on the objectives for this lab, write a question you would like to explore about the history of life on Earth.

Procedure

PART A: Making a Timeline

1. Make a mark every 20 cm along a 5 m length of adding-machine tape. Label one end of the tape "5 billion years ago" and the other end "Today." Write "20 cm = 200 million years" near the beginning of your timeline.
2. Locate and label a point representing the origin of Earth on your timeline. Use your textbook as a reference. See the timeline at the bottom of Section 2 and Section 3 of this chapter. Also locate and label the 11 periods of the geologic time scale beginning with the Cambrian period.
3. Using your textbook as a reference, mark the following events on your timeline: the first cyanobacteria appear; oxygen enters the atmosphere; the five mass extinctions; the first eukaryotes appear; the first multicellular organisms appear; the first vertebrates appear; the first plants,

DATA TABLE

Organism	Kingdom	Characteristics/adaptation for life on Earth

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Answers to Before You Begin

1. Definitions: *fossil*—preserved remains or traces of a past life form; *fossil record*—the record of past life-forms found in fossils; *timeline*—a series of events arranged in chronological order.
2. Students should each create a data table as shown.
3. Answers will vary. For example: How did life on Earth change after oxygen entered the atmosphere?

Answers to Procedure

2. The Earth is estimated to be about 4 billion years old. Students should label the 12 divisions of the geologic time scale approximately as follows: *Precambrian time*—>3.5 billion to 540 million; *Cambrian*—540 million to 505 million years ago (mya); *Ordovician*—505 to 438 mya; *Silurian*—438 to 408 mya; *Devonian*—408 to 360 mya; *Carboniferous*—360 to 283 mya; *Permian*—283 to 247 mya; *Triassic*—247 to 203 mya; *Jurassic*—203 to 144 mya; *Cretaceous*—144 to 67 mya; *Tertiary*—67 to 2 mya; and *Quaternary*—1 mya to the present.

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fungi, and land animals appear; the first dinosaurs and mammals appear; the first flowering plants appear; the first humans appear.

4. Look at the photographs of organisms provided by your teacher. Identify the major characteristics of each organism. Record your observations in your data table.
5. Lay out your timeline on the floor in your classroom. Place photographs (or drawings) of the organisms you examined on your timeline to show when they appeared on Earth.
6. Fold the timeline at the mark representing 4.8 billion years ago. This leaves 24 segments, each representing 200 million years, in your timeline. Now you can think of each segment as 1 hour in a 24-hour day.
7. When you are finished, walk slowly along your timeline. Note the sequence of events in the history of life on Earth and the relative amount of time between each event.

PART B: Cleanup and Disposal

8. Dispose of paper scraps in the designated waste container.
9. Clean up your work area and all lab equipment. Return lab equipment to its proper place.

Analyze and Conclude

1. **Analyzing Information** Think of each segment of your timeline as 1 hour in a 24-hour day as you answer each of the following questions:
   - **a.** How long has life existed on Earth?
   - **b.** For what part of the day did only unicellular life-forms exist?
   - **c.** At what time of day did the first plants appear on Earth?
   - **d.** At what time of day did mammals appear on Earth?
2. **Summarizing Information** Identify the major developments in life-forms that have occurred over the last 3.5 billion years.
3. **Inferring Relationships** How do mass extinctions appear to be related to the appearance of new major groups of organisms?
4. **Justifying Conclusions** Cyanobacteria are thought to be responsible for adding oxygen to Earth's atmosphere. Use your timeline to justify this conclusion.
5. **Calculating** Determine the amount of time, as a percentage of the time that life has existed on Earth, that humans *(Homo sapiens)* have existed.
6. **Further Inquiry** Write a new question about the history of life on Earth that could be explored in another investigation.

On the Job

Timelines are used to organize events in chronological order. Do research to discover how other scientists use timelines in their work. For more about careers, visit **go.hrw.com** and type in the keyword **HX4 Careers.**

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3. Cyanobacteria appear—3.5 billion years ago; oxygen enters the atmosphere—2.75 billion years ago; five mass extinctions—440 million years ago (mya), 360 mya, 247 mya, 203 mya, and 65 mya; eukaryotes appear—1.5 billion years ago; multicellular organisms appear—700 mya; vertebrates appear—500 mya; land plants and fungi appear—430 mya; land animals appear—370 mya; dinosaurs and mammals appear—230 mya; flowering plants appear—120 mya; humans appear—500,000 years ago.
4. Answers will vary. See sample data table at the bottom of page 273.
5. Students should place the photograph or specimen at the point on the timeline where that type of specimen appeared. For example, a photograph of a flowering plant should be placed on the timeline at 120 million years ago.

Answers to On the Job

Many types of scientists use timelines in their work. For example, an epidemiologist (a scientist who tracks the emergence and spread of disease) might arrange the known cases of a disease on a timeline to track the events of an outbreak.

Answers to Analyze and Conclude

1. **a.** Life on Earth has existed for at least 17.5 "hours." **b.** Solely unicellular life forms existed for about 14 "hours." **c.** The first plants appeared at about 9:30 PM. **d.** Mammals appeared at about 11 PM.
2. Life has changed from all prokaryotic, unicellular forms to complex multicellular forms composed of eukaryotic cells. A vast variety of living things have lived on Earth during the last 3.5 billion years. Most life forms that evolved have become extinct.
3. Mass extinctions appear to be followed closely by the evolution of many new types of organisms.
4. Cyanobacteria appeared before the accumulation of oxygen in the atmosphere, and cyanobacteria produce oxygen. Therefore, it is reasonable to conclude that they are responsible for adding oxygen to Earth's atmosphere.
5. Humans have existed for 0.014 percent of the time that life has existed on Earth.
6. Answers will vary. Sample answer: How have Earth's climates changed since Precambrian times?

Sample Data Table

ORGANISM	KINGDOM	CHARACTERISTICS/ADAPTATIONS FOR LIFE ON EARTH
Insect (fossil in amber)	Animal	Segmented body, jointed legs, and wings
Fern (fossil mold in shale)	Plant	Large surface area to capture sunlight; reproductive structures on fronds

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