BIG IDEA  Scientists use many types of data collection and experimentation to form hypotheses and theories about how life formed on Earth.

12.1  The Fossil Record

12.2  The Geologic Time Scale

12.3  Origin of Life [TEKS 9D]

12.4  Early Single-Celled Organisms [TEKS 7F, 7G, 11C]

Data Analysis
CALCULATING AXES INTERVALS [TEKS 2G]

12.5  Radiation of Multicellular Life [TEKS 7E]

12.6  Primate Evolution

ONLINE BIOLOGY  HMDScience.com

ONLINE Labs
- Radioactive Decay
- QuickLab  Geologic Clock
- Stride Inferences
- Understanding Geologic Time
- Comparing Indexes Among Primates
- Virtual Lab  Comparing Hominoid Skulls

Video Lab  Model of Rock Strata
What can fossils teach us about the past?

This man, known only as Tollund Man, died about 2200 years ago in what is now Denmark. Details such as his skin and hair were preserved by the acid of the bog in which he was found. A bog is a type of wetland that accumulates peat, the deposits of dead plant material. Older remains from bogs can add information to the fossil record, which tends to consist mostly of hard shells, teeth, and bones.

Chapter 12: The History of Life

USING LANGUAGE
Describing Time  Certain words and phrases can help you get an idea of a past event's time frame (when it happened) and duration (for how long it happened). These phrases are called specific time markers. Specific time markers include phrases such as 1 hour, yesterday, the 20th century, and 30 years later.

YOUR TURN
Read the sentences below, and write the specific time markers.
1. Jennifer celebrated her 16th birthday on Saturday two weeks ago.
2. Dinosaurs became extinct about 65 million years ago, at the end of the Cretaceous Period.
**12.1 The Fossil Record**

**Vocabulary**
- relative dating
- radiometric dating
- isotope
- half-life

**Key Concept**  Fossils are a record of life that existed in the past.

**Main Ideas**
- Fossils can form in several ways.
- Radiometric dating provides a close estimate of a fossil's age.

**Connect to Your World**
Do you ever consider how much the world and its inhabitants have changed in the past 15, 50, or 100 years? Have you studied ancient civilizations that existed thousands of years ago? These time frames are tiny blips on the scale of time revealed by the fossil record. Some of the world’s oldest fossils, found at the Burgess Shale site in Canada, offer a glimpse of what life was like 500 million years before Tollund Man lived. These specimens are keys to understanding the history of life on Earth.

**Main Idea**
Fossils can form in several ways.

Fossils are far more diverse than the giant dinosaur skeletons we see in museums. The following processes are some of the ways fossils form. **FIGURE 1.1** shows examples of fossils produced in these different ways.

- **Permineralization** occurs when minerals carried by water are deposited around a hard structure. They may also replace the hard structure itself.
- **Natural casts** form when flowing water removes all of the original bone or tissue, leaving just an impression in sediment. Minerals fill in the mold, recreating the original shape of the organism.
- **Trace fossils** record the activity of an organism. They include nests, burrows, imprints of leaves, and footprints.
- **Amber-preserved fossils** are organisms that become trapped in tree resin that hardens into amber after the tree gets buried underground.
- **Preserved remains** form when an entire organism becomes encased in material such as ice or volcanic ash or immersed in bogs.

**FIGURE 1.1** The fossil record includes fossils that formed in many different ways.

- Permineralized skeleton of a *Velociraptor* dinosaur
- Natural cast of a crinoid, a marine animal
- Trace fossils of footprints from a *Dimetrodon* dinosaur
- Amber-preserved spider
- Ice-preserved 5000-year-old remains of a man found in the Italian Alps
Most fossils form in sedimentary rock, which is made by many layers of sediment or small rock particles. The best environments for any type of fossilization include wetlands, bogs, and areas where sediment is continuously deposited, such as river mouths, lakebeds, and floodplains.

The most common fossils result from permineralization. Several circumstances are critical for this process, as shown in Figure 1.2. The organism must be buried or encased in some type of material—such as sand, sediment, mud, or tar—very soon after death, while the organism’s features are still intact. After burial, groundwater trickles into tiny pores and spaces in plants, bones, and shells. During this process, the excess minerals in the water are deposited on the remaining cells and tissues. Many layers of mineral deposits are left behind, creating a fossilized record by replacing organic tissues with hard minerals. The resulting fossil has the same shape as the original structure and may contain some original tissue.

With such specific conditions needed for fossilization, it is easy to see why only a tiny percentage of living things that ever existed became fossils. Most remains decompose or are destroyed before they can be preserved. Even successful fossilization is no guarantee that an organism’s remains will be added to the fossil record. Natural events such as earthquakes and the recycling of rock into magma can destroy fossils that took thousands of years to form.

Infer: What conditions could occur that would prevent an organism from being preserved through permineralization?

Summarize: Why are so few complete fossils discovered?
Main Idea

Radiometric dating provides a close estimate of a fossil’s age.

Recall that geologists in the 1700s had realized that rock layers at the bottom of an undisturbed sequence of rocks were deposited before those at the top, and therefore are older. The same logic holds true for the fossils found in rock layers. Relative dating estimates the time during which an organism lived by comparing the placement of fossils of that organism with the placement of fossils in other layers of rock. Relative dating allows scientists to infer the order in which groups of species existed, although it does not provide the actual ages of fossils.

To estimate a fossil’s actual, or absolute, age, scientists use radiometric dating—a technique that uses the natural decay rate of unstable isotopes found in materials in order to calculate the age of that material. Isotopes are atoms of an element that have the same number of protons but a different number of neutrons. Most elements have several isotopes. For example, the element carbon (C) has three naturally occurring isotopes. All carbon isotopes have six protons. Isotopes are named, however, by their number of protons plus their number of neutrons. Thus, carbon-12 (12C) has six neutrons, carbon-13 (13C) has seven neutrons, and carbon-14 (14C) has eight neutrons. More than 98 percent of the carbon in a living organism is 12C.

Some isotopes have unstable nuclei. As a result, their nuclei undergo radioactive decay—they break down—over time. This releases radiation in the form of particles and energy. As an isotope decays, it can transform into a different element. The decay rate of many radioactive isotopes has been measured and is expressed as the isotope’s half-life, as shown in Figure 1.3. A half-life is the amount of time it takes for half of the isotope in a sample to decay into a different element, or its product isotope. An element’s half-life is not affected by environmental conditions such as temperature or pressure. Both 12C and 13C are stable, but 14C decays into nitrogen-14 (14N), with a half-life of roughly 5700 years.

Radiocarbon Dating

The isotope 14C is used commonly for radiometric dating of recent remains, such as those of Tollund Man shown at the beginning of this chapter. Organisms absorb carbon through eating and breathing, so 14C is constantly being resupplied. When an organism dies, its intake of carbon stops, but the decay of 14C continues. The fossil’s age can be estimated by comparing the ratio of a stable isotope, such as 12C, to 14C. The longer the organism has been dead, the larger the difference between the amounts of 12C and 14C there will be. The half-life of carbon-14 is roughly 5700 years, which means that after 5700 years, half of the 14C in a fossil will have decayed into 14N, its decay product. The other half remains as 14C. After 11,400 years, or two half-lives, 75 percent of the 14C will have decayed.
One-quarter of the original $^{14}\text{C}$ remains. Radioactive decay of $^{14}\text{C}$ is shown in FIGURE 1.4. Carbon-14 dating can be used to date objects only up to about 45,000 years old. If the objects are older than that, the fraction of $^{14}\text{C}$ will be too small to measure accurately. Older objects can be dated by using an isotope that has a longer half-life, such as uranium.

**Determining Earth’s Age**

Scientists have used radiometric dating to determine the age of Earth. Because Earth constantly undergoes erosion and rock recycling, rocks on Earth do not remain in their original state. Unlike Earth’s rocks, meteorites—which are mostly pieces of rock and iron that have fallen to Earth’s surface from space—do not get recycled or undergo erosion. Meteorites are thought to have formed at about the same time as Earth. Therefore, meteorites provide an unspoiled sample for radiometric dating. Uranium-to-lead isotope ratios in many meteorite samples consistently estimate Earth’s age at about 4.5 billion years.

**Summarize** Why are meteorites helpful for determining the age of Earth?

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**SELF-CHECK**

1. What types of evidence of ancient life can be preserved as fossils?
2. In radiometric dating, why is a uranium isotope often used instead of $^{14}\text{C}$ to determine the age of Earth?
3. **Apply** Considering that millions of species have lived on Earth, why are there relatively few fossils?
4. **Contrast** Explain the difference between relative dating and absolute dating.

**EARTH SCIENCE**

5. When mountains form, the order of rock layers can be disturbed. How could radiometric dating be used to sort out the relative ages of such rock layers?
Comparing Hominoid Skulls  Examine hominoid skulls to determine how modern humans are similar to chimps and australopithecines.

**Geologic Dating**
How do scientists decide which type of geologic dating to use for a sample? Decide which method of geologic dating would be best to date two different types of fossil samples.

Endosymbiosis  Watch endosymbiosis in action to discover how mitochondria and chloroplasts likely evolved.
The Geologic Time Scale

VOCABULARY

index fossil
geologic time scale
era
period
epoch

KEY CONCEPT
The geologic time scale divides Earth’s history based on major past events.

MAIN IDEAS
- Index fossils are another tool to determine the age of rock layers.
- The geologic time scale organizes Earth’s history.

Connect to Your World
Life is marked by increments of progress. From your first year of school through high school graduation, each new year is a step in your life development. Earth’s life spans about 4.5 billion years. Scientists have divided the Earth’s progress into manageable units based on the occurrence of major geologic changes.

MAIN IDEA
Index fossils are another tool to determine the age of rock layers.

You have learned that both relative dating and radiometric dating can help scientists determine the age of rock layers. Scientists who are trying to determine the age of a rock layer almost always use two or more methods to confirm results. Index fossils provide an additional tool for determining the age of fossils or the strata in which they are found. Index fossils are fossils of organisms that existed only during specific spans of time over large geographic areas.

Using index fossils for age estimates of rock layers is not a new idea. In the late 1700s, English geologist William Smith discovered that certain rock layers contained fossils unlike those in other layers. Using these key fossils as markers, Smith could identify a particular layer of rock wherever it was exposed.

The shorter the life span of a species, the more precisely the different strata can be correlated. The best index fossils are common, easy to identify, found widely around the world, and existed only for a relatively brief time. The extinct marine invertebrates known as fusulinids (fyoo-zuh-LY-nihdz), shown in FIGURE 2.1, are one example of an index fossil. They were at one time very common, but disappeared after a mass extinction event about 251 million years ago. The presence of fusulinids indicates that a rock layer must be between 251 million and 359 million years old. Fusulinid fossils are useful for dating fossils of other organisms in strata, because the presence of both organisms in one layer shows that they lived during the same time period.

Apply Could a rock layer with fusulinid fossils be 100 million years old? Explain.

FIGURE 2.1 Fusulinids, tiny fossils usually less than 2 millimeters wide, are good index fossils. They are abundant in marine sediment, widely distributed, and representative of a specific period of time.
This time span makes up the vast majority of Earth's history. It includes the oldest known rocks and fossils, the origin of eukaryotes, and the oldest animal fossils. (colored SEM; magnification 50×)

**CENOZOIC ERA**

**QUATERNARY PERIOD (NEogene)**
1.8 mya–present This period continues today and includes all modern forms of life.

**TERTIARY PERIOD (PALEogene)**
65–1.8 mya Mammals, flowering plants, grasslands, insects, fish, and birds diversified. Primates evolved.

**MESOZOIC ERA**

**CRETACEOUS PERIOD**
145–65 mya Dinosaur populations peaked and then went extinct. Birds survived to radiate in the Tertiary period. Flowering plants arose.

**JURASSIC PERIOD**
200–145 mya Dinosaurs diversified, as did early trees that are common today. Oceans were full of fish and squid. First birds arose.

**TRIASSIC PERIOD**
251–200 mya Following the largest mass extinction to date, dinosaurs evolved, as did plants such as ferns and cycads. Mammals and flying reptiles (pterosaurs) arose.

**PALEozoic ERA**

**PERMian PERIOD**
299–251 mya Modern pine trees first appeared, and Pangaea supercontinent was formed as major landmasses joined together.

**CARBONIFEROUS PERIOD**
359–299 mya Coal-forming sediments were laid down in vast swamps. Fish continued to diversify. Life forms included amphibians, winged insects, early conifers, and small reptiles.

**DEVONIAN PERIOD**
416–359 mya Fish diversified. First sharks, amphibians, and insects appeared. First ferns, trees, and forests arose.

**SILURIAN PERIOD**

**ORDOVICIAN PERIOD**
488–444 mya Diverse marine invertebrates evolved, as did the earliest vertebrates. Massive glaciers formed, causing sea levels to drop and a mass extinction of marine life to occur.

**CAMBRIAN PERIOD**
542–488 mya All existing animal phyla developed over a relatively short period of time known as the Cambrian Explosion.
The **geologic time scale**, shown in **FIGURE 2.2**, is a representation of the history of Earth. It organizes Earth’s development by major changes or events that have occurred, using evidence from the fossil and geologic records. Scientists worked out the entire geologic time scale during the 1800s and early 1900s. Although the scale is still being changed a little bit here and there, the main divisions of geologic time have stayed the same for over a hundred years.

The time scale is divided into a series of units based on the order in which different groups of rocks and fossils were formed. The geologic time scale consists of three basic units of time.

- **Eras** last tens to hundreds of millions of years and consist of two or more periods.
- **Periods** are the most commonly used units of time on the geologic time scale, lasting tens of millions of years. Each period is associated with a particular type of rock system.
- **Epochs** (EHP-uhks) are the smallest units of geologic time and last several million years.

The names of the eras came from early ideas about life forms preserved as fossils. **Paleozoic** means “ancient life,” **Mesozoic** means “middle life,” and **Cenozoic** means “recent life.” Within the eras, the boundaries between many of the geologic periods are defined by mass extinction events. These events help to define when one period ends and another begins. The largest adaptive radiations tend to follow large mass extinctions. Recall that adaptive radiation happens when a group of organisms diversifies into several species. Those species adapt to different ecological niches because mass extinctions make many niches available. Over generations, the adaptive traits favored within these newly opened niches may become common for that population of organisms, and speciation may occur.

**Summarize** Why do adaptive radiations often occur after mass extinctions?

### 12.2 Formative Assessment

**Reviewing Main Ideas**

1. How are **index fossils** used to date rock layers?
2. What is the usefulness of categorizing Earth’s history into the **geologic time scale**?

**Critical Thinking**

3. **Infer** The most common index fossils are shells of invertebrates. Give two reasons why this is so.
4. **Analyze** Scientists have inferred that there have been at least five mass extinctions in Earth’s history. How would fossil evidence support this inference?

5. **French physicist Henri Becquerel discovered radioactivity in 1896, after geologists had developed the geologic time scale. How did Becquerel’s discovery help later geologists as they refined the time scale?**

**TEKS 3F**
Origin of Life

KEY CONCEPT  The origin of life on Earth remains a puzzle.

MAIN IDEAS
- Earth was very different billions of years ago.
- Several sets of hypotheses propose how life began on Earth.

Connect to Your World

By studying the geologic time scale, it is clear that the farther back in Earth’s history we go, the tougher it is to piece together what life was like at that time. Hypotheses about the way Earth formed and life began have been proposed and researched. But as with any branch of science, questions still remain.

Earth was very different billions of years ago.

For centuries, many of history’s greatest minds have wondered about the origin of Earth and its living things. Despite differences over the details of Earth’s origins, most scientists agree on two key points: (1) Earth is billions of years old, and (2) the conditions of the early planet and its atmosphere were very different from those of today.

Today, the most widely accepted hypothesis of Earth’s origins suggests that the solar system was formed by a condensing nebula, a cloud of gas and dust in space, as shown in FIGURE 3.1. This hypothesis is supported by computer models and observations made with the Hubble Space Telescope. It suggests that about 4.6 billion years ago, the sun formed from a nebula. Over time, most of the material in the nebula pulled together because of gravity. Materials that remained in the nebula’s disk circled the newly formed sun. Over millions of years, repeated collisions of this space debris built up into the planets of our solar system.

Earth was most likely violent and very hot for its first 700 million years, a time now called the Hadean eon. Many asteroids, meteorites, and comets struck the planet, releasing enormous amounts of heat. Meanwhile, the radioactive decay of elements trapped deep within Earth released heat as well. This intense heat kept the materials making up Earth in a molten state. Over time, these materials separated into Earth’s layers. Hydrogen, carbon monoxide, and nitrogen gas were released from the interior. They combined to form an atmosphere containing compounds such as ammonia, water vapor, methane, and carbon dioxide. Most scientists agree that free oxygen was not abundant until about 2 billion years ago, after the first forms of life had begun to evolve.

Toward the end of the Hadean eon, between 4 and 3.8 billion years ago, impacts became less frequent. That allowed Earth to cool down. Solar radiation and lightning produced energy for reactions on Earth and in the early atmosphere. The continents began to form. Water vapor condensed and fell as rain that collected in pools and larger bodies of water.
Once liquid water was present, organic compounds could be formed from inorganic materials. All living matter is organic, as are the building blocks of life, such as sugars and amino acids. However, you’ll see below that the leap that resulted in life on Earth required conditions other than just the presence of water.

**Summarize** Describe the nebular hypothesis of Earth’s origin.

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**MAIN IDEA**

**Several sets of hypotheses propose how life began on Earth.**

Since the 1950s, scientists have proposed several hypotheses to explain how life began on Earth. These hypotheses have taken into consideration early organic molecules, the formation of organic polymers from these organic building blocks, the evolution of cell structures, and early genetic material.

**Organic Molecule Hypotheses**

There are two general hypotheses about the way life-supporting molecules appeared on early Earth.

**Miller-Urey experiment** In 1953 Stanley Miller and Harold Urey designed an experiment to test a hypothesis first proposed by Alexander Oparin in the 1920s. Earlier scientists had proposed that an input of energy from lightning led to the formation of organic molecules from inorganic molecules present in the atmosphere of early Earth. Miller and Urey built a system to model conditions they thought existed on early Earth, as shown in Figure 3.2. They demonstrated that organic compounds could be made by heating and passing an electrical current, to simulate lightning, through a mixture of gases. These gases—methane (CH₄), ammonia (NH₃), hydrogen (H₂), and water vapor (H₂O)—were thought to be present in the early atmosphere. The Miller-Urey experiment produced a variety of organic compounds, such as amino acids.

After Miller’s death in 2007, scientists found sealed vials from his early experiments that when tested, proved that more than 20 different amino acids had been formed. Since Miller’s experiments occurred, it has been suggested by some scientists that due to volcanic eruptions more than 4 billion years ago, different compounds were present in the early atmosphere. Experiments using more recent estimates of conditions on early Earth have also produced organic molecules, including amino acids and nucleotides.

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**FIGURE 3.2 Miller-Urey Experiment**

A laboratory model was used to represent the conditions of early Earth. This experiment demonstrated that organic molecules can be made from inorganic molecules.

A boiling chamber was used to heat “ocean” water to produce water vapor. The vapor traveled through a tube to the “atmosphere.” An electric spark in a mixture of gases simulated lightning.

**VOCABULARY**

Organic compounds are carbon based and contain carbon–carbon bonds.
Meteorite hypothesis  Analysis of a meteorite that fell near Murchison, Australia, in 1969 revealed that organic molecules can be found in space. More than 90 amino acids have been identified from this meteorite. Nineteen of these amino acids are found on Earth, and many others have been made in experiments similar to the Miller-Urey study. This evidence suggests that amino acids could have been present when Earth formed, or that these organic molecules may have arrived on Earth through meteorite or asteroid impacts.

Organic Polymer Hypotheses
Once amino acids and other organic building blocks existed on early Earth, certain requirements would have to have been met in order for more complex organic polymers to form. Planetary conditions were still extreme, ranging from ice sheets to areas having high temperatures and extensive volcanic activity. Since there was no ozone layer at that time, high levels of ultraviolet radiation would have permeated the atmosphere. All of these factors would have contributed to breaking apart the chemical bonds of organic molecules unless they were protected in some way. The survival of organic molecules would have depended on them either dissolving in water or adsorbing to some type of mineral.

Frozen seawater hypothesis  If you fill a container to the top and place it into your freezer, the ice that forms will expand beyond the rim of the container. This occurs as water molecules form into rigid crystals. Because of this, a solution that is water-based will push any dissolved materials into the spaces between the crystals as it freezes. Recent research has shown that when solutions containing nucleotides are frozen, the nucleotides are pushed into the spaces between the water crystals. As FIGURE 3.3 illustrates, when nucleotides are concentrated into a tiny area, they can bind together and form long, complex molecules that can carry information. On the basis of these experiments, Scripps Oceanographic scientist Jeffrey Bada proposed in 2004 that biological polymers may have formed in sea ice on the early planet.

Clay adsorption hypothesis  In the late 1950s and early 1960s, Florida State University scientist Sidney Fox found that when dilute solutions of amino acids and cyanide were dripped onto hot, dry sand, rock, or clay, polymers that he called “proteinoids” were formed spontaneously. The metallic ions on the particles of clay acted as catalysts, binding to the monomers and concentrating them closely enough for the molecules to join together, forming more-complex organic polymers similar to proteins.

FIGURE 3.3  Frozen Seawater Hypothesis
Nucleotides trapped within the spaces between ice crystals and kept in close proximity to one another may have combined to form more-complex polymers.
Implications of polymer formation  Many hypotheses describing the origin of life on Earth rely on the formation of self-replicating polymers—made from either amino acid or nucleic acid monomers—on early Earth. Once a molecule capable of replication formed, the sequence information contained in the molecule, as well as any variation introduced during replication, would have been inherited by each new generation of molecules. In successive generations, molecules with variations that improved replication efficiency or added other advantageous functions may have been selected, leading to more-complex molecules that carried more information.

Early Cell Formation Hypotheses

There are several hypotheses about the formation of the first cells. One focuses on the way organic molecules could have been brought together, and others addresses the way cell membranes may have formed.

Iron-sulfide bubbles hypothesis  In the 1990s, biologists William Martin and Michael Russell noted that hot iron sulfide rising from below the ocean floor reacts with the cooler ocean water to form chimneylike structures with many compartments, such as those shown in Figure 3.4. Russell modeled this in the laboratory by injecting warm sodium sulfide into a cool, iron-rich solution. Iron sulfide bubbles quickly formed, making a chimney structure within minutes. Russell proposed that, around 4 billion years ago, biological molecules combined in the compartments of these chimneys. The compartment walls concentrated the basic organic molecules in a small space. The walls of the compartments, Russell proposed, acted as the first cell membranes. Once the right ingredients combined, the first organic cell membranes could form. These membranes would have let early microbes leave their rocky compartments and spread out into other environments.

FIGURE 3.4 Iron–Sulfide Bubbles Hypothesis

Hydrothermal vents produce sulfur that mixes with ocean water to make compartments of rock. These structures may have created conditions necessary for early life to form.
Lipid membrane hypothesis Several scientists have proposed that the evolution of lipid membranes was a crucial step for the origin of life. Lipid molecules spontaneously form membrane-enclosed spheres, called liposomes, shown in Figure 3.5. In 1992 biochemist Harold Morowitz tested the idea that at some point liposomes were formed with a double, or bilayer, lipid membrane. These liposomes could then form around a variety of organic molecules, such as amino acids, fatty acids, sugars, and nucleotides. The liposomes would act as membranes that separated these organic molecules from the environment. These cell-like structures may have later given rise to the first true cells.

Coacervate hypothesis In the 1930s, long before Morowitz proposed that cell-like structures formed from liposomes, Alexander Oparin found that by adding a substance called gum arabic into a water-based solution of gelatin, then cooling it down, tiny capsules that he called “coacervates” were produced. These coacervates, when surrounded by water, could absorb and release some compounds in a way that was similar to how bacteria feed and then excrete wastes.

Proteinoid microsphere hypothesis In the late 1950s, Sydney Fox, working with Kaoru Harada, took his previous work with the clay adsorption hypotheses a step further. The two scientists discovered that when the proteinoids, produced in hot conditions, were cooled by dropping them into water, they spontaneously formed into microspheres. The proteinoids had a water-soluble chemical group attached to a water-insoluble group. The parts that were water-soluble turned inwards and the insoluble group outwards, forming a bilayer similar to the structure of cell membranes. Under certain laboratory conditions, these proteinoid microspheres would slowly grow larger and eventually bud, forming new spheres.

Liposomes, coacervates, and microspheres were not capable of genetic coding or true replication. In other words—none of them were alive. However, the research of these scientists into how cells originally formed provided the foundations upon which current research is based.

RNA as Early Genetic Material
A hypothesis that has gained much support in recent years proposes that RNA, rather than DNA, was the genetic material that stored information in living things on early Earth. In the 1980s, Thomas Cech from the University of Colorado and Sidney Altman from Yale University independently discovered that RNA can catalyze reactions. Ribozymes are RNA molecules that can catalyze specific chemical reactions. As Figure 3.6 shows, ribozymes can catalyze their own replication and synthesis. RNA can copy itself, chop itself into pieces, and from these pieces make even more RNA. Unlike RNA, DNA needs enzymes to replicate itself.
1. Describe the environmental conditions that are thought to have existed during the Hadean eon.

2. What evidence do the two organic molecule hypotheses provide regarding the formation of simple organic molecules?

3. Analyze What factors do the two organic polymer hypotheses have in common regarding how more-complex organic polymers originated? **TEKS 9D**

4. Compare and Contrast Choose two of the early cell formation hypotheses and discuss their differences. **TEKS 9A, 9D**

Along with the discovery of ribozymes, several other types of evidence support the RNA hypothesis. Short chains of RNA will form from inorganic materials in a test tube. If zinc is added as a catalyst, longer chains will grow. Also, RNA will fold into different shapes depending upon its sequence of nucleotides. Thus, it can perform more functions than DNA. But RNA does not catalyze chemical reactions as well as proteins do, nor does it store genetic information as well as DNA does. Over time, RNA may have become less important for these functions.

Perhaps the earliest replicating RNA molecule gained simple membranes over many generations through natural selection. Membranes might protect chemical reactions and make them work more efficiently. RNA molecules that made copies of themselves in a double-stranded form, similar to DNA, might eventually have been selected because fewer mutations would occur. Because DNA is more stable than RNA, it could reliably store more sequence information for a longer period of time. This may have led to DNA replacing RNA as the primary genetic material. Currently, there are several hypotheses about how RNA could have led to life as we know it today. Laboratory experiments in which RNA molecules survive and self-replicate support the idea of early cells being based on RNA. This model of the origins of life on Earth is sometimes called the RNA world.

**Synthesize** Could cell structures or RNA have been present before organic molecules existed on Earth? Explain.
Early Single-Celled Organisms

KEY CONCEPT  Single-celled organisms existed 3.8 billion years ago.

MAIN IDEAS
- Microbes have changed the physical and chemical composition of Earth.
- Several theories have been proposed for how eukaryotic cells evolved from prokaryotic cells.
- The evolution of sexual reproduction led to increased diversity.

Connect to Your World
If you have ever assembled a complicated model or worked on a car, you know that putting the parts together to get a working result can be very difficult. Billions of years ago, organic molecules were everywhere. However, they didn't yet fully work together. Once the first cells arose from these molecules, the steps toward even more complicated organisms, such as humans, truly began.

Microbes have changed the physical and chemical composition of Earth.

Single-celled organisms changed Earth’s surface by depositing minerals. These organisms changed the atmosphere by giving off oxygen as a byproduct of photosynthesis. Before photosynthesis evolved, however, the first prokaryotes would have been anaerobic, or living without oxygen. Many of these early prokaryotes probably got their energy from organic molecules.

Scientists have found evidence that photosynthetic life evolved around 3.5 billion years ago, since that is the age of the oldest known fossils. These fossils are of a group of marine cyanobacteria (sy-ah-noh-bak-TEER-ee-uh), which are bacteria that can carry out photosynthesis. Like all early life forms, each cyanobacterium was a single prokaryotic cell. Recall that prokaryotic cells have no membrane-bound organelles.

Some cyanobacteria live in colonies and form stromatolites (stroh-MAT-l-yts). Stromatolites are domed, rocky structures made of layers of cyanobacteria and sediment. There are many stromatolite fossils, but some are living communities, as shown in Figure 4.1. Fossils of stromatolites as old as 3.5 billion years have been found. Communities of photosynthesizing cyanobacteria in stromatolites released oxygen as a byproduct. Higher oxygen levels in the atmosphere and the ocean allowed the evolution of aerobic prokaryotes, which need oxygen to live.

Apply  How are stromatolites evidence of Earth’s early life?
Several theories have been proposed for how eukaryotic cells evolved from prokaryotic cells.

The fossil record shows that eukaryotic organisms had evolved by 1.5 billion years ago. A eukaryote is more complex than a prokaryote, having a nucleus and other membrane-bound organelles. While the first eukaryotes were made of only one cell, later eukaryotic organisms became multicellular. Bacterial, plant, and animal cells share certain complex traits, including specific enzymes, metabolic pathways, ribosomes, cell membranes, and the genetic code carried in DNA. While these traits originated in prokaryotes, other eukaryotic traits such as organelles arose through the processes of evolution.

Endosymbiont theory One hypothesis of eukaryote evolution did not get much attention until the 1970s. Biologist Lynn Margulis found evidence to support the endosymbiont theory. Endosymbiosis (ehn-doh-sihm-bee-OH-sihs) is a relationship in which one organism lives within the body of another—with both organisms benefitting.

The endosymbiont theory suggests that mitochondria and chloroplasts were once simple prokaryotic cells that were engulfed by larger prokaryotes around 1.5 billion years ago. Instead of being digested, some of the smaller prokaryotes may have survived inside the larger ones as illustrated in FIGURE 4.2. If it took in a prokaryote that acted as a mitochondrion, the larger cell got energy in the form of ATP. If it took in a prokaryote that acted as a chloroplast, the larger cell could use photosynthesis to make sugars. In exchange, the mitochondria and the chloroplasts found a stable environment and nutrients.

Margulis based her theory on several factors. Unlike other organelles, mitochondria and chloroplasts have their own DNA and ribosomes. They can copy themselves within the cell in which they are found. Mitochondria and chloroplasts are also about the same size as prokaryotes, their DNA forms a circle, and their gene structures are similar to those of prokaryotes.

Analyze What evidence supports the theory of endosymbiosis?

The theory of endosymbiosis proposes that the mitochondria found in eukaryotic cells descended from ancestors of infection-causing bacteria. Likewise, chloroplasts are considered descendants of cyanobacteria.

Endosymbiosis

Infection-causing bacteria entering a host cell

[Diagram showing the process of endosymbiosis]
Autogenous theory  In 1976 botanist F.J.R. Taylor proposed an alternative to the endosymbiont theory. Taylor’s theory, known as autogeny, is based upon the extensive folding of the internal membranes found within chloroplasts and mitochondria, as seen in FIGURE 4.3.

You may recall that one of the major differences between prokaryotes and eukaryotes is that eukaryotes have membrane-bound organelles and prokaryotes do not. This provides eukaryotes with a distinct adaptive advantage. Since prokaryotic metabolic reactions all occur in the cytoplasm, it is possible for them to interfere with one another. Eukaryotes, on the other hand, have the specialized chemical reactions involved in metabolism separated by the membranes surrounding each organelle.

The autogenous theory proposes that eukaryotic organelles evolved from infoldings of the plasma membrane, creating pockets that eventually pinched off. When they pinched off into separate structures, small sections of nucleic acids and ribosomes were trapped inside. These new structures became specialized in performing different metabolic processes. Having these reactions isolated from one another is much more efficient, allowing eukaryotic cells to evolve even greater complexity. According to the autogenous theory, those organelles that performed photosynthesis eventually developed into chloroplasts. The theory also proposes that those new structures that specialized in providing energy to the other organelles through cellular respiration evolved into mitochondria.

Analyze  Why do membrane-bound organelles give eukaryotes an adaptive advantage over prokaryotes?  

FIGURE 4.3 Autogenous Theory

According to the autogenous theory, eukaryotes arose directly from a single prokaryotic ancestor through isolation of metabolic functions by infoldings of the plasma membrane. Such infoldings and pockets can be seen in chloroplasts and in mitochondria.
Horizontal gene transfer theory  In 2002 biologist Carl Woese proposed a third theory of how the complexity of eukaryotes evolved. Woese's earlier research into the genetic differences among prokaryotes led to the establishment of the currently accepted classification of all living things into three domains: eukaryotes and two groups of prokaryotes, bacteria and archaea.

Woese pointed out that the endosymbiotic theory posits that eukaryotes arose when fully evolved prokaryotic cells engulfed and incorporated other prokaryotes. Based on his genetic research, Woese proposed instead that the genetic makeup of early cells was highly fluid and that eukaryotes, bacteria, and archaea evolved more or less in parallel. Woese further hypothesized that extensive exchange of genetic information took place among these evolving cell types through a process of horizontal gene transfer (HGT). This type of gene transfer continues to take place today when modern prokaryotes reproduce by a process called conjugation, as illustrated in Figure 4.4.

According to Woese’s theory, horizontal gene transfer enabled the appearance of more complex cell structures. Distinct cell types emerged only when each of the cell organizations we know today reached a degree of complexity and interconnectedness that made it impossible for HGT to further change the organization in a fundamental way. Woese called this critical point the “Darwinian threshold,” because this was the point in the evolution of life when natural selection on distinctly separated gene pools could begin to act.

Evaluate Some scientists propose that a combination of theories may best describe the evolution of eukaryotes. What information would you use to support this view?
The evolution of sexual reproduction led to increased diversity.

The first prokaryotes and eukaryotes could only reproduce asexually. Some time later, eukaryotic cells began to reproduce sexually. Of the groups of organisms that reproduce asexually today, only a few—such as bacteria—appear to have ancient asexual origins.

Recall that in asexual reproduction, a single parent produces offspring that are genetically identical to itself. Asexual reproduction lets organisms have many offspring quickly. Sexual reproduction, on the other hand, needs two parents. Both parents give genes to their offspring. This means that individuals must use time and energy to produce gametes, find a mate, and pass on genetic information. Recall that each parent passes on only half of its genes to offspring.

The evolution of sexual reproduction is still an active area of research. The disadvantages of sexual reproduction—needing a partner and passing on only half of a set of genes—seem clear. One advantage to sexual reproduction, however, is genetic variation. Sexual reproduction allows new combinations of genes to come together. This process may mask harmful mutations, and in some cases it may also bring beneficial mutations together.

Sexual reproduction may also have resulted in an increase in the rate of evolution by natural selection. Sexual reproduction creates more genetic variation, which lets a population adapt quickly to new conditions. Over a long time, early eukaryotes may have gained variations that made living closely together, and eventually cooperating, beneficial. Thus, sexual reproduction may have been the first step in the evolution of multicellular life.

Infer How can mutations be beneficial to organisms?
Calculating Axes Intervals

Determining the correct scales of axes on graphs is important so that all data points can be plotted. The scale can also influence the reader’s perception of the results. If the intervals are too far apart, the slope of the graph will seem steep—indicating a fast rate or a large change in the data. If the intervals are too small, the graph will be flatter, with change that seems small or nonexistent.

Model

Some species that reproduce asexually have the benefit of short generation times. They may be able to adapt more quickly to changing environmental conditions. Bacteria populations, for instance, can quickly become resistant to antibiotics. Individual bacteria that survive antibiotic treatment will pass the gene for resistance to their offspring when they reproduce.

The population of bacteria doubles with each generation. The following are the steps used to determine axis intervals of the line graph of the growth of Escherichia coli over 5 generations:

1. Calculate the difference between the smallest and largest values of the variable and divide the difference by the number of data points. For the E. coli data, 85 – 17 = 68. Divided by 5, this equals 13.6.
2. Round the result to the nearest convenient number, such as 2, 5, or 10. For E. coli, the interval was rounded down to 12.
3. Use the rounded number as the interval.
4. Begin the scale on the axis at zero (or at one interval lower than the lowest value if the values to be graphed are much larger than the interval).
5. End the scale above the highest value. For E. coli, the scale ranges from 0 to 96.

Practice  Calculate Axes Intervals

1. **Graph Data**  Calculate the intervals for the y-axis and x-axis for a graph that compares the generation times of all three of the bacteria species listed below. Draw the axes, plot the data, and label each of the three plotted lines. Be sure to title your graph and label your axes.

2. **Analyze**  Using your graph for E. coli as an example, explain how changing the axes of a graph can influence how data are interpreted.

### TABLE 1. GENERATION TIMES FOR COMMON BACTERIA

<table>
<thead>
<tr>
<th>Bacteria</th>
<th>Generation 1 Time (min)</th>
<th>Generation 2 Time (min)</th>
<th>Generation 3 Time (min)</th>
<th>Generation 4 Time (min)</th>
<th>Generation 5 Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10 bacteria</td>
<td>20 bacteria</td>
<td>40 bacteria</td>
<td>80 bacteria</td>
<td>160 bacteria</td>
</tr>
<tr>
<td>E. coli</td>
<td>17</td>
<td>34</td>
<td>51</td>
<td>68</td>
<td>85</td>
</tr>
<tr>
<td>B. megaterium</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100</td>
<td>125</td>
</tr>
<tr>
<td>S. lactis</td>
<td>48</td>
<td>96</td>
<td>144</td>
<td>192</td>
<td>240</td>
</tr>
</tbody>
</table>
The trend toward multicellular organisms was one of the most important transitions in the history of life. One hypothesis suggests that it was an advantage for early one-celled organisms to increase in size by becoming multicellular. Cells that cooperated could compete more effectively for energy, by processes such as cooperative feeding. At some point, increased dependence on neighboring cells would have led the cells to function as a colony.

Multicellular organisms first appeared during the Paleozoic era, which began 542 million years ago. Members of every major animal group evolved within only a few million years. The era ended 251 million years ago with a mass extinction. More than 90 percent of marine species and 70 percent of land species of that time became extinct. In between these remarkable events, multicellular animals radiated, the first vertebrates evolved, and early plants moved onto land.

The earliest part of the Paleozoic era is often called the Cambrian explosion. During the Cambrian explosion, a huge diversity of animal species evolved. At the start of the Paleozoic era, all life was found in the ocean. Among the earliest vertebrates was a group of jawless fishes. The only species of jawless fish still remaining are the Agnathan fish, which you will read about in the chapter Vertebrate Diversity. Marine invertebrates, such as the trilobites, were especially abundant. This highly diverse group of arthropods had thousands of species, though almost half of these species died in the mass extinction event at the end of the Cambrian period. Many other animals from this time period are also extinct. The best known of these are found at the Burgess Shale site in British Columbia, where many fossils were well preserved.
The middle of the Paleozoic era was a time of great diversity as life moved onto land. The number and variety of plant groups greatly increased. Four-legged vertebrates, such as amphibians, became common. Most of the coal used in the United States formed during the Carboniferous period of this era, illustrated in Figure 5.1. The decomposed remains of millions of organisms were buried in sediment. Over time they changed into coal and the petroleum that fuels our cars today.

**Summarize** Why is part of the Cambrian period also called the Cambrian explosion?

**Main Idea**

Reptiles radiated during the Mesozoic era.

The Mesozoic (mehz-uh-ZOH-ihk) era began 251 million years ago and ended 65 million years ago. Called the Age of Reptiles because the dinosaurs roamed Earth during this era, the Mesozoic also featured birds and flowering plants. The oldest direct ancestor of mammals first appeared during this era. By the era’s end, mammals—particularly marsupials, whose young develop in a pouch—had evolved numerous key traits that improved their chances of survival during the mass extinction at the end of the era.

The Mesozoic era is divided into three periods: the Triassic, the Jurassic, and the Cretaceous. Life took off slowly in the early Triassic. On land, the earliest crocodiles and dinosaurs arose. The fossil record shows that the first mammals also evolved during this time. An extinction event near the end of the Triassic destroyed many types of animals. This mass extinction allowed the radiation of the dinosaurs in the Jurassic period, illustrated in Figure 5.2.

Although life had moved onto land, it was still abundant underwater. Ichthyosaurs (IK-thee-uh-sawrz), a group of predatory marine reptiles, dominated the oceans. Sharks and bony fishes continued to evolve more complex forms.

The Cretaceous period also ended in a mass extinction—the cause of which is still debated. Evidence shows that a massive asteroid struck Earth. The most accepted hypothesis is that this impact sent enormous amounts of dust and debris into the atmosphere, blocking much of the Sun’s light. As a result, the climate changed, and plants were unable to perform photosynthesis. Without sufficient plants to eat, herbivorous dinosaurs and many other animal species became extinct. The loss of these herbivorous animals reduced the food supply of meat-eating dinosaurs, contributing to the meat eaters’ extinction.

**Analyze** How did life on Earth change from the beginning of the Paleozoic era to the end of the Mesozoic?
Mammals radiated during the Cenozoic era.

The Cenozoic era (seh-nuh-ZOH-ihk) began 65 million years ago and continues today. It is divided into two periods, the Tertiary (65–1.8 million years ago), illustrated in Figure 5.3, and the Quaternary (1.8 million years ago until today). During the Tertiary, placental mammals and monotremes—a small group of mammals that lay eggs—evolved and diversified. Their adaptive radiation rivaled that of the marsupials in the Mesozoic. The most dramatic radiation of the mammals, however, occurred with the placentals. Today, this group numbers roughly 4000 species. During the Tertiary period, birds, ray-finned fishes, and flowering plants also underwent dramatic radiations.

The earliest ancestors of modern humans evolved near the end of the Tertiary. However, anatomically modern humans did not appear until very recently in Earth’s history, nearly 200,000 years ago. The evolution of primates is covered in the next section.

Infer Why is the Cenozoic era sometimes referred to as the Age of Mammals?

12.5 Formative Assessment

**REVIEWING MAIN IDEAS**

1. What important events occurred during the Paleozoic era?
2. What were some of the key appearances and radiations in the Mesozoic era?
3. What two groups of mammals evolved during the Cenozoic era?

**CRITICAL THINKING**

4. **Evaluate** Explain how natural selection related to the development of diversity in and among species during the Mesozoic era [TEKS 7E]
5. **Infer** How does a great diversity of organisms increase the chances that some will survive a major change in the environment? [TEKS 7E]

**CONNECT TO ECOLOGY**

6. How do you think the evolution of flowering plants affected the evolution and radiation of birds? [TEKS 7E]
Humans appeared late in Earth’s history.

**Main Ideas**
- Humans share a common ancestor with other primates.
- There are many fossils of extinct hominins.
- Modern humans arose nearly 200,000 years ago.

**Connect to Your World**
In terms of the geologic time scale, the evolution of humans has occurred only very recently. Many fossils of our early ancestors consist of partial skeletons from which details must be inferred through careful study. Though far from complete, this fossil record offers a fascinating glimpse of our past.

**Main Idea**
Humans share a common ancestor with other primates.

The common ancestor of all primates probably arose before the mass extinction that closed the Cretaceous period 65 million years ago. **Primates** make up a category of mammals with flexible hands and feet, forward-looking eyes—which allow for excellent three-dimensional vision—and enlarged brains relative to body size. Primates also have arms that can rotate in a circle around their shoulder joint, and many primates have thumbs that can move against their fingers. Primates include lemurs, monkeys, apes, and humans. In addition to sharing similar physical traits, primates share strong molecular similarities.

**Primate Evolution**
Similar to other groups of related organisms, the relationship among the primate groups forms a many-branched tree. At the tree’s base is the common ancestor of all primates. Just above this base, the tree splits into two main subgroups: the prosimians and the anthropoids.

**Prosimians** (proh-SIHM-ee-uhnz) are the oldest living primate group, and most are small and active at night. This group of nocturnal animals includes the lemurs, the lorises, and the tarsiers, like the ones shown in **FIGURE 6.1**. Prosimians are differentiated from anthropoids by smaller size and skull plates that are not fused together when mature.

**FIGURE 6.1** Prosimians, such as these tarsiers, are the oldest living primate group. They are active at night and have large eyes and ears.
Further distinguishing the prosimians is a single, long grooming claw on the second toe of their hind feet and a unique type of horizontal tooth structure known as a grooming comb. Tarsiers have been called living fossils, as their physical traits have changed little since their appearance in the fossil record more than 40 million years ago.

**Anthropoids** (AN-thruh-poydz), the humanlike primates, are further subdivided into the New World monkeys, Old World monkeys, and hominoids, as shown in **Figure 6.2**. New World monkeys, which are native to the Americas, all live in trees. Many species have prehensile, or grasping, tails, an adaptation that allows them to hang by their tails from tree branches while feeding. Some Old World monkeys also spend time in trees, but most travel and forage on the ground as well. They have larger brains than do New World monkeys and a greater ability to manipulate objects.

Classification of organisms will be covered in much more detail in the chapter Tree of Life. You will then learn more about how scientists determine how to categorize and name an organism. However, to reduce confusion, it is necessary to show the difference between some of the terms used to classify anthropoids. The terms *hominoid*, *hominid*, and a third term, *hominin*, all sound very similar because they all originate from the same Latin root word, *homo*, meaning “man”.

Hominoids include gibbons and the great apes (orangutans, chimpanzees, and gorillas) as well as humans. **Hominids** include orangutans, chimpanzees, gorillas, and humans, but not gibbons. The term hominin refers only to modern humans and their immediate ancestors.

Among primates, hominids are particularly known for using opposable thumbs to their advantage. Because their thumbs are placed in opposition to the four fingers, this allows the hominids to manipulate objects and adapt them. This trait enables hominids to not only pick up and grasp an object, but also use it for multiple purposes. For example, wild chimpanzees in Tanzania have been observed adapting grass and sticks to remove honey from beehives, as well as to dig up roots to eat, and to pry open boxes of bananas left for them by scientists. The chimpanzees also use leaves for collecting water and for wiping mud and sticky fruit from their bodies. Young chimps in Gombe learn how to “fish” for termites by observing adults demonstrate the steps involved. Without these observations, it is unlikely that the youngsters would become successful at obtaining termites for food.

**Interpret** How did the ability to manipulate objects, as well as adapt them for use as tools or weapons, give hominids an evolutionary advantage over other primates?
Phylogenetic trees, or cladograms, that depict evolutionary relationships between primate groups can be constructed by scientists using karyotype analysis of chromosomes.

**FIGURE 6.2 Evolutionary Relationships of Primates**

Analyze Based on this cladogram, which group of anthropoids is the least closely-related to modern humans?
Walking Upright

Many hypotheses have been proposed to explain the evolutionary success of the hominins. Enlarged brain size and the ability to make and use tools were for many years among the most accepted ideas. However, fossil discoveries have revealed that another trait came before tool use and large brains—walking upright on two legs. Upright posture and two-legged walking required changes in skeletal anatomy. Examples of these changes include a more strongly curved, cuplike pelvis, the increased alignment of the knees with the body, and a change in the spine from arch-shaped to an S-shaped curve. The skull became more centered on the top of the spine, allowing for greater ease in using forward-facing vision. These changes can be found in intermediate fossils between hominoids that walked only on all fours and early hominins that walked on two legs, as seen in FIGURE 6.4.

FIGURE 6.4 Walking Upright

Changes in the skeletal structure of primates were necessary before bipedalism was possible.

<table>
<thead>
<tr>
<th>55 MILLION YEARS AGO</th>
<th>37 MILLION YEARS AGO</th>
<th>3-4 MILLION YEARS AGO</th>
<th>1 MILLION YEARS AGO</th>
<th>200,000-30,000 YEARS AGO</th>
<th>MODERN HUMAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smilodectes gracilis</td>
<td>Biretia fayumensis</td>
<td>Australopithecus afarensis</td>
<td>Homo erectus</td>
<td>Homo neanderthalensis</td>
<td>Homo sapiens</td>
</tr>
</tbody>
</table>

Analyze  Give a brief summary of the skeletal changes that occurred through time that allowed for an upright posture and bipedal stance in higher primates.
Animals that can walk on two legs are called **bipedal**. This trait has important adaptive advantages for higher primates. It allows higher reach into tree branches while foraging, and perhaps most importantly, it frees the hands for foraging, carrying infants and food, and using tools. As the landscapes where ancestral humans evolved gradually shifted from heavily forested areas to vast grasslands, food would have become more scarce. Hunter-gatherers would have had to travel farther in order to find enough sources of nutrition for survival. The ability to travel upright on two feet would have enabled them to travel farther while expending less energy than animals that walked on their hind feet and their front knuckles.

In addition to tool usage, bipedal hominin would have been able to fashion weapons to kill prey or to protect themselves, their mates, and their offspring. The higher vantage point provided by their upright posture would have enabled them to better see over obstacles to observe approaching threats.

**Connect** What is another common animal that is bipedal? Why did this organism need its forelimbs to be free from providing support for its body?

### QUICK LAB: MODELING

#### Geologic Clock

One way to understand the relative length of time in Earth’s history is to compare its age to a clock face. Precambrian time goes from 12 noon to about 10:30 p.m. The time span from early human ancestors—more than 5 million years ago—to *Homo sapiens* covers less than a second on our 12-hour clock!

**PROBLEM** How do different geologic time periods compare?

**PROCEDURE**

1. Draw a large circle and mark the 12, 3, 6, and 9 positions of a clock face. Use the scale 1 hour = 400 million years ago, and label the four positions with the appropriate number of years, starting with 12 o’clock = 4800 million years ago. (Example: the three o’clock position = 3600 million years ago.)

2. Using the geological time scale, label Precambrian time and the three eras on your clock, along with the approximate time frames in which they occurred.

3. Label the following events on your clock in the appropriate positions, also filling in the approximate time frames they occurred: formation of Earth, oldest rocks, first stromatolites, first aerobic prokaryotes, first eukaryotes, first fishes, first flowering plants, first dinosaurs, first birds, and earliest hominids.

**ANALYZE AND CONCLUDE**

1. **Synthesize** How are eras and periods related? Where would the periods fit in this diagram?

2. **Calculate** Using your scale of 1 hour = 400 million years, how many millions of years in Earth’s history would 1 minute represent?
Hominins are classified into several groups. Two important groups are the genus *Homo* and the older genus *Australopithecus* (au-stray-loh-PIHTH-ih-kuhs). *Australopithecus* was a long-lived and successful genus. *Australopithecus afarensis* (AF-uh-REHN-sihs), which lived 3 to 4 million years ago in Africa, is one of the better known species of early hominins. Although its brain was much smaller than that of a modern human—about the size of a modern-day chimpanzee’s brain—*A. afarensis* had very humanlike limbs.

The earliest member of the genus *Homo* was *Homo habilis*. Nicknamed “handy man” because of the crude stone tools associated with its skeletons, *H. habilis* lived 2.4–1.5 million years ago in what are now Kenya and Tanzania. This species may have lived alongside the australopithecine species for about 1 million years. *H. habilis* is the earliest known hominin to make stone tools. The brain of *H. habilis* was much larger than that of any of the australopithecines, and it more closely resembled the modern human brain in shape.

Another hominin species was *H. neanderthalensis*, commonly called Neanderthals for the Neander Valley in Germany, where their fossils were first found. This group lived from 200,000 to around 30,000 years ago in Europe and the Middle East. Some evidence suggests that *H. neanderthalensis* coexisted with modern *Homo sapiens*. Did the two species live side by side? Or did they engage in a fierce competition for resources, causing the extinction of the Neanderthals by the better-adapted *H. sapiens*? This puzzle has not yet been solved.

Observations from the fossil record, such as the fossil seen in *FIGURE 6.5*, demonstrate a trend toward increased brain size in the human lineage. Although brain size can only be loosely related to intelligence, the combination of modern-day humans’ physical and cultural adaptations has no doubt contributed to our success as a species.

**Hypothesize** What type of evidence could indicate that *H. sapiens* and *H. neanderthalensis* coexisted?

Modern humans arose nearly 200,000 years ago.

Fossil evidence reveals that *Homo sapiens* evolved nearly 200,000 years ago in what is now Ethiopia. However, many of their features were different than those of humans today. After becoming a distinct species, *H. sapiens* clearly did not stop evolving.

**The Role of Culture**

Human evolution is influenced by culture. Tools are among key markers of culture in human evolution, although they are used by some other animals as well. A comparison of tools from their first appearance some 2.5 million years ago, through their association with later *Homo* fossil sites, shows a steady trend of increasing sophistication and usefulness.
1. What characteristics shared by humans and other primates suggest that they have a common ancestor?

2. According to the fossil record, what other Homo species was present when modern humans arose?

3. From the hominin fossils described, what common trends can be found?

4. Explain why, according to the fossil record, it is not correct to say that humans evolved from chimps.

5. Scientists can often identify whether a fossil skull was from a bipedal primate. What characteristics of a skull might help them make this determination?

6. Consider the skull illustrations above. Besides size, how did skull structure change as hominins evolved? What features are considered more apelike than humanlike?
12 Summary

KEY CONCEPTS

12.1 The Fossil Record
Fossils are a record of life that existed in the past. Fossils can form in several different ways. The age of a fossil or rock can be determined by radiometric dating, which uses radioactive isotopes to determine the age of a fossil or the rock in which it is found. Through radiometric dating, scientists estimate that Earth is about 4.5 billion years old.

12.2 The Geologic Time Scale
The geologic time scale divides Earth’s history based on major past events. Index fossils can be used along with radiometric dating to determine the age of a fossil or rock.

12.3 Origin of Life
The origin of life on Earth remains a puzzle. There are several hypotheses about the way early organic molecules appeared on Earth and about the way early cells may have formed. The discovery of ribozymes, RNA molecules that can catalyze reactions without the help of proteins, led to the hypothesis that RNA arose before DNA as the first genetic material on Earth.

12.4 Early Single-Celled Organisms
Single-celled organisms existed 3.8 billion years ago. The first organisms on Earth were most likely anaerobic prokaryotes. The theory of endosymbiosis proposes that the first eukaryotic cells arose from a large prokaryote engulfing a smaller prokaryote.

The theories of autogeny and horizontal gene transfer provide alternate ideas of how more complex cell structure arose.

12.5 Radiation of Multicellular Life
Multicellular life evolved in distinct phases. During the Paleozoic era, members of every major animal group evolved within only a few million years. During the Mesozoic era, dinosaurs, flowering plants, birds, and mammals inhabited Earth. During the Cenozoic era, mammals, birds, fishes, and flowering plants diversified and flourished. Modern humans did not appear until 200,000 years ago.

12.6 Primate Evolution
Humans appeared late in Earth’s history. Humans share a common ancestor with other primates. Primates include all mammals with flexible hands and feet, forward-looking eyes, and enlarged brains relative to their body size. The hominins include all species in the human lineage, both modern and extinct.

TIMELINE

Make a timeline noting the history of hominid evolution. Add details about characteristics of each hominid that is on your diagram.

TERTIARY PERIOD

QUATERNARY PERIOD

CONCEPT MAP

Use a concept map to summarize hypotheses about the origin of life on Earth.

Hypotheses of early life

include

organic molecules

examples

examples

Concept Map
**Reviewing Vocabulary**

**Compare and Contrast**

Describe one similarity and one difference between the two terms in each of the following pairs.

1. relative dating, radiometric dating
2. isotope, half-life
3. era, period
4. cyanobacteria, endosymbiosis
5. Paleozoic, Cambrian explosion
6. primate, hominid

**Keep It Short**

Write a short, precise phrase that describes the meaning of each vocabulary term below. For example, a short phrase to describe **geologic time scale** could be “organizes life’s history.”

7. index fossil
8. epoch
9. ribozyme
10. bipedal

**Reviewing MAIN IDEAS**

13. Fossils can form in several ways, one of which is by permineralization. Describe the process of permineralization and give an example of the type of fossil that may result.

14. Give an example of the way the concept of half-life is used in radiometric dating.

15. How are index fossils used in relative dating?

16. The geologic time scale organizes the history of Earth into eras, periods, and epochs. How are these units of time related to one another?

17. Compare and contrast the evidence that supports the two hypotheses describing how long, complex molecules that carry information, such as DNA, might have formed on early Earth. [TEKS] 9D

18. What are two ways that cyanobacteria have changed the physical or chemical composition of Earth? [TEKS] 11C

19. Summarize the evidence supporting each of the theories describing the origins of eukaryotic cells. [TEKS] 7G

20. One evolutionary advantage of sexual reproduction is that it creates more genetic variation in a population than asexual reproduction. Why might this be an advantage? [TEKS] 7D

21. What are some criteria by which we can evaluate the relative complexity of a cell? [TEKS] 7G

22. In which era did mammals, dinosaurs, and birds appear on Earth? What happened to these groups in the following era?

23. Humans, apes, monkeys, and lemurs are all examples of primates. What characteristics do all primates share?
Critical Thinking

24. **Analyze** Some scientists propose that more than one of the theories given in Section 4 may be involved in the evolution of the eukaryotic cell. Explain how this might be possible. **TEKS 7G**

25. **Apply** Why is it likely that autotrophs appeared on Earth before any aerobes, organisms that depended on oxygen?

26. **Evaluate** How does the frozen seawater hypothesis suggest that complex molecules that contain information, such as DNA, could have formed in spite of conditions on early Earth that would have inhibited their formation? How persuasive do you find the evidence supporting this hypothesis? **TEKS 9D**

27. **Evaluate** Thirteen of the 20 amino acids used to make proteins in modern-day cells were made by Miller-Urey’s simulation of early Earth’s conditions. Do the results support Miller and Urey’s hypothesis? Why or Why not? **TEKS 9D**

Interpreting Visuals
The chart below shows when some human ancestors lived and traits that they had. Use the chart to answer the next three questions.

![Chart showing human ancestors and traits](chart.png)

28. **Summarize** In one or two sentences, summarize the information in the chart.

29. **Infer** *Sahelanthropus tchadensis* was pictured in FIGURE 6.5 of Section 6 as a three-dimensional computer reconstruction. Although skull fragments of this species have been found, the chart above shows that there is not enough evidence to describe the traits of *S. tchadensis*. Explain why this might be so. Consider the scientific process in your explanation.

30. **Analyze** Some scientists suggest that *Homo habilis* should be classified as *Australopithecus habilis*. Based upon the information in the chart, explain why this might be the case.

Analyzing Data  Calculate Intervals
Both graphs show the rate of decay of chlorine-36, which changes into argon-36. Use the graphs to answer the next two questions.

**GRAPH 1 OF CHLORINE-36 DECAY**

![Graph 1 of Chlorine-36 Decay](graph1.png)

31. **Analyze** Which graph better shows the concept that the percentage change of $^{36}\text{Cl}$ and $^{36}\text{Ar}$ slows down dramatically over time? Explain.

32. **Analyze** From which graph can you more accurately determine the half-life in years of $^{36}\text{Cl}$? Explain.

Making Connections

33. **Write a Detailed Description** Choose one of the periods in geological time and describe it in detail. Be sure to include vivid details about the organisms of the period.

34. **Connect** The time that the Tollund Man on the chapter opener lived was determined by radiocarbon dating. Why can’t $^{14}\text{C}$ be used to date Burgess Shale fossils from the Cambrian period?
MULTIPLE CHOICE

**TEKS 7D**

1. Sexual reproduction and mutation provides means for genetic variation in a population. Why is genetic variation an important element of natural selection?
   A. It ensures that all members of a population receive only traits that provide them with a survival advantage in their environment.
   B. It may provide an individual with traits that do not provide any survival advantage.
   C. It increases the chances that some individuals in a population will gain genes for traits that provide a survival advantage in a changing environment.
   D. It increases the likelihood that a population will go extinct, providing more resources for other, stronger populations.

**TEKS 2G, 7G**

2. The table above shows the fossil evidence of birds in a section of cave wall in Hawai'i. What can be determined from the data presented?

<table>
<thead>
<tr>
<th>Excavated Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavated Section</td>
</tr>
<tr>
<td>% Bones from Non-native Species</td>
</tr>
<tr>
<td>% Bones from Native Species</td>
</tr>
<tr>
<td>I</td>
</tr>
<tr>
<td>II</td>
</tr>
<tr>
<td>III</td>
</tr>
<tr>
<td>IV</td>
</tr>
</tbody>
</table>

The table above shows the fossil evidence of birds in a section of cave wall in Hawai'i. What can be determined from the data presented?
   A. A catastrophic event occurred between 770 and 4340 years ago.
   B. Native species out-competed non-native species.
   C. Most native species died out over 800 years ago.
   D. The disappearance of non-native species is a function of time.

**TEKS 7G**

3. In the evolution of eukaryotes, cells that contained mitochondria-like organelles had an advantage because they—
   A. could make use of photosynthesis
   B. could make use of more available energy
   C. had more DNA
   D. were protected from bacterial invasion

**THINK THROUGH THE QUESTION**

This question is really just asking about the way mitochondria can help a cell.

**TEKS 3A, 7G**

4. Many scientists believe that the cell parts that are now known as mitochondria and chloroplasts were early types of prokaryote cells. The theory of endosymbiosis suggests that early eukaryote cells formed when large prokaryote cells took in mitochondria or chloroplasts, enabling them to live inside the larger cell without harm. What advantage would the larger host prokaryote cell provide to the chloroplast?
   A. a stable, protected environment
   B. the ability to carry out photosynthesis
   C. access to sunlight
   D. ability to reproduce

**TEKS 3A, 7G**

5. The theory of endosymbiosis proposes that the chloroplasts present in some of today’s eukaryotic cells descended from ancient cyanobacteria. Which piece of evidence supports this theory?
   A. Cyanobacteria are single-celled heterotrophs.
   B. Chloroplasts are much larger than today’s prokaryotes.
   C. Chloroplasts are able to copy themselves independently of the cell.
   D. Chloroplasts help eukaryotic cells process energy more efficiently.
Drug-Resistant Bacteria—A Global Health Issue

A bicyclist falls, scrapes his knees, and within a few days is unable to walk. Soccer players with turf burns suddenly find themselves in the hospital with skin infections that require intravenous antibiotics. Why are these young, healthy athletes developing such serious infections?
Staph Infections

These athletes were infected by *Staphylococcus aureus*, or “staph.” Staph is a common bacteria that most people carry on the surface of their skin and in their nose. To cause an infection, staph bacteria must get inside your body. The scrapes athletes commonly get provide an ideal entrance.

Serious problems due to staph infections used to be rare. Doctors would prescribe antibiotics, such as penicillin, to kill the staph bacteria. Ordinary staph infections can still be treated this way. The athletes in our examples did not have ordinary infections. These athletes’ scrapes were infected by methicillin-resistant *Staphylococcus aureus* (MRSA). This bacteria strain is one of many that has evolved resistance to antibiotics.

Drug-Resistant Bacteria

Bacteria that can survive antibiotic treatment are called drug-resistant bacteria. Some bacteria have resistance for one particular antibiotic, some have resistance for several, and a few cannot be treated with any known antibiotic.

MRSA can resist an entire class of antibiotics. Patients with an MRSA infection must often be treated with what doctors call “the drug of last resort,” vancomycin. Vancomycin is a drug that must be given intravenously. Not surprisingly, doctors began to see cases of vancomycin-resistant *Staphylococcus aureus* (VRSA) in 1997. By 2010, vancomycin-resistant bacteria were being discovered in the droppings of one out of ten seagulls, leading scientists to postulate that migrating birds may play a role in spreading drug-resistant “superbugs.”

Staph isn’t the only type of bacteria that is making a comeback with drug-resistant strains. In the mid-twentieth century, antibiotics nearly wiped out tuberculosis (TB). But in the 1990s, TB began to approach epidemic numbers again, and now it kills more than 2 million people every year. Drug-resistant TB kills thousands. Drug-resistant strains of cholera and bubonic plague also have been reported.

How Does Drug Resistance Evolve?

When you take antibiotics for a bacterial infection, most bacteria may be killed right away, but a few will likely survive. Antibiotics leave behind the more resistant bacteria to survive and reproduce. When they reproduce, the genes that make them resistant are passed on to their offspring. Some bacteria reproduce rapidly — *E. coli*, for example, doubles its population every 20 minutes.

In addition to their ability to reproduce quickly, populations of bacteria evolve rapidly. Bacteria use plasmids — small loops of DNA — to transfer genetic material between individual cells. This process is called conjugation. Some plasmids pass on resistance for one particular antibiotic. Others can transfer resistance for several antibiotics at once.

What characteristics do resistant bacteria pass on to their offspring? Some have cell membranes through which antibiotics cannot easily pass. Others have pumps that remove antibiotics once they enter the cell. Some can even produce enzymes that attack the antibiotic drugs themselves.
Fighting Back

Some scientists are trying to develop ways to treat patients without killing the bacteria that are making them sick. Instead, they target the toxins produced by bacteria. If the bacteria are not harmed by the treatment, no selective pressure is produced. Scientists hope that by using this approach, bacteria will be slower to evolve defense mechanisms against the antibiotics. Other scientists hope to fight back by using bacteria’s ancient rival, bacteriophages, which are viruses that infect bacteria.

Evolutionary Biologist in Action

**DR. RICHARD LENSKI**

**TITLE** Professor, Microbial Ecology, Michigan State University

**EDUCATION** Ph.D., Zoology, University of North Carolina, Chapel Hill

If you want to observe evolution in action, you must find populations that reproduce quickly. Dr. Richard Lenski, a professor at Michigan State University, has done just that. Dr. Lenski studies populations of *E. coli* bacteria, which he grows in flasks filled with a sugary broth. These bacteria produce about seven generations each day. Dr. Lenski has now observed more than 30,000 generations of *E. coli*.

The rapid rate of *E. coli* reproduction allows Dr. Lenski to watch evolution take place. Dr. Lenski can subject each generation of bacteria to the same environmental stresses, such as food shortages or antibiotics. He then can compare individuals from more recent generations with their ancestors, which he keeps in his laboratory freezer. By comparing generations in this way, Dr. Lenski can study how the population has evolved.

When Dr. Lenski began his research in 1988, watching evolution in action was still new. Now, many evolutionary biologists are following in his footsteps.

Unanswered Questions

Some important research questions involving drug-resistant bacteria include the following:

- Can plasmids or bacteriophages be used in vaccines to fight bacteria?
- Are bacteria being exposed to antibiotics in sewage systems and evolving resistant strains there?
- How do antibacterial soaps and household cleaners contribute to the evolution of drug-resistant bacteria?
- Can drug-resistant bacteria be transferred from domestic animals to humans through food?