Make your own fossils!

Take some modeling clay and roll it out into a flattened circle or square about a half inch thick. Choose some parts of organisms like shells, leaves, and twigs.

Press the objects into the clay to make an impression. Take the objects off and you have a fossil! How do you think fossils were created millions of years ago? Write your thoughts down in a paragraph.
Chapter 13
Evolution

Why are polar bears white instead of brown or black? White fur helps polar bears blend into the Arctic ice and snow so they can hunt more successfully. White fur has a survival advantage for polar bears. As millions of years passed, and generations upon generations of polar bears survived and reproduced, natural selection occurred in the bear population to favor white fur. Evolutionary concepts like adaptation and natural selection are featured in this chapter.

Key Questions

1. What is evolution and how does it work?
2. What can fossils tell us about the history of life on Earth?
3. What causes animals and plants to become extinct?
13.1 Evidence for Evolution

Imagine going back in time 50 million years. You see a horse about the size of a cat. Would you believe you are looking at an ancestor of the modern horse (Figure 13.1)? *Eohippus* was only 20 cm tall at the shoulders and had five toes. A modern horse is about 150 cm tall at the shoulders and has only one toe. A scientific theory states that newer species have descended from older species through a process called *evolution*. What is evolution and what is the evidence that supports it as a theory?

**What is evolution?**

**Adaptation and evolution**

An *adaptation* is an inherited trait that helps an organism survive. Adaptations include body structures that help an organism feed, move around, and protect itself. *Evolution* is the process of how organisms acquire adaptations over time.

**A moth and a bird**

Through evolution, the structures of organisms become adapted for their functions. Look at the organisms below. The one on the left is a sphynx moth (an insect). The one on the right is a hummingbird. Both species have evolved similar adaptations for feeding on flower nectar. Can you identify how they are similarly adapted for feeding? How are they different?

*Figure 13.1: Eohippus is an ancestor of the modern horse.*

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adaptation - an inherited trait that helps an organism survive.

evolution - the process of how organisms acquire adaptations over time.
Evolution is a branching process

All life forms had a common beginning

There is great diversity in living species. Diversity means variety. Scientists estimate that there are between 5 and 50 million living species. Among those species are single-celled bacteria that lack cell nuclei, single-celled eukaryotes that have cell nuclei, and multicellular fungi, plants, and animals. Where did all of these different species come from? Scientists hypothesize that all life forms evolved from a common ancestor and new species branch off from earlier species. An ancestor is an organism from which others have descended.

Cell evidence

You have learned that all living things are made of cells. There are many similarities among all cells. For example, all cells have a similar cell membrane. Many cells have the same type of cellular respiration. Also, all cells have DNA as their hereditary material. Similarities among all cells support the hypothesis that all life evolved from a common ancestor.

Bacteria were the first living things

Earlier, you learned that bacteria were the first organisms on Earth. Evidence for this comes from fossils of single-celled prokaryotes found in rocks that are more than 3 billion years old. Scientists hypothesize that all species evolved from a single prokaryotic cell such as a bacteria. Eukaryotic cells evolved from bacteria. Multicellular organisms followed. From there, more and more species branched off through the process of evolution.

Branching diagrams

A cladogram displays evolutionary relationships among living species and their ancestors. A cladogram resembles a branching tree. Each branch represents a different evolutionary path. The point where two branches come together represents a common ancestor that shares evolved characteristics with the species that branch off from it. Figure 13.2 shows a simple cladogram.

Figure 13.2: An example of a cladogram.
An evolutionary timeline

Scientists believe that Earth is about 4.6 billion years old. The first life appeared over 3 billion years ago in the form of tiny, single-celled prokaryotes. About 2 billion years ago, those cells evolved into larger cells with a nucleus. Smaller prokaryotic cells took up residence inside the larger cells and eventually evolved into organelles like mitochondria. Multicellular organisms appeared about a billion years ago. Larger animals and plants have been evolving for the past 500 million years. The diagram below shows a theoretical timeline of how the diversity of life evolved.
Lines of evidence

Evolution is a scientific theory that explains how life changes through time. A theory is based on scientific evidence gathered from data and observations. Many lines of evidence provide the basis for the theory of evolution. These include comparative anatomy, DNA analysis, and the fossil record.

Comparative anatomy

Comparative anatomy is the study of anatomical similarities and differences among species. For example, what does your arm have in common with the wing of a bird, the flipper of a porpoise, and the forelimb of an elephant? The diagram below shows that each has a similar bone structure. Homologous structures have a common origin, but do not necessarily perform the same function. The structures in the limbs below indicate that the organisms are related by a common ancestor.

Analogous structures serve the same function but come from different origins. Though structurally similar, they do not arise from a common ancestor. An example of analogous structures is the wing of an insect and the wing of a bird (Figure 13.3).

Figure 13.3: An insect wing and the wing of a bird are both similar in function but do not come from a common ancestor.
Comparing embryos
Another way to compare the anatomy of different species is to compare their embryos. Scientists have discovered similarities in embryos of vertebrates (Figure 13.4). Vertebrates are animals with a backbone. You are a vertebrate. So are other mammals, birds, reptiles, and fish. Adult vertebrates also share many similarities in their skeletons and muscles. This is evidence that all vertebrates descended from a common ancestor.

DNA evidence
All species of organisms have DNA as their hereditary material. Scientists compare the DNA base sequences of different species to determine evolutionary relationships. Species that share more similarities in their DNA base sequences are more closely related than those that share fewer similarities. Scientists hypothesize that if two species have similarities in their base sequences, they share a common ancestor. The diagram compares the DNA base sequences in the gene that codes for hemoglobin in vertebrates. The greater the number of differences in base sequences, the farther the evolutionary distance from humans.

Figure 13.4: Comparing the embryos of different vertebrates.
Fossils

What are fossils? Much of the evidence for evolution comes from studying fossils. A fossil is a remnant or trace of an organism from the past, such as a skeleton or leaf imprint, embedded and preserved in Earth’s crust. Earth’s crust is its outermost layer made of rock.

Sedimentary rock Most fossils are dug up from sedimentary rock layers. Sedimentary rock is rock that has formed from sediments, like sand, mud, or small pieces of rock. Over long periods of time, sediments are squeezed together as they are buried under more and more layers that pile up. Eventually, those sediments are compressed into sedimentary rock. The layers that are farther down in Earth’s crust are older than the upper layers. Figure 13.5 shows layers of sedimentary rock that have been exposed along a river. Each layer contains fossils. Which fossils are oldest?

How fossils are formed Many fossils are formed from the hard parts of an organism’s body like bones and teeth. Fossil formation begins when an organism’s body is quickly covered in sediments from an event like a mudslide or a sand storm. Over time, more and more sediments cover the remains. The body parts that do not rot are buried under layers of sediments. After a long time, the organic compounds in the body parts are replaced with rock-like minerals. This process results in a heavy, rock-like copy of the original object—a fossil.

Fossil - a remnant or trace of an organism from the past, such as a skeleton or leaf imprint, embedded and preserved in Earth’s crust.

Figure 13.5: Which fossils are oldest? Which are youngest?
The fossil record

What is the fossil record? Fossils provide a historical sequence of life on Earth known as the fossil record. Fossils found in the upper (newer) sedimentary layers more closely resemble present-day organisms than fossils found in deeper (older) layers. Through that information, scientists have been able to piece together parts of the fossil record. Scientists use the fossil record to trace the order in which evolutionary changes occurred.

Gaps in the fossil record Although scientists have collected thousands of fossils, there are many gaps in the fossil record. That is because most ancient species did not fossilize. They simply decayed and were lost from the fossil record. Scientists estimate that only a small percentage of past organisms have been (or will be) found as fossils.

Using the fossil record A good example of how scientists use the fossil record to trace evolution is the horse. Scientists have found many fossils of horse ancestors. Figure 13.6 shows how some of the horse’s ancestors may have looked. Below are the limb bones of horse ancestors and the modern horse. The evolution of a species takes millions of years and does not occur in a straight line. There are many branches that lead to different species with different adaptations.

Figure 13.6: Ancestors of the modern horse.
13.1 Section Review

1. What are adaptations? Give an example of an adaptation.
2. For each organism, name one adaptation and its function.

3. Use the words evolution and ancestor in a sentence.
4. Name one reason scientists believe that all life evolved from a single common ancestor.
5. Match the organism with its place on the cladogram (Figure 13.7). Explain the reasoning behind your placement.
6. How do similarities in the bones of humans, dolphins, horses, and birds provide evidence for evolution?
7. How is DNA evidence used to show evolutionary relationships?
8. The diagram (right) shows different fossil layers. Match each layer with the ages of the fossils that would be found there.
   a. 150 million years ago
   b. 140 million years ago
   c. 120 million years ago
9. Explain why there are gaps in the fossil record.

Figure 13.7: Use the diagram above to answer question 5.
13.2 How Evolution Works

In 1831, the research ship *H.M.S. Beagle* left England for a five-year cruise around the world. On the ship was a young man named Charles Darwin (1809–1882). During the trip, Darwin collected thousands of plant and animal species. He was amazed at the diversity of life he encountered. Darwin wrote down his observations and collected evidence about evolution. That evidence led him to propose a theory about how evolution works called *natural selection*.

The finches of the Galapagos

One of the places where the *Beagle* stopped was the Galapagos Islands, located 965 km west of South America. There, Darwin observed that the finches were different than those found on the mainland. He also noted differences in finches from island to island. One difference he found was in the shape of their beaks. The shape of finch beaks appeared to differ with the type of food eaten (Figure 13.8). Darwin concluded that finch beaks were adapted for the type of food they ate. He began to think about why and how the finches became different from each other.

Figure 13.8: The beaks of finches are adapted to obtain food in different ways.
Darwin hypothesized that an ancestral species of finch from the mainland somehow ended up on the Galapagos Islands. The finches of that species scattered to different environments. There, they had to adapt to different conditions. Over many generations, they evolved adaptations that allowed them to get enough food to survive and reproduce. Each group of finches became isolated from the other groups. Eventually, each group became a different species (Figure 13.9). When Darwin returned to England from his voyage, he began to develop a theory about how the adaptations evolved.

From geologists, Darwin learned that Earth was formed very slowly over a long period of time. Its surface also changed slowly over time through natural processes like sedimentation and erosion. Darwin reasoned that populations of organisms changed slowly as their environment slowly changed. If the environment changes rapidly from an event like a flood, an earthquake, or a volcanic eruption, a species could become extinct (all members die off completely).

Darwin used fossils as evidence that different species evolve over a long period of time. He found fossils of species that lived a few million years ago that resembled living species. For example, the glyptodon, an extinct mammal, resembled the armadillo, an organism Darwin knew as a living species (Figure 13.10).

In Darwin’s time, animal and plant breeders used selective breeding to produce organisms with the traits they desired. Darwin called selective breeding artificial selection because the breeders selected the desired traits to produce changes in a species over a few generations. In wild animals and plants, Darwin believed that traits were selected by the environment. He called this process natural selection. He believed that natural selection took longer than artificial selection because it happened by chance.
Darwin’s theory of evolution and natural selection

Darwin publishes his results
In 1859, Darwin published the results of his study in a book called *On the Origin of Species by Means of Natural Selection*. Based on his research and evidence, Darwin concluded that:

1. Organisms change over time.
2. All organisms are descended from common ancestors by a process of branching.
3. Evolution is gradual, taking place over a long time.
4. The mechanism of evolution is natural selection.

What is natural selection?
Natural selection is the process by which organisms with favorable adaptations survive and reproduce at a higher rate than organisms with less-favorable adaptations. Darwin based his ideas about natural selection, in part, on the work of British professor Thomas Malthus (1766–1834).

Populations grow faster than their food supply
In 1798, Malthus published his *Essay on Population*. In that essay, he argued that the human population tends to grow faster than the food supply (Figure 13.11). This causes food shortages and a “struggle for existence.” Darwin’s observations in the Galapagos Islands led him to apply Malthus’ ideas to animals and plants.

Darwin’s conclusions
Darwin proposed that environmental variables affect the size of a population. Variables include predators, food supply, disease, and climate. He reasoned that if a species produces too many offspring and only a certain number survive, the survivors must be better adapted to their environment than those that die. Darwin concluded that offspring of the survivors would inherit the favorable adaptations. Organisms with unfavorable adaptations die before they can pass them on to offspring.

Figure 13.11: Populations tend to grow faster than their food supply.

When wolves hunt deer, they are usually able to catch only the weak or sick deer. The stronger and faster deer can escape. Explain how the wolf population may influence the adaptations of the deer population over time.
The process of natural selection

Darwin proposed that natural selection is the process for evolution. Today, it is still the most thorough explanation of how evolution occurs. The process of natural selection may be summarized in the steps below.

1. **Populations over-reproduce.** All organisms produce more offspring than can survive to adulthood and reproduce. This means that many of those offspring will die without reproducing. Survivors that are able to reproduce pass their traits on to their offspring.

2. **Individuals in a population vary.** There is random variation in traits among individuals in a population of a species. The variations each individual possesses happen by chance. Those variations are inherited.

3. **Favorable adaptations are selected.** The changing environment causes a selection of favorable traits (adaptations). Adaptations that fit well with the environment are passed on to offspring in greater numbers than adaptations that do not fit well.

4. **Favorable adaptations accumulate.** Favorable adaptations accumulate over many generations. This may lead to new species.
13.2 Section Review

1. On his journey, Darwin observed how different animal and plant species had adapted to function in their environments. Explain how each of the following items is best suited to its unique function.

2. Why did Darwin use selective breeding as evidence for evolution?

3. How did the work of geologists support Darwin’s theories about evolution?

4. What is natural selection?

5. How did the work of Malthus help Darwin reach his conclusion about natural selection?

6. List three environmental variables that affect the size of a population.

7. A population of beetles eats only red flowers. Most of the beetles are red but a few of them are yellow. The red beetles are hidden from hungry, beetle-eating birds. The beetles eat up all of the red flowers and now there are only yellow flowers left. What would you expect to happen to the traits of the beetle population over time? What process would cause this to happen?

A challenge to Darwin’s theory

Darwin’s theory of evolution states that changes occur gradually and over many years. He used the fossil record to support his ideas. In the 1970s, American biologist Stephen Jay Gould (1941–2002) presented a challenge to Darwin’s theory called *punctuated equilibrium*. He argued that a species can remain unchanged for millions of years. If a dramatic environmental event occurs, a species can undergo rapid changes in a short period of time. He also found evidence in the fossil record to support his idea.

1. What does Gould mean by a dramatic environmental event? List some of your ideas.

2. Do you agree or disagree with Gould’s ideas? Explain your position and justify it with your knowledge about evolution.

3. Could Darwin’s model for evolution and Gould’s model both be correct? Explain your reasoning.
13.3 Natural Selection

Natural selection explains how a population changes in response to its environment. Those changes are called adaptations. Adaptations are inherited, therefore they must be carried on genes. Since Darwin developed his theory before Gregor Mendel’s experiments, he knew nothing about genes. In this section, you will learn about the connection between natural selection and heredity.

**Mutations**

**What causes genetic variation?** Since Darwin’s time, there has been a growing body of knowledge about heredity. That knowledge explains many of Darwin’s observations and supports the theory of evolution. For example, Darwin observed that individuals in a population show variation in their traits. Today, scientists know that variations in the population of a species are caused by random mutations in genes.

*Random mutations in genes produce variations of traits in a population.*

**Mutations lead to alleles** Recall that alleles are different forms of a gene. A gene mutation leads to different alleles of that gene which in turn, leads to variations of a trait. Mutated alleles may cause favorable and unfavorable adaptations.

**Favorable alleles are selected** Imagine a population of brown squirrels that has a single gene that determines fur color. A mutated allele causes white fur instead of brown fur. The squirrels with brown fur can hide from predators better than squirrels with white fur (Figure 13.12). Most of the squirrels that survive to reproduce are brown. Since brown fur is a favorable adaptation, the allele for brown fur is selected over the allele for white fur. What would happen to the frequency of the brown fur allele if the climate changed and the ground became covered in snow for most of each year?

Reviewing past topics will help you understand the concepts in this chapter. Below are topics and the page number in the text where you will find them. For each topic, go back and reread the page. Then, write down how that topic relates to what you are currently learning.

- Species (definition) - page 47
- Populations - page 95
- Bacteria and evolution - page 181
- Alleles - page 218
- Mutations - page 242
The importance of genetic variation

Helpful mutations
You have learned that some mutations are harmful because they cause genetic disorders. Mutations may also be helpful because they contribute to genetic variation. Genetic variation refers to the variety of alleles in a population. Genetic variation is necessary for natural selection and ensures that a population has a better chance of survival should the environment change.

Changing environment
Because our fictional squirrel population carries an allele for white fur, it may have a better chance of surviving a change to a colder climate. The allele for white fur may be selected over the brown if the ground is covered in snow for most of each year. Over many generations, the frequency of the white fur allele may increase in the population while brown decreases.

Natural selection in action
Scientists have observed natural selection in species that produce new generations quickly. An example is pesticide resistance in the potato beetle. Farmers routinely spray pesticides to prevent this pest from destroying their crops. Each time they spray, a few of the beetles survive. The survivors carry a mutated allele that resists the pesticide. The survivors pass the resistant allele to their offspring. Because generations multiply quickly, it does not take long for a population of pesticide-resistant beetles to evolve (Figure 13.13).

Figure 13.13: How a population of potato beetles changes over time.
How a new species evolves

How does a new species evolve?

Scientists theorize that natural selection leads to the formation of new species. Recall that a species is an isolated population of similar organisms that interbreed and produce fertile offspring. One way for a new species to evolve happens in three steps: **isolation**, **adaptation**, and **species formation**.

**Isolation**  
**Isolation** happens when a population becomes divided by an event. Possible events include floods, volcanic eruptions, mountain formation, earthquakes, and storms. The original population becomes divided into smaller populations. Each population is physically and reproductively isolated from the others.

**Adaptation**  
**Adaptation** happens through natural selection. The event that causes isolation may also change the environment. As the environment changes, the population that lives there undergoes natural selection. Over time, each separated population may become adapted to their environment. If the environments are different, each population will have different adaptations.

**Species formation**  
**Species formation** happens when the isolated populations become so different that they can no longer interbreed, even if they could unite again. Over many generations, the isolated populations become genetically different from each other. Each population may have different allele frequencies. Random mutations in each population may create new alleles and thus new traits. As a result, one or more new species are formed.
Extinction of a species

What is extinction? Extinction occurs when the environment changes and the adaptations of a species are no longer sufficient for its survival. Changes may include increased competition with other species, newly introduced predators, loss of habitat, and catastrophes. Based on the fossil record, scientists think most of the species that once lived on Earth are now extinct.

An example of extinction The dodo bird is an example of how human impact may contribute to extinction. The dodo was first sighted around 1600 on Mauritius, an island in the Indian Ocean (Figure 13.14). It was a flightless bird with a stubby body and tiny wings (Figure 13.15). Scientists believe that the dodo evolved from a bird capable of flight. When an ancestor of the dodo landed on Mauritius, it found a habitat with plenty of food and no predators. It had no reason to fly and eventually evolved into a flightless bird.

The cause of the dodo’s extinction The dodo was extinct less than eighty years after its discovery. Some of the birds were eaten by the Dutch sailors who discovered them. Also, domestic pigs and cats destroyed their nests which were built on the ground. But the main cause of their extinction was the human destruction of their habitat.

The importance of genetic variation One reason the dodo may have become extinct is the lack of genetic variation. As a species’ population gets smaller, its genetic variation may decrease. Natural selection requires genetic variation. Therefore, a small population may be more susceptible to extinction than a large population if their environment changes. If genetic variation is not present, the population may not have enough favorable adaptations to survive changes in the environment. Scientists study extinctions like the dodo’s in hope of preventing future extinctions.
13.3 Section Review

1. Why are mutations beneficial to the process of evolution?
2. Many species of animals carry an allele for albinism (lack of pigmentation). Albinos are usually pale or white in color. Explain why the allele for albinism is present at a lower frequency than the allele for having pigments. What conditions would be necessary for the albino allele to be more frequent?
3. Why is genetic variation necessary for natural selection to occur?
4. Construct a concept map that shows how a population of bacteria can develop resistance to antibiotics.
5. Describe how a new species evolves.
6. What is meant by the term extinction? List three causes of extinction.
7. Cheetahs are the largest of the small cats. The cheetah population once covered all of Africa and Asia. Now cheetahs are an endangered species. Loss of habitat, commercial farming, and development are major causes of its decline. Today, there are fewer than 12,000 cheetahs left on the planet. Explain, using your knowledge of natural selection, why it may be difficult to stop the decline of the cheetah population.
Chameleons of the Sea

All animals try to blend into their surroundings—even us humans—but some are nearly perfect at it. Or should that read “nearly invisible?” What animal do you think is the best at blending in? If you guessed the chameleon, you’re close. That reptile can change the color of its skin to match its surroundings. Yet no animal compares to the octopus and its relative the squid when it comes to disguises.

Most animals blend into their surroundings in order to protect themselves. But predators also want to blend in so that they can surprise their prey. Many animals, like the octopus and squid, need to remain unseen because they are both predator and prey.

The octopus and squid can change color almost instantly, far faster than a chameleon. Indeed, they have been called “the chameleons of the sea.” Their ability to change their body color, shape, and texture is quite a complicated process. They can create an amazing variety of appearances. The way they blend into their surroundings is one of nature’s most dramatic examples of how organisms can adapt to their environments.

Intelligent invertebrates

The octopus and squid are cephalopods. In ancient times, cephalopods were one of the dominant life forms in the planet’s oceans. They are the most biologically advanced of the mollusks (which include snails, clams, and oysters), and are considered to be highly intelligent invertebrate animals.

Cephalopods have large brains and complex nervous systems. They are very sensitive to their environments and are able to adapt quickly to change. Their eyes are sophisticated and similar to the human eye, with a cornea, lens, and retina.

Remember that their ability to blend into their surroundings is an adaptation that also makes cephalopods excellent predators. On the other hand, they lack the protection of a hard shell, which makes them attractive as prey.

So what adaptations have the octopus and squid made to ensure their survival? The ability to blend into their surroundings is their primary defense. Their soft bodies allow them to squeeze into small burrows between rocks, and they also have chemical weapons they use as a defensive smokescreen. They can shoot a cloud of ink into the water, giving them time to escape a predator.
In a blink of its eye

So just how do cephalopods blend into the ocean background so well? Their advantage is a special skin cell called a chromatophore. There are hundreds of chromatophores in each square centimeter of a cephalopod’s skin.

Each of those chromatophores has three bags that contain different colors of liquid pigment. The bags are squeezed or expanded to change the color displayed by each cell. And each of those cells is controlled separately. The cephalopod’s complex brain coordinates all this.

Imagine how many subtle differences in color can be created in this way. The octopus or squid is capable of producing millions of patterns to match any background. And, amazingly, the cephalopod does all this instantaneously.

Survival strategies

Cephalopods still must use a variety of other strategies to adapt to their environments. For example, an octopus or squid can change its texture using muscles in the skin. They also use different body postures to sculpt themselves into their surroundings. So they may curl into a ball and change their skin texture and look like a rock—to predator or prey.

Cephalopods change their appearance in courtship, in acts of aggression, and to warn of danger. Squid will display a high-contrast zebra pattern when courting in order to discourage other males from mating with a certain female.

These chameleons of the sea have survived over eons because they adapted to their surroundings. Like every animal, their survival depends on escaping predators, finding food, and reproducing. Think of it: The cephalopod’s complex ability to sometimes render itself nearly invisible has meant the species has not disappeared from the ocean.

Questions:
1. How do cephalopods differ from other mollusks?
2. Why is it an advantage to be able to blend into the environment?
3. Why is it important for cephalopods to blend in?
4. What are chromatophores?
In this chapter, you learned about the process of natural selection. In this activity you will simulate how natural selection works in a population of mice. Imagine a population of mice that have variations in their fur color. They are hunted by a species of hawk that has pincher-like claws. You and your classmates will play the role of the hawks. The materials and what they represent in the simulation are shown below.

You will also need a stopwatch or a watch with a second hand, pencils, and graph paper.

**What you will do**

1. Open your sheet of newspaper and place it on a flat surface such as a lab table. This will serve as the environment for your mice.
2. Place the petri dish on the other side of the table. This will be the nest.
3. Select one person from your group to act as a hawk. This person should stand by the nest.
4. The hawk should have a pair of forceps. These represent one of its claws. The hawk can only pick up the mice with the forceps.
5. Spread the mice on their environment evenly.
6. Have another student play the role of the timer.
7. The hawk now swoops over and has 1 minute to pick up as many mice as possible. The hawk may only pick up one mouse at a time. Then, the hawk must place it in the nest before flying back to pick up another. The goal is to pick up as many mice as possible in the time period.
8. When the time is up record the number of mice left in the environment in the data table below.
9. Repeat this procedure for each person in the lab group.
10. After all data is collected, construct a bar graph. Be sure to label the graph and its axes.

**Questions:**

a. What variations are present in your mouse population?

b. Why is variation important to the survival of a population?

c. Make a bar graph of your data.

d. What happened to the mouse population after each trial?

e. Suppose the surviving population goes on to reproduce. What do you think the next generation will look like?

f. How might the mouse population change over many generations?

g. In this simulation, which variation is a favorable adaptation? Which variations are least favorable?

h. If the environment suddenly changed to white, which variation would be the most favorable?
Chapter 13 Assessment

Vocabulary

Select the correct term to complete the sentences.

<table>
<thead>
<tr>
<th>evolution</th>
<th>vertebrates</th>
<th>fossil</th>
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<tbody>
<tr>
<td>ancestor</td>
<td>genetic variation</td>
<td>fossil record</td>
</tr>
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<td>adaptations</td>
<td>homologous structures</td>
<td>natural selection</td>
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<td>cladogram</td>
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Section 13.1
1. Inherited from parent to offspring, ____ increase an organism's chance of survival in their environment.
2. Biologists use a ____ to illustrate evolutionary relationships between organisms and their ancestors.
3. ____ share common evolutionary origins, but can be functionally unalike.
4. Mammals, bony fish, and birds are just a few examples of _____, animals with backbones.
5. Typically found in sedimentary rock, remains of organisms called ____ offer clues into evolutionary history.
6. The location in which fossils appear in the sedimentary layers is used to piece together an evolutionary sequence of life on Earth called the ____.

Section 13.2
7. ____ is a process by which organisms with favorable traits survive and reproduce more successfully.

Section 13.3
8. Greater ____ signifies a larger variety of alleles and therefore greater survivability of a species over time.

Concepts

Section 13.1
1. As environmental conditions change over time, which population will have a better chance of survival?
   a. A population with a high level of variation.
   b. A population with several very fit and genetically similar organisms.
   c. Organisms that mutate very rarely.
   d. A population that feeds exclusively on one type of food.
2. How would a mutation in a skin cell differ from a mutation within a sperm or egg cell in relation to the theory of evolution?
3. In trying to understand the evolutionary relationships between two species which of the following would NOT be helpful?
   a. DNA analysis shows nearly identical strings of DNA sequence within each genome.
   b. Both species live in the similar environments and feed the same food.
   c. Embryos of each species show distinct similarities.
   d. Comparative analysis of dental impressions shows similarities in number and structure of each tooth.
4. Which statement best describes adaptation:
   a. A lily suddenly mutates its tissues to store more water in a drought.
   b. Fish swim away from a sudden source of pollution.
   c. A beetle hatches in time of food shortage with a mutation that contains enzymes to digest a greater variety of food.
   d. Environmental factors are a cause of natural selection in which there are only favorable traits.
Section 13.2

5. After studying the beaks of finches, Darwin developed a theory of how adaptations evolved. Are there other ideas that led him to this theory? Explain.

6. The size of a white-footed mouse population is influenced by
   a. the availability of acorns, a main source of food.
   b. an increase in the owl population, a primary predator.
   c. an extremely dry summer leading to a severe drought.
   d. All of the above

7. Variation:
   a. is not random and occurs due to an environmental change.
   b. describes only changes in the behavior of a species.
   c. is acquired throughout an organism's lifetime.
   d. happens by chance and is passed on to offspring.

Section 13.3

8. Mutations:
   a. occur randomly and produce variation in a population.
   b. occur due to changes in the environment.
   c. change only the physical appearance of an organism and not its genotype.
   d. were explained by Darwin's analysis of Mendel's pea experiments.

9. Do changes in the environment CAUSE mutations or are they already present in the gene pool of a population? Explain.

10. Give an example of how a random mutation in an organism could give it an environmental edge over other members of its species.

11. A pregnant jungle tree frog is released into a remote and isolated mountain community. Of the 2000+ eggs she lays only a few hundred last a sudden freeze. How might this situation develop further to create a new species?

12. Which is not a cause of extinction:
   a. Sudden environmental changes occur
   b. Poor adaptations to the changing environment
   c. Too much variation in the gene pool
   d. Introduction of a foreign species increases competition

Math and Writing Skills

In earlier periods of history, people believed fossils were organisms that spontaneously sprouted from the ground but were unable to properly develop and come to the surface. How is this different from modern understanding of fossil formation? How is the fossil record used to understand Earth's evolutionary history?

Chapter Project—Endangered Species

Extinct species are living things that have disappeared from Earth. The United States government has a protection program that places animals and plants on a special list if they are in danger of extinction. If a plant or animal makes the "endangered" or "threatened" list, funding is available for protecting it. The U.S. Fish and Wildlife Service maintains a list of endangered species. Find a list of animals that are listed as "endangered" in the United States. Choose a mammal, bird, reptile, amphibian, or fish from the list and create a large poster to teach others about this endangered species. On the poster, be sure to include the common and scientific name of the animal, interesting facts, a map with current locations marked, and list important things being done to protect this species. Your goal is to educate others about this endangered species.
Chapter 14

Earth and Life History

There was a time when Earth had a warm, tropical climate all over. Dinosaurs roamed Earth, and giant plants called cycads grew everywhere. Earth’s land masses formed one giant continent. This might sound like science fiction, but it is actually a simple description of what geologists call the Mesozoic era in Earth’s history. How do geologists know what Earth and its life forms were like millions of years ago? Explore this chapter to find out!

Key Questions

1. What do rock layers tell us about Earth’s history?
2. How is Earth’s surface like a giant jigsaw puzzle?
3. How long ago did dinosaurs live on Earth, and what happened to them?
14.1 Evidence from Rocks

Earth’s environment has been changing slowly since it was formed 4.6 billion years ago. These changes are the driving force behind evolution. **Geology** is the study of Earth’s formation and structure. Geologists study rocks to find clues to Earth’s formation. **Evidence from rocks and fossils allows us to understand the evolution of life on Earth.**

**Fossil formation**

*Tonguestones and shark’s teeth*  
In 1666, Nicholas Steno, a Danish anatomist, studied a shark’s head and noticed that the shark’s teeth resembled mysterious stones called “tonguestones” that were found inside of local rocks. At this time, people believed that tonguestones had either fallen from the moon, or that they grew inside the rocks. Steno theorized that tonguestones looked like shark’s teeth because they actually *were* shark’s teeth that had been buried and became fossils.

*Fossil formation*  
Steno concluded that when a shark dies, sediments are deposited over its body. After a short time, the shark’s soft parts decay, but the teeth do not. Over many years, layers of sediment cover the teeth. Over many more years, the layers of sediment are pressed together and become sedimentary rock. The shark’s teeth become part of the rock. Steno’s work led him to develop some important principles in geology, explained in this section.
The formation of sedimentary rock

The rock cycle

The rock cycle is the process of rock formation and recycling. Sedimentary rock formation is part of the rock cycle. (The other two types of rocks are igneous and metamorphic.) When rocks are unearthed and exposed to Earth’s atmosphere, they are subject to weathering and erosion. This breaks rocks up into sediments.

Sedimentary rock layers form horizontally

Sediments are washed from the land and transported into bodies of water. They settle to the bottom because of gravity. Any change in the composition of material being deposited shows up as a distinct horizontal layer. Over time, those layers of sediment become layers of rock. Parts of organisms that do not decompose may become fossils within the layers (Figure 14.2).

Rock layers form from the bottom up

The relative age of each layer of sedimentary rock can be determined by applying an idea called superposition. Superposition states that the bottom layer of sedimentary rock is older than the layer on top because the bottom layer formed first. Stacking old newspapers in the order in which you received them illustrates superposition (Figure 14.3). The oldest newspaper will be on the bottom, and the newest on top.

Figure 14.2: Fossil formation.

Figure 14.3: A stack of newspapers illustrates superposition.

VOCABULARY

rock cycle - the process of rock formation and recycling.

superposition - the principle that states that in layers of sedimentary rocks the lowest layers were the earliest to be deposited.
Rock layers may bend and shift. Sometimes rock layers are found standing vertically, or tilted, or rolled into curves. Slow movements of Earth’s crust create very powerful forces. Those forces can move and twist horizontal rock layers into different positions. The photo in Figure 14.4 shows what curved layers of sedimentary rock look like.

Layers of rock are continuous. Horizontal layers of rock are continuous. When layers of sediment form, they extend in all directions. By comparing rock layers in the Grand Canyon, geologists have found that the layers on one side of the canyon more or less match up with the layers on the other side. A flowing river can interrupt layers or an earthquake can offset them. The Colorado River formed the gap that is now the Grand Canyon.

Figure 14.4: Curved layers of sedimentary rock. The object in the middle is a pocket knife, shown for scale.
Relative dating

Steno’s principles are used by geologists to determine the age of fossils and rocks in a process called relative dating. Relative dating is a method of sequencing events in the order they happened.

What is relative dating?

Figure 14.5 shows an example of relative dating. When you use relative dating, you are not trying to determine the exact age of an object. Instead, you use clues to sequence the order of events that occurred around it. Then you determine the age of the object relative to the other objects or events in the sequence. Can you list the three events shown in Figure 14.5 in order of occurrence?

Using relative dating to sequence fossils

Paleontologists use relative dating to determine the sequence of fossils in the order that each species existed. A paleontologist is a scientist who studies fossils. A cross section of sedimentary rock has many different layers. The oldest layers are found at the bottom and the newest at the top. Suppose fossils were found in the layers shown below. A paleontologist could sequence the organisms found according to their location in the layers. The organisms found in the top layers appeared after the organisms found in the layers below them.

Figure 14.5: This graphic illustrates three events: a footprint, a tire track, and snowfall. Which event happened first? Sequencing these events in the correct order is a form of relative dating.

VOCABULARY

relative dating - a method of sequencing events in the order in which they happened.
paleontologist - a scientist who studies fossils.
More relative dating

Cross-cutting relationships

The idea of cross-cutting relationships states that a vein of rock that cuts across a rock’s layers is younger than the layers. Figure 14.6 shows a rock formation with three layers and a cross-cutting vein. The rock layers formed first. The vein formed in a crack in the original rock. The bottom layer is the oldest part of the rock formation and the vein is the newest. The middle and top layers formed after the bottom layer but before the vein.

Inclusions

Sometimes rock pieces called inclusions are found inside another rock. During the formation of a rock with inclusions, sediments or melted rock surrounded the inclusion and then solidified. Therefore, the inclusions are older than the surrounding rock (Figure 14.6). A rock with inclusions is like a chocolate chip cookie. The chocolate chips (inclusions) are made first. Then they are added to the batter (melted rock or sediment) before being baked (hardened) into a cookie (rock).

Faunal succession

Faunal succession means that fossils can be used to identify the relative age of the layers of sedimentary rock (Figure 14.7). For example, dinosaur fossils are found in rock that is about 65 to 200 million years old because these animals lived that long ago. The fossils of modern human beings (Homo sapiens) are found in rock that is about 40,000 years old, but not in rock that is 65 to 251 million years old. And dinosaur fossils are not found in rock that is 40,000 years old. This means that human beings did not live at the same time as the dinosaurs. How might you learn which plants and animals did live at the same time as the dinosaurs?
14.1 Section Review

1. Who is Nicolas Steno? What ideas did he come up with that have contributed to modern geology?

2. A river cuts through a canyon and exposes the rock layers. How would the rock layers on either side of the canyon compare? Explain your reasoning.

3. What idea is represented in Figure 14.8? Which fossil is the oldest? Which is the newest? How can you tell?

4. True or False: Superposition states that rock layers near the surface of Earth are more recent than rock layers further from the surface. Explain your reasoning.

5. Study the following picture. Which is the oldest layer of rock? Which layer is the newest?

6. The rock in Figure 14.9 has many features. Use what you know about relative dating to place the features in order of occurrence from oldest to newest.

7. What are inclusions? Which part of a chocolate chip cookie are similar to inclusions?
14.2 How Earth Changes

In their work, geologists study the features that are observable today, to interpret the ancient geologic record. For example, geologists have used the fossil record to determine how and why Earth’s environments have been slowly changing over millions of years.

Pangaea

A supercontinent called Pangaea

In 1915, Alfred Wegener (1880–1930) theorized that the continents that we know today had been part of an earlier supercontinent. He called this great landmass Pangaea. According to his theory, Pangaea broke apart and the pieces drifted to their present places, becoming today’s continents.

Evidence to support Wegener’s theory

To support his theory, Wegener observed that fossils of plants and animals found on different continents were very similar. Also, there were matching geologic features on both sides of the Atlantic Ocean. Furthermore, the current shapes of the continents seemed to fit together like puzzle pieces (Figure 14.10).

Figure 14.10: The continents on either side of the Atlantic Ocean fit together like puzzle pieces.
Plate tectonics

What is plate tectonics? How the continents move is explained by a theory called plate tectonics. Earth’s outer layers are called the lithosphere. The theory of plate tectonics, first stated in 1965, refers to the movement of giant pieces of the lithosphere called lithospheric plates. The movement of one plate causes the pulling or pushing of other plates, significantly affecting Earth’s surface. There are seven large lithospheric plates and many smaller ones.

Movement of tectonic plates Forces beneath the lithosphere cause the plates to move. Some plates include continents (Figure 14.11). The continents move with their plates. The plates that include North America and Europe are moving apart at a rate of a little over 2 centimeters each year. By comparison, your fingernails grow at a rate of 2.5 centimeters a year. Though that rate may seem slow, it has produced enormous changes in Earth’s surface over millions and millions of years.

Figure 14.11: The movement of lithospheric plates causes the continents to move.

plate tectonics - a theory that describes how the continents move.
lithospheric plates - giant pieces of solid rock on Earth’s surface.
Plate tectonics and fossil distribution

Fossil evidence for Pangaea

The distribution of fossils provides evidence that the continents were once joined and have slowly separated over time. Fossils of the same species have been found on several different continents. If the continents had always been separated, we would not find these fossils on different continents.

Fossil distribution

*Glossopteris*, an ancient plant species, was found on the continents of South America, Africa, India, and Australia (Figure 14.12). If the continents are reassembled into Pangaea, the distribution of glossopteris can be accounted for over a much smaller and connected geographic area. The distribution of other fossils can also be accounted for using the same method of analysis.

Figure 14.12: *Glossopteris* was a woody, seed-bearing shrub or tree, 4–6 m in height. *Glossopteris* and the other fossil organisms shown have been found on different continents.
Plate tectonics and evolution

Plate tectonics results in the formation of new species. One result of plate tectonics is the geographic separation of populations. Separation of lithospheric plates separated the continents and divided populations. Collision of plates pushed up mountain ranges which also divided populations (Figure 14.13). Once populations became geographically separated they could no longer interbreed. The separated populations evolved different adaptations. Eventually, they became different species.

Organisms adapt to their environments. Because the movement of plates is slow, organisms usually have time to adapt to changes in the environment. That is why organisms alive today are well adapted. But in the same location where well-adapted organisms thrive, scientists have discovered fossils of organisms that could not adapt to the changes. Dinosaur and plant fossils have been found on the continent of Antarctica. Today, Antarctica is permanently frozen and supports only species that have adapted to the gradual change in climate—like penguins (Figure 14.14).

Using fossils to interpret changes in the environment. Scientists use fossils to interpret environmental changes brought about by plate tectonics. To do this, they apply the principle of uniformitarianism. For example, ancient animals that resembled clams probably lived in the same type of environment as modern clams. If clam fossils are found on a mountain top, scientists assume that the mountain top may have once been part of an environment that supported a clam population. Geologic processes resulted in changes in that environment and the extinction of the clam population in that location. The fossils were probably brought to the surface by the collision of lithospheric plates.

Figure 14.13: Collision of plates may push up mountain ranges and divide populations.

Figure 14.14: A penguin.
14.2 Section Review

1. How is Earth’s surface like a giant jigsaw puzzle?
2. What was Pangaea? List three examples of evidence that Wegener used to support his idea of Pangaea.
3. Describe the theory of plate tectonics.
4. Write a paragraph describing the graphic below. Answer these questions in your paragraph.
   a. What does the left side of the graphic show?
   b. What does the right side of the graphic show?
   c. How does this graphic support the idea of plate tectonics?

Imagine you are a penguin living in Antarctica. Write a short story describing a day in your life.

5. How does plate tectonics contribute to the formation of new species?
14.3 Life History

Scientists have developed a model of the history of life on Earth called the geologic time scale (Figure 14.15). It is based on studies of Earth’s geology and the fossil record. Most of Earth’s changes have occurred slowly, over millions of years. But occasionally, Earth’s history has been interrupted by catastrophes such as massive volcanic eruptions or asteroid impacts. These events had a significant effect in shaping Earth’s surface and on the evolution of life. In this section you will read about the history of life on Earth as told by the fossil and geologic records.

The geologic time scale

Divisions of the geologic time scale

Paleontologists divide the geologic time scale into blocks of time called eras and periods. Eras are determined by the dominant life forms that were present at the time. Each era is divided into smaller blocks of time called periods. Periods are based on types of fossils found within each era.

Precambrian era

The Precambrian era lasted from Earth’s formation 4.6 billion years ago until 542 million years ago (mya). The first prokaryotic cells appeared more than 3 billion years ago. Then, photosynthetic bacteria (cyanobacteria) evolved and began to add oxygen to Earth’s atmosphere. Some of that oxygen reached Earth’s upper atmosphere and formed the ozone layer. The ozone layer blocked harmful radiation from the sun. This allowed life to move out of the water and onto dry land. The first eukaryotic cells appeared in the Precambrian era, about 2 billion years after the first prokaryotic cells.
Paleozoic era  The Paleozoic era lasted from 542 to 251 mya. *Paleozoic* is a Greek word meaning “ancient life.” Rocks dated from the Paleozoic era contain fossils of trilobites, snails, clams, and corals. Early in the era, many new, complex life forms developed, but glaciers covered the Earth in the Ordovician period, causing many of these new organisms to become extinct. In the Silurian period, fishes with backbones appeared. Next, plants and air-breathing animals began to populate the land. Toward the end of the Paleozoic era, much of the land was covered with forests of palm trees and giant ferns. Therapsids are a group of animals that dominated the land in the Permian period. Scientists believe that mammals evolved from therapsids.

Mesozoic era  The Mesozoic era lasted from 251 to 65 mya. *Mesozoic* is a Greek word meaning “middle life.” This era is often called the Age of Reptiles. Dinosaurs are the most well-known reptiles of the Mesozoic era and dominated Earth for about 150 million years (Figure 14.16). The Jurassic period was marked by the appearance of the first birds. Flowering plants evolved during the Cretaceous period. At the end of the Mesozoic era, 65 ya, dinosaurs and many other animal and plant species suddenly became extinct. Geologic evidence indicates that an asteroid may have hit Earth. This may have been the cause of the extinctions.

Cenozoic era  The Cenozoic era began 65 mya and is still going on. *Cenozoic* means “recent life.” Fossils from the Cenozoic era are closest to Earth’s surface, making them easier to find. Therefore, scientists have the most information about life in this era. The Cenozoic era is often called the Age of Mammals because many species of mammals appeared. Eohippus appeared in the Cenozoic era (Figure 14.17). The first human ancestors appeared about 4 million years ago. Modern humans appeared 40,000 years ago during the Quaternary period.
Mass extinctions

What are mass extinctions? There have been at least five mass extinctions in which many types of plants and animals were wiped out. Mass extinctions are periods of large-scale extinction. They seem to be part of the evolutionary process because after each, new life forms emerge.

The greatest mass extinction Scientists believe the greatest mass extinction was about 250 million years ago towards the end of the Paleozoic era. It is known as the Permian extinction, and it killed as many as 90 percent of all living things on Earth. Some scientists believe it was caused by an event such as a volcanic eruption or asteroid impact. That event sent particles of dust into the atmosphere and changed Earth’s climate causing long- and short-term changes in the habitats of organisms living at that time. (Figure 14.18).

The most recent mass extinction The Cretaceous-Tertiary extinction happened about 65 million years ago, ending the Mesozoic era. Many scientists believe a large asteroid hit Earth. The impact was so violent that once again, huge amounts of dust were thrown into the atmosphere. The sun was blocked out, possibly for years. Changes in climate and habitats caused the extinction of the dinosaurs. Afterwards, mammals became the dominant vertebrate life form on land.

A sixth mass extinction? Today, some scientists think we are in the middle of a sixth mass extinction because many species have become extinct in the last few hundred years. This time, human impact may be the cause. But humans can also help prevent extinctions. The California condor is one example (Figure 14.19). A typical California condor has a 10-foot wingspan, making them the largest bird in North America. Government and private groups have created the California Condor Recovery Program. Because of the program, there are now almost 300 condors, over 100 of them in the wild in California, Baja California, and Arizona.
Absolute dating

What is absolute dating?

Relative dating provides information about the sequence of events in Earth’s history. **Absolute dating** is a method of estimating the age of a fossil in years. Scientists use both absolute and relative dating to develop the geologic time scale. Absolute dating requires the use of a natural “clock.” That clock is the radioactive decay of certain naturally-occurring elements like uranium and carbon.

What is radioactive decay?

Elements that undergo radioactive decay contain unstable atoms. All atoms are made of tiny particles held together by strong forces. Atoms of different elements contain different numbers of particles. Unstable atoms contain more particles than can be held together by the strong forces. They undergo radioactive decay by releasing some of those particles. In the process, they transform into different kinds of atoms. For example, when uranium atoms decay, one of the products is lead atoms (Figure 14.20).

What is half-life?

Half-life is the amount of time it takes for half of the unstable atoms in a sample to decay. Half-lives range from fractions of a second to billions of years. In a sample of uranium-238, it takes 4.5 billion years for half of the uranium atoms to transform into lead atoms. The half-life of carbon-14 is 5,730 years (Figure 14.20). One of the products of carbon-14 decay is nitrogen.

Using absolute dating

Scientists estimate the age of fossils by measuring the ratio of unstable to stable atoms in a sample of rock from a fossil. Earth’s age is estimated by measuring the radioactive decay of uranium to lead. Scientists compared the amount of lead to uranium in a piece of uranium ore. With that measurement, the age of Earth was estimated to be about 4.6 billion years. The fossils of ancient bacteria, the first life forms, have been dated to be over 3 billion years old.
1. Explain how time is divided in the geologic time scale.
2. Match the organism or event to the time period in which it first appeared.
   a. dinosaur
   b. woolly mammoth
   c. archaebacteria
   d. human
   e. mass extinction of dinosaurs
   f. Pangaea
   g. plants
   h. fishes with backbones
3. What is a mass extinction?
4. How could an asteroid impact change Earth’s climate?
5. How have catastrophes contributed to the evolution of life on Earth?
6. Explain the difference between relative dating and absolute dating.
7. The age of a fossil is estimated to be about 280 million years old.
   a. Explain how scientists estimate the age, in years, of a fossil.
   b. To which era and period does the fossil belong? What are some organisms that lived during that time?

**SOLVE IT!**

1. A sample of rock contains 10 mg of carbon-14 atoms. The half-life of carbon-14 is 5,730 years. How many grams of carbon-14 will be in the sample after 11,460 years?
2. A sample of rock contains 4 mg of an unstable element. After 50 years, the sample contains 2 mg of the unstable element. What is the half-life of the element?
Something drastic happened about 65 million years ago—the fossil evidence is clear. At the end of the Cretaceous Period, almost all of Earth’s large vertebrates (including the dinosaurs), and most of the oceans’ plankton became extinct. In fact, 60 to 70 percent of all plant and animal species disappeared.

So, what on Earth happened?
It’s impossible to say for sure what caused this mass extinction, but we know that two dramatic events occurred around the time of the extinction. There is strong evidence that a huge asteroid crashed into Earth just off the coast of Mexico’s Yucatan peninsula (top, right) 65 million years ago, creating an egg-shaped crater 150 kilometers in diameter (below, right).

Scientists estimate that to make a crater that big, the asteroid must have been at least 10 kilometers wide and hurtling toward Earth at the astonishing speed of 30 kilometers per second (that’s three times as fast as a jet airliner!). The impact of such a huge crash would cause tsunamis and earthquakes and send a huge cloud of dust into the atmosphere, blocking most of the sun’s rays for months.

In Western India we find evidence that enormous volcanic eruptions also occurred around 65 million years ago. At the plate boundary between India and Africa, there are huge lava beds called the Deccan traps that still cover 500,000 square kilometers. That’s about the size of the states of Washington and Oregon combined! Geologists estimate that the total volume of lava from the eruptions was more than 500,000 cubic kilometers. A volcanic eruption of this size would have spewed enormous amounts of ash, carbon dioxide, and water vapor into the atmosphere. This event may have caused temporary cooling but then significant global warming and major changes in the ocean’s acidity.

We don’t actually know exactly how much dust and ash spewed into the air from either of these events, and we can’t say exactly how much global temperatures changed or how acidic the ocean became for how long. We can’t prove that either event triggered the extinction of a specific plant or animal species. But it is hard to imagine that events of this size wouldn’t make an impact on Earth’s plants and animals.

Evidence from the fossil record
Looking at the fossil record provides more clues about what may have happened around 65 million years ago. The fossil record shows that around the globe, photosynthetic organisms suffered huge losses. Especially hard-hit were the oceans, where many types of plankton died out, and North America, which experienced the loss of...
the vast majority of plant species. These losses suggest that something in the atmosphere did, indeed, block out the sun’s rays for a period of time.

Animals whose food chains depended on photosynthetic plants were very hard-hit. These include both the plant-eating dinosaurs and the carnivorous dinosaurs that ate plant-eaters. In the oceans, plankton-feeders died out as did some of the large marine predators like mososaurs (giant lizards) and plesiosaurs (giant reptiles). Animals that built calcium-carbonate shells (like primitive sea urchins, clams, and coccolithophores) suffered heavy losses, suggesting a change in the ocean’s acidity. Coral reefs, which are especially sensitive to temperature changes, were devastated.

The fossil record also provides information about what did survive. Animals whose food chains were based on detritus (dead or decaying plants and animals) fared much better. Insects, lizards, turtles, and snakes that could burrow underground had a much higher survival rate. Amazingly, birds did not suffer tremendous losses. Ocean-floor dwellers were much less affected than those living closer to the surface. This is probably because bottom-dwellers tend to feed on decaying matter, and tend to be less affected by changes in water temperature.

New Opportunities

In a stable ecosystem, food webs are predictable. It is difficult for a new species to take another’s place in a food web. Evolution and change happen, but at a slow, gradual rate. Mass extinctions disrupt ecosystems, and entire food webs collapse. While this is devastating for many species, it provides a tremendous opportunity for the few that survive.

No land animal larger than a cat survived the mass extinction 65 million years ago. However, small mammals fared amazingly well. Afterward, these primitive mammals demonstrated what evolutionary biologists call *adaptive radiation*. A few species evolved into many newer species to fill the roles that the dinosaurs and other extinct species left behind.

Earth’s biodiversity (the number of different plants and animals species) eventually returned to pre-extinction levels. What was a catastrophe for the dinosaurs became an opportunity for mammals. New forms of life emerged from the ruins. The fossil record suggests that there may have been five mass extinctions in Earth’s history. Each time, biodiversity eventually returned, but with new dominant plant and animal species. As a result, scientists hypothesize that mass extinctions play an important role in evolution.

Questions:

1. Research: There are many theories about what caused the mass extinction at the end of the Cretaceous period. Use the Internet or a library to find out about another possible cause. Write a paragraph describing the theory.
2. Why do you think burrowing animals may have had a survival advantage over other land animals?
3. Explain the term adaptive radiation in your own words.
Radioactivity and Half-life

Scientists use absolute dating to estimate the age of a fossil in years. Absolute dating uses the decay of radioactive elements as a natural “clock.” Uranium-238 decays naturally to lead-206 which is not radioactive. The time for half of the atoms in a sample of uranium-238 to perform this entire nuclear decay process takes about 4.5 billion years! In other words, the half-life of uranium-238 is 4.5 billion years. In this activity, you will simulate the radioactive decay of a fictional element.

What you will do

Your teacher has given you a can of pennies to represent the atoms of a sample of a fictional, radioactive element. To simulate the process of radioactive decay follow the steps below.

1. Make a data table in your notebook like the one shown at the left.
2. Shake your can of pennies and spill them out onto a tray or table.
3. Remove all pennies that are “heads” up and count them.
4. Record these as decayed atoms in your data table.
5. Put the rest of the pennies back into the can, shake them again.
6. Spill them out onto the tray or table, and again, remove and count the “heads.”
7. Repeat this process until you have no more pennies left.
8. If necessary, add extra rows to your table.

Questions

a. Graph your data for number of decayed atoms per sample vs. sample number. Sample number will be on the x-axis, and number of decayed atoms will be on the y-axis. Label the axes clearly. Be sure to provide a title for the graph. Be sure to use the entire graph in plotting your data.

b. Write a paragraph that describes what your graph looks like.

c. What part of this simulation represents the half-life of this new element? Explain your answer.

d. If the half-life of your element was 430 years and you had 2000 atoms of this element, how long would it take for the element to undergo complete radioactive decay? What year would it be when the element finished decaying? Note: As you work through this problem, round the number of atoms left to a whole number. For example, round 62.5 to 63.
Chapter 14 Assessment

Vocabulary
Select the correct term to complete the sentences.

<table>
<thead>
<tr>
<th>rock cycle</th>
<th>lithospheric plates</th>
<th>absolute dating</th>
</tr>
</thead>
<tbody>
<tr>
<td>geologic time scale</td>
<td>paleontologists</td>
<td>pangaea</td>
</tr>
<tr>
<td>half-life</td>
<td>superposition</td>
<td>relative dating</td>
</tr>
<tr>
<td>geology</td>
<td>plate tectonics</td>
<td>uniformitarianism</td>
</tr>
</tbody>
</table>

Section 14.1
1. Understanding volcanoes, dinosaurs, earthquakes, rock cycles, and other Earth systems and the processes that act upon it is the study of _____.
2. Sedimentary, igneous, and metamorphic rocks are created, altered, and worn down in a process called the _____.
3. Estimating the age of fossils and rock layers from the arrangement of sedimentary layers is the principle of _____.
4. Before radioactive decay was understood, geologists were limited to _____ techniques to sequence geologic and prehistoric events.
5. Uncovering fossils in rock layers and conducting laboratory techniques that date specimens help _____ uncover the history of life on Earth.

Section 14.2
6. Using the present as a key to the past is consistent with the idea of _____.
7. Approximately 254 million years ago all major continents were fused into a massive landmass called _____.
8. _____ explains the changes and movement of lithospheric plates.
9. As _____ move slowly across Earth’s surface they sometimes collide and create huge mountain ranges.

Section 14.3
10. Earth’s history is divided into eras and periods known as the _____.
11. Believed to have occurred at least five times in Earth’s history, ____ seem to be a natural evolutionary process.
12. By comparing the amount of radioactive decay in a sample, _____ makes it possible to estimate the age of rock samples in years.
13. The _____ of radioactive isotope potassium-40 is 1.3 billion years therefore it takes 1.3 billion years for half of its atoms to break down into argon-40.

Concepts
Section 14.1
1. The idea that sediments deposit and cover dead organisms in lakebeds, which eventually leads to fossilization, was introduced by
   a. Nicholas Steno
   b. Charles Darwin
   c. Alfred Wallace
   d. Alfred Wegener
2. Distinguish between the two terms: superposition and sedimentation
3. All of the following are used in relative dating except
   a. Superposition
   b. The fossil record
   c. Crosscutting and inclusions
   d. Radioactive carbon-14 dating
4. Canyons and gorges are carved out of existing landmasses. The surrounding rock walls tell stories of the area’s past history. What type of information can be revealed in canyon walls?

5. Describe in your own words the processes involved in the rock cycle.

6. Although sediments are deposited in even continuous layers, some sedimentary rocks exist in curved and interrupted forms. Explain two major reasons why this happens.

Section 14.2

7. The coelacanth is “living fossil” first caught off the coast of South Africa in 1939. Prior to this, it was believed to have lived 360 years ago and then suddenly became extinct approximately 70 million years ago. How can paleontologists use the coelacanth to understand life on Earth at the time of the dinosaurs?

8. How might the collision of two lithospheric plates contribute to the evolution of a species?

9. The movement of lithospheric plates helps explain all of the following except
   a. the distribution of fossils and living animals around the world.
   b. the occurrence of earthquakes and volcanic activity.
   c. the amount of solar radiation emitted from the sun.
   d. evidence of fossilized sea creatures found on high mountain ranges.

10. Australia is a unique continent with thriving marsupial populations like kangaroos. North America however has a thriving placental mammal population but only one known marsupial, the opossum. How might this be explained given what you know about plate tectonics?

11. The continents were once joined in a massive supercontinent called Pangaea and have slowly drifted over time. Which of the following statements does not support this idea?
   a. Fossils of the same species have been found on several different continents.
   b. Evidence from an asteroid impact broke apart the continent.
   c. Matching geological features such as mountain ranges and coal beds are distributed systematically across oceans.
   d. The shapes of today’s continents fit together like a puzzle.

Section 14.3

12. Which of the following matches the geologic era with the correct historical event.
   b. Cenozoic- evidence of the first human ancestors emerges.
   d. Precambrian- mammals became the dominant life form on land.

13. Why are the units of geologic eras not divided into equal time spans? What is the basis of division and how long did each era last? Provide an example.

14. After a mass extinction, species who survive
   a. Usually do not adapt to the new environmental conditions.
   b. Are usually only mammals.
   c. Frequently cannot survive and also become extinct.
   d. Often branch out into highly adapted species suited for the new environment.
15. Many theories exist about what caused the major mass extinctions throughout Earth’s history. How might major changes in global temperature, sea level and atmospheric composition explain mass extinctions and the emergence of new life forms following such events?

16. Absolute dating
   a. Predicts the approximate age based upon position in sedimentary layers of rock.
   b. Can only be used to date animals and not other life such as plants and bacteria.
   c. Estimates the age of a fossil by measuring the decay of radioactive elements within the fossil.

**Math and Writing Skills**

1. Absolute dating using radioactive isotope potassium-40 is used to date rocks millions of years old. The half life of potassium-40 is 1.3 billion years. If sample of rock containing about 16g of radioactive potassium-40 when it was formed now contains 4g of potassium-40, how old is the rock?

2. What percentage of carbon-14 will remain after 3 half lives?

3. If the amount of radioactive carbon-14 left in a fossil indicates that the sample has decayed 85 half-lives, in what geologic time period did the organism live?

**Chapter Project—Scaled Timeline**

A timeline is a visualization of a sequence of events. A scaled timeline is helpful when learning about historical events, because it gives you an idea of how much time it took for different events to occur. For example, how much time went by between the age of dinosaurs and when humans first appear in the fossil record? Reading the numbers of millions of years is one way to answer the question, but it is easier to visualize this amount of time if you can see it pictured on a relative time scale. For this project, you will construct your own scaled timeline of important events in the history of our changing Earth. You will need a roll of adding machine tape, colored pencils or markers, and a measuring tape. To make the timeline, follow these steps:

1. Measure out 20 feet of adding machine tape. Every inch equals 19 million years; every foot equals 230 million years.
2. Using the scale described in step 1, place each event in the correct spot on the timeline. Use words and a sketch to represent each event on the timeline.
3. Use a lightly colored pencil to shade in the correct areas of the timeline that correspond to the Precambrian, Paleozoic, Mesozoic, and Cenozoic eras.
4. Stretch out the entire timeline and reflect on what this shows you about Earth's history.

<table>
<thead>
<tr>
<th>Event</th>
<th>MYA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human recorded history (5,000 yrs)</td>
<td>0.005</td>
</tr>
<tr>
<td>Earliest humans (Cro-Magnon)</td>
<td>0.1</td>
</tr>
<tr>
<td>Hominids (ancestors of humans)</td>
<td>3</td>
</tr>
<tr>
<td>Extinction of the Dinosaurs</td>
<td>66</td>
</tr>
<tr>
<td>First flowering plants</td>
<td>144</td>
</tr>
<tr>
<td>First mammals</td>
<td>200</td>
</tr>
<tr>
<td>First dinosaurs</td>
<td>230</td>
</tr>
<tr>
<td>Mass extinctions occurred</td>
<td>245</td>
</tr>
<tr>
<td>Forests that formed fossil fuels (coal and oil)</td>
<td>300</td>
</tr>
<tr>
<td>First vertebrates (fish)</td>
<td>400</td>
</tr>
<tr>
<td>Seedless land plants become common</td>
<td>400</td>
</tr>
<tr>
<td>First animals</td>
<td>600</td>
</tr>
<tr>
<td>First multicellular organisms</td>
<td>650</td>
</tr>
<tr>
<td>First eukaryotes</td>
<td>1500</td>
</tr>
<tr>
<td>Oldest fossils</td>
<td>3600</td>
</tr>
<tr>
<td>Formation of Earth</td>
<td>4600</td>
</tr>
</tbody>
</table>