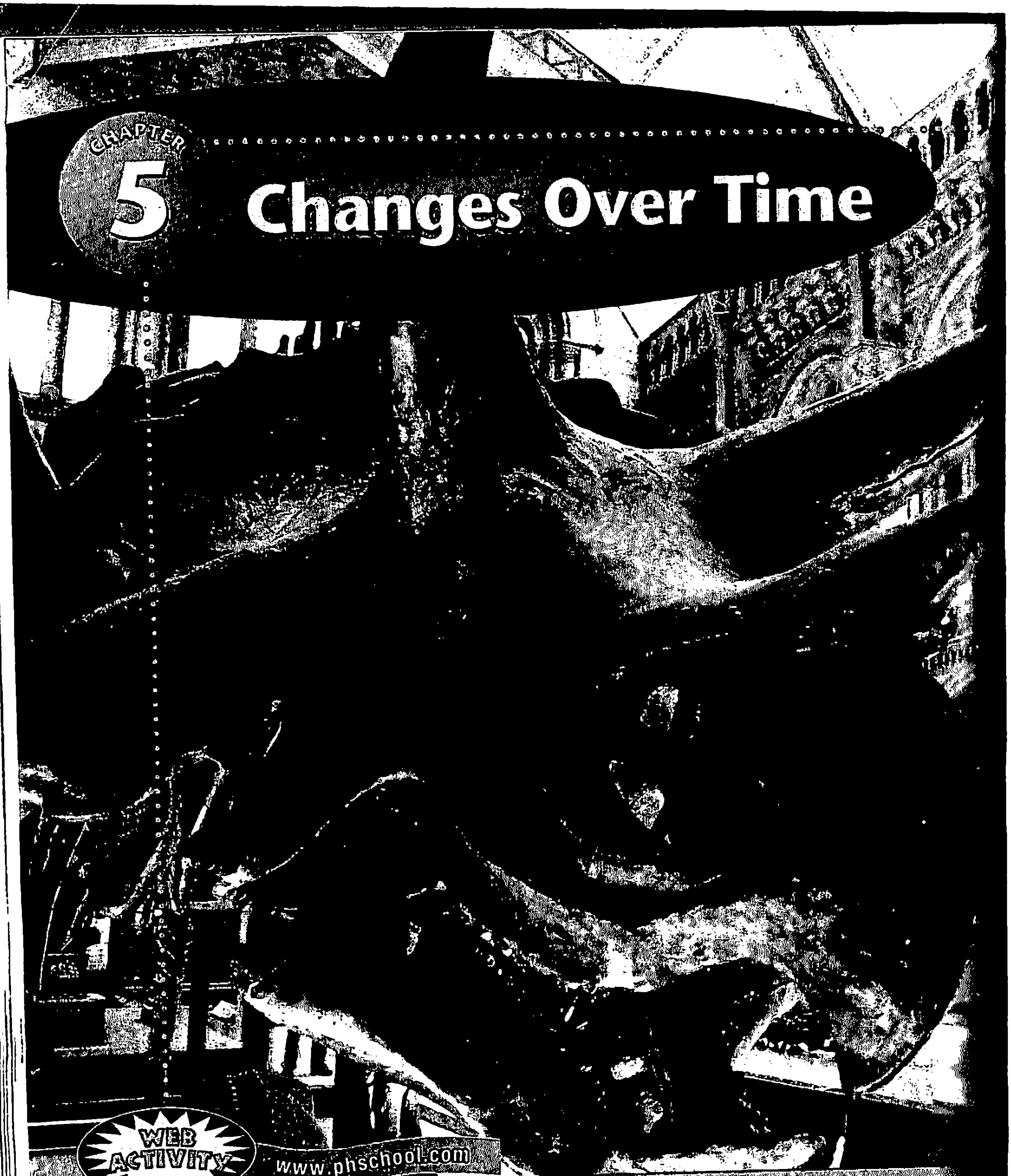
Chapter 5 Changes Over Time



WEB ACTIVITY www.phschool.com

Section 1 Darwin's Voyage

Discover How Do Living Things Vary?
Try This Bird Beak Adaptations
Sharpen Your Skills Inferring
Skills Lab Nature at Work

Section 2 The Fossil Record

Integrating Earth Science

Discover What Can Fossils Tell You?
Try This Preservation in Ice
Sharpen Y[illegible] Skills Calculating
Scienc[illegible]

Section 3 Other Evidence for Evolution

Discover How Can You Classify Spe[illegible]
Sharpen Your Skills Drawing Conclu[illegible]
Skills Lab Telltale Molecules

Mr. PIERRO

CHAPTER 5 PROJECT

Life's Long Calendar

How far back in your life can you remember? How far can the adults you know remember? Think of how life has changed in the last ten, fifty, or one hundred years. This chapter looks back in time as well. But instead of looking back hundreds of years, you'll explore millions, hundreds of millions, and even billions of years.

The time frame of Earth's history is so large that it can be overwhelming. This chapter project will help you understand it. In this project, you'll find a way to convert enormous time periods into a more familiar scale.

Your Goal To use a familiar measurement scale to create two time lines for Earth's history.

To complete the project you will

- represent Earth's history using a familiar scale, such as hours on a clock, months on a calendar, or yards on a football field
- use your chosen scale twice, once to plot out 5 billion years of history, and then to focus on the past 600 million years
- include markers on both scales to show important events in the history of life

Get Started Preview *Exploring Life's History* on pages 162–163 to see what events occurred during the two time periods. In a small group, discuss some familiar scales you might use for your time lines. You could select a time interval such as a year or a day. Alternatively, you could choose a distance interval such as the length of your schoolyard or the walls in your classroom. Decide on the kind of time lines you will make.

Check Your Progress You will be working on this project as you study this chapter. To keep your project on track, look for Check Your Progress boxes at the following points.

Section 1 Review, page 156: Plan your time lines.

Section 3 Review, page 169: Construct your time lines.

Present Your Project At the end of the chapter (page 173), you'll display your time lines for the class.

This *Triceratops* lived in western North America about 70 million years ago. It used its sharp horns to defend itself against predators.

SECTION 1 Darwin's Voyage

DISCOVER ACTIVITY

How Do Living Things Vary?

1. Use a metric ruler to measure the length and width of 10 sunflower seeds. Record each measurement.
2. Now use a hand lens to carefully examine each seed. Record each seed's shape, color, and number of stripes.

Think It Over

In what ways are the seeds in your sample different from one another? In what ways are they similar? How could you group the seeds based on their similarities and differences?

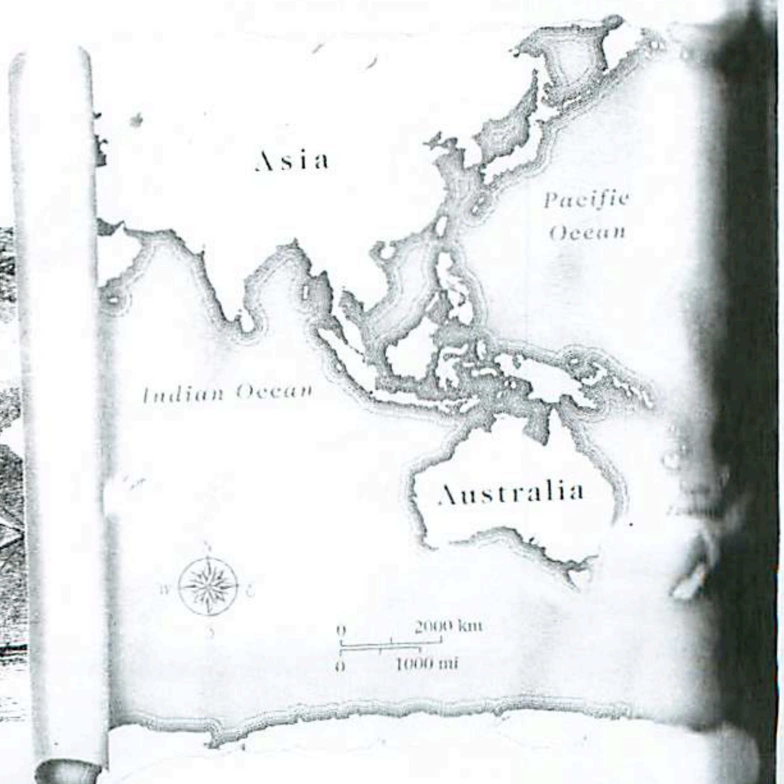
GUIDE FOR READING

- **How did Darwin explain the differences between species on the Galapagos Islands and on mainland South America?**
- **How does natural selection lead to evolution?**
- **How do new species form?**

As you read, make a list of main ideas and supporting details about evolution.

In December 1831, the British naval ship HMS *Beagle* set sail from England on a five-year-long trip around the world. On board was a 22-year-old named Charles Darwin. Darwin eventually became the ship's naturalist—a person who studies the natural world. His job was to learn as much as he could about the living things he saw on the voyage.

During the voyage, Darwin observed plants and animals he had never seen before. He wondered why they were so different from those in England. Darwin's observations led him to develop one of the most important scientific theories of all time: the theory of evolution by natural selection.



Darwin's Observations

One of the *Beagle's* first stops was the coast of South America. In Brazil, Darwin saw insects that looked like flowers, and ants that marched across the forest floor like huge armies. In Argentina, he saw armadillos—burrowing animals covered with small, bony plates. He also saw sloths, animals that moved very slowly and spent much of their time hanging upside down in trees.

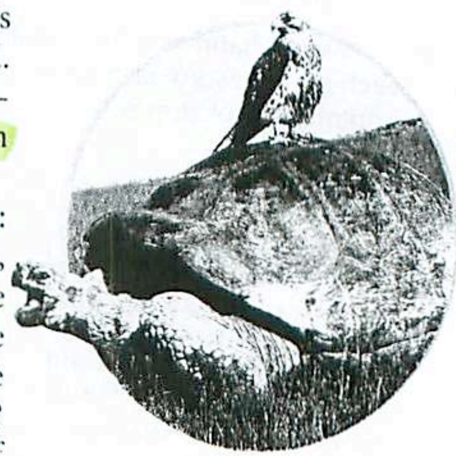
Darwin was amazed by the tremendous diversity, or variety, of living things he saw. Today scientists know that living things are even more diverse than Darwin could ever have imagined. Scientists have identified more than 1.7 million species of organisms on Earth. A **species** is a group of similar organisms that can mate with each other and produce fertile offspring.

Darwin saw something else in Argentina that puzzled him: the bones of animals that had died long ago. From the bones, Darwin inferred that the animals had looked like the sloths he had seen. However, the bones were much larger than those of the living sloths. He wondered why only smaller sloths were alive today. What had happened to the giant creatures from the past?

In 1835, the *Beagle* reached the Galapagos Islands, a group of small islands in the Pacific Ocean off the west coast of South America. It was on the Galapagos Islands that Darwin observed some of the greatest diversity of life forms. He saw large numbers of giant tortoises, or land turtles, which he described as 'immense' in size. There were fur-covered seals, and lizards that ate cactus plants for food and water.

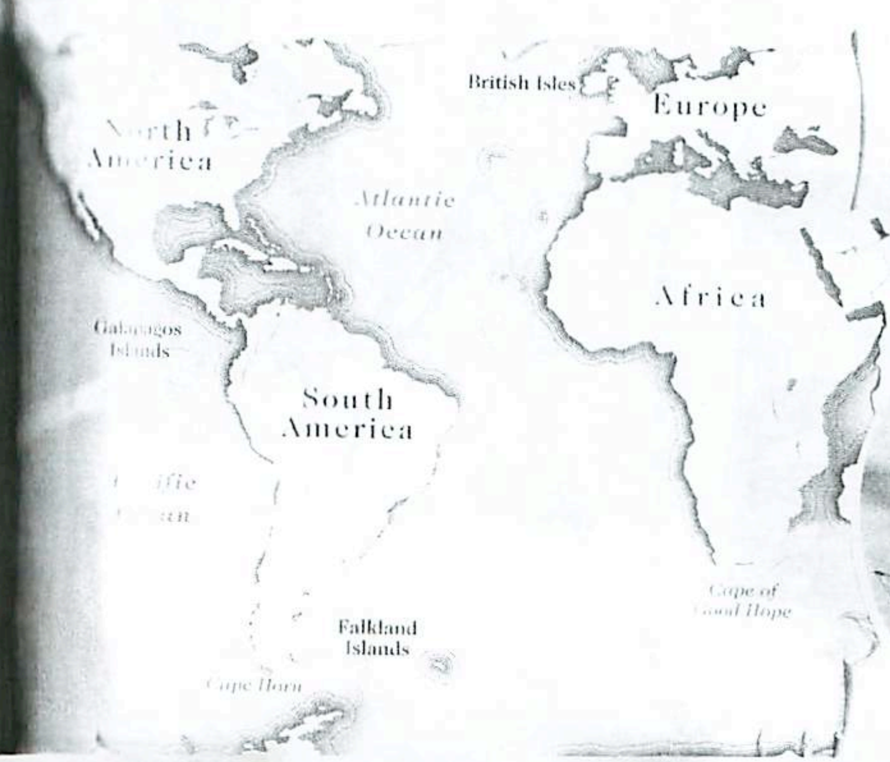
Figure 1 Charles Darwin sailed on HMS *Beagle* from England to South America and then to the Galapagos Islands. He saw many unusual organisms on the Galapagos Islands.

Galapagos hawk ▼



▲ *Giant tortoise*

▲ *Sally light-foot crab*



◀ *Blue-footed booby*

Similarities and Differences

Darwin was surprised that many of the plants and animals on the Galapagos Islands were similar to organisms on mainland South America. For example, many of the birds on the islands, including hawks, mockingbirds, and finches, resembled those on the mainland. Many of the plants were also similar to plants Darwin had collected on the mainland.

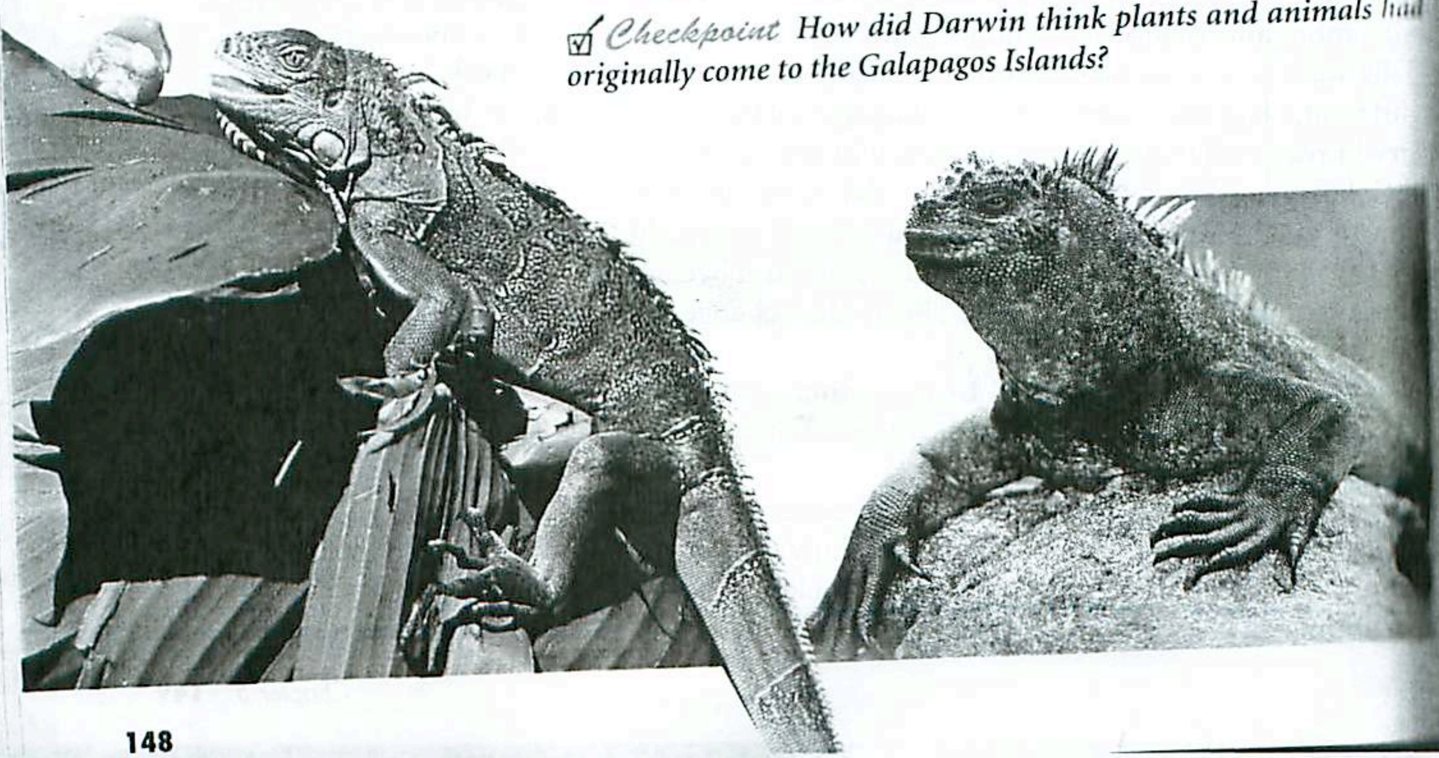
However, there were also important differences between the organisms on the islands and those on the mainland. Large sea birds called cormorants, for example, lived in both places. The cormorants on the mainland were able to fly, while those on the Galapagos Islands were unable to fly. The iguanas on the Galapagos Islands had large claws that allowed them to keep their grip on slippery rocks, where they fed on seaweed. The iguanas on the mainland had smaller claws. Smaller claws allowed the mainland iguanas to climb trees, where they ate leaves.

From his observations, Darwin inferred that a small number of different plant and animal species had come to the Galapagos Islands from the mainland. They might have been blown out to sea during a storm or set adrift on a fallen log. Once the plants and animals reached the islands, they reproduced. Eventually, their offspring became different from their mainland relatives.

Darwin also noticed many differences among similar organisms as he traveled from one Galapagos island to the next. For example, the tortoises on one island had dome-shaped shells. Those on another island had saddle-shaped shells. The governor of one of the islands told Darwin that he could tell which island a tortoise came from just by looking at its shell.

☑ *Checkpoint* ***How did Darwin think plants and animals had originally come to the Galapagos Islands?***

Figure 2 Darwin observed many differences between organisms in South America and similar organisms on the Galapagos Islands. For example, green iguanas (left) live in South America. Marine iguanas (right) live on the Galapagos Islands. *Comparing and Contrasting How are the two species similar? How are they different?*



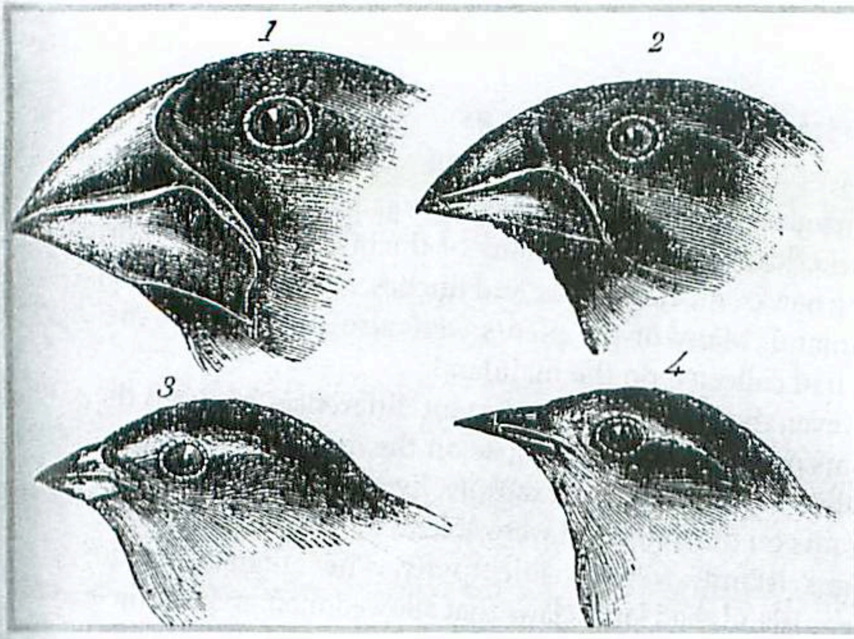


Figure 3 Darwin made these drawings of four species of Galapagos finches. The beak of each finch is adapted to the type of food it eats.

Adaptations

Like the tortoises, the finches on the Galapagos Islands were noticeably different from one island to another. The most obvious differences were the varied sizes and shapes of the birds' beaks. As Darwin studied the different finches, he noticed that each species was well suited to the life it led. Finches that ate insects had sharp, needlelike beaks. Finches that ate seeds had strong, wide beaks. Beak shape is an example of an **adaptation,** a trait that helps an organism survive and reproduce.

Evolution

After he returned home to England, Darwin continued to think about what he had seen during his voyage on the *Beagle.* Darwin spent the next 20 years consulting with many other scientists, gathering more information, and thinking through his ideas. He especially wanted to understand how the variety of organisms with different adaptations arose on the Galapagos Islands.

Darwin reasoned that plants or animals that arrived on one of the Galapagos Islands faced conditions that were different from those on the mainland. **Perhaps, Darwin thought, the species gradually changed over many generations and became better adapted to the new conditions.** The gradual change in a species over time is called **evolution.**

Darwin's ideas are often referred to as the theory of evolution. A **scientific theory** is a well-tested concept that explains a wide range of observations.

It was clear to Darwin that evolution had occurred on the Galapagos Islands. *He did not* know, however, how this process had occurred. Darwin had to draw on other examples of changes in living things to help him understand how evolution occurs.

TRY THIS

Bird Beak Adaptations

Use this activity to explore adaptations in birds.

1. Scatter a small amount of bird seed on a paper plate. Scatter 20 raisins on the plate to represent insects.
2. Obtain a variety of objects such as tweezers, hair clips, clothes pins, and hairpins. Pick one object to use as a "beak."
3. See how many seeds you can pick up and drop into a cup in 10 seconds.
4. Now see how many "insects" you can pick up and drop into a cup in 10 seconds.
5. Use a different "beak" and repeat Steps 3 and 4.

Inferring What type of beak worked well for seeds? For insects? How are different-shaped beaks useful for eating different foods?

Darwin knew that people used selective breeding to produce organisms with desired traits. For example, English farmers used selective breeding to produce sheep with fine wool. Darwin himself had bred pigeons with large, fan-shaped tails. By repeatedly allowing only those pigeons with many tail feathers to mate, Darwin produced pigeons with two or three times the usual number of tail feathers. Darwin thought that a process similar to selective breeding must happen in nature. But he wondered why certain traits were selected for, and how.

☑ *Checkpoint* ***What observations led Darwin to propose his theory of evolution?***

Natural Selection

In 1858, Darwin and another British biologist, Alfred Russel Wallace, proposed an explanation for how evolution occurs. The next year, Darwin described this mechanism in a book entitled *The Origin of Species.* In his book, Darwin explained that evolution occurs by means of natural selection. **Natural selection** is the process by which individuals that are better adapted to their environment are more likely to survive and reproduce than other members of the same species. Darwin identified a number of factors that affect the process of natural selection: overproduction, competition, and variations.

Overproduction Most species produce far more offspring than can possibly survive. In many species, so many offspring are produced that there are not enough resources—food, water, and living space—for all of them. For example, each year a female sea turtle may lay more than 100 eggs. If all the young turtles survived, the sea would soon be full of turtles. Darwin knew that this doesn't happen. Why not?

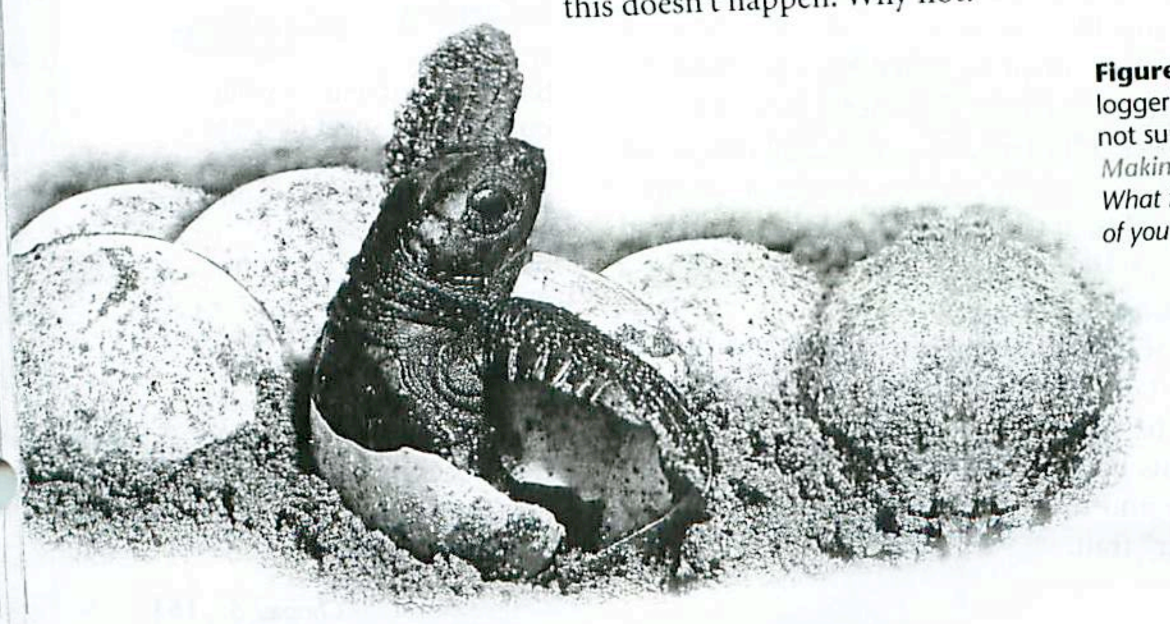


Figure 4 Most newborn loggerhead sea turtles will not survive to adulthood. *Making Generalizations What factors limit the number of young that survive?*

Figure 5 The walruses lying on this rocky beach in Alaska must compete for resources. All organisms compete for limited resources such as food.

Competition Since food and other resources are limited, the offspring must compete with each other to survive. Competition does not usually involve direct physical fights between members of a species. Instead, competition is usually indirect. For example, some turtles may fail to find enough to eat. Others may not be able to escape from predators. Only a few turtles will survive long enough to reproduce.

Variations As you learned in your study of genetics, members of a species differ from one another in many of their traits. Any difference between individuals of the same species is called a **variation.** For example, some newly hatched turtles are able to swim faster than other turtles.

Selection Some variations make certain individuals better adapted to their environment. Those individuals are more likely to survive and reproduce. When those individuals reproduce, their offspring may inherit the allele for the helpful trait. The offspring, in turn, will be more likely to survive and reproduce, and thus pass on the allele to their offspring. After many generations, more members of the species will have the helpful trait. In effect, the environment has "selected" organisms with helpful traits to be the parents of the next generation—hence the term "natural selection." **Over a long period of time, natural selection can lead to evolution. Helpful variations gradually accumulate in a species, while unfavorable ones disappear.**

For example, suppose a new fast-swimming predator moves into the turtles' habitat. Turtles that are able to swim faster would be more likely to escape from the new predator. The faster turtles would thus be more likely to survive and reproduce. Over time, more and more turtles in the species would have the "fast-swimmer" trait.

Sharpen your Skills

Inferring ACTIVITY

Scatter 15 black buttons and 15 white buttons on a sheet of white paper. Have a partner time you to see how many buttons you can pick up in 10 seconds. Pick up the buttons one at a time.

Did you collect more buttons of one color than the other? Why? How can a variation such as color affect the process of natural selection?

Making Models

Nature at Work

In this lab, you will investigate how natural selection can lead to changes in a species over time. You'll explore how both genetic and environmental factors play a part in natural selection.

Problem

How do species change over time?

Materials

scissors
marking pen
construction paper, 2 colors

Procedure

1. Work on this lab with two other students. One student should choose construction paper of one color and make the team's 50 "mouse" cards, as described in Table 1. The second student should choose a different color construction paper and make the team's 25 "event" cards, as described in Table 2. The third student should copy the data table and record all the data.

Part 1 A White Sand Environment

2. Mix up the mouse cards.
3. Begin by using the cards to model what might happen to a group of mice in an environment of white sand dunes. Choose two mouse cards. Allele pairs *WW* and *Ww* produce a white mouse. Allele pair *ww* produces a brown mouse. Record the color of the mouse with a tally mark in the data table.
4. Choose an event card. An "S" card means the mouse survives. A "D" or a "P" card means the mouse dies. A "C" card means the mouse dies if its color contrasts with the white sand dunes. (Only brown mice will die when a "C" card is drawn.) Record each death with a tally mark in the data table.
5. If the mouse lives, put the two mouse cards in a "live mice" pile. If the mouse dies, put the cards in a "dead mice" pile. Put the event card at the bottom of its pack.
6. Repeat Steps 3 through 5 with the remaining mouse cards to study the first generation of mice. Record your results.
7. Leave the dead mice cards untouched. Mix up the cards from the live mice pile. Mix up the events cards.
8. Repeat Steps 3 through 7 for the second generation. Then repeat Steps 3 through 6 for the third generation.

Table 1: "Mouse" Cards

Number	Label	Meaning
25	*W*	Dominant allele for white fur
25	*w*	Recessive allele for brown fur

Table 2: "Event" Cards

Number	Label	Meaning
5	S	Mouse survives.
1	D	Disease kills mouse.
1	P	Predator kills mice of all colors.
18	C	Predator kills mice that contrast with the environment.

DATA TABLE

Type of Environment:

Generation	*White Mice*	*Brown Mice*	*Deaths*	
			White Mice	*Brown Mice*
1				
2				
3				

Part 2 A Forest Floor Environment

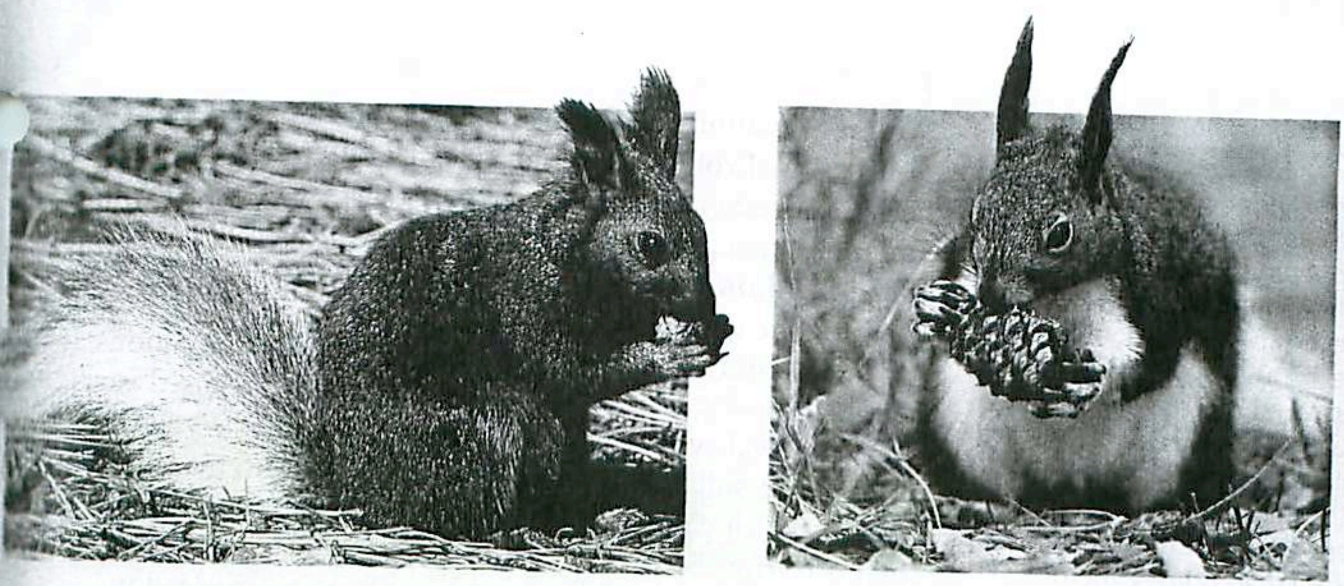
9. How would the data differ if the mice in this model lived on a dark brown forest floor? Record your prediction in your notebook.
10. Make a new copy of the data table. Then use the cards to test your prediction. Remember that a "C" card now means that any mouse with white fur will die.

Analyze and Conclude

1. In Part 1, how many white mice were there in each generation? How many brown mice? In each generation, which color mouse had the higher death rate? (*Hint:* To calculate the death rate for white mice, divide the number of white mice that died by the total number of white mice, then multiply by 100%.)
2. If the events in Part 1 occurred in nature, how would the group of mice change over time?
3. How did the results in Part 2 differ from those in Part 1?
4. What are some ways in which this investigation models natural selection? What are some ways in which natural selection differs from this model?
5. **Think About It** How would it affect your model if you increased the number of "C" cards? If you decreased the number?

Design an Experiment

Choose a different species with a trait that interests you. Make a set of cards similar to these cards to investigate how natural selection might bring about the evolution of that species.



How Do New Species Form?

Darwin's theory of evolution by natural selection explains how variations can lead to changes in a species. But how does an entirely new species evolve? Since Darwin's time, scientists have come to understand that geographic isolation is one of the main ways that new species form. Isolation, or complete separation, occurs when some members of a species become cut off from the rest of the species.

Sometimes a group is separated from the rest of its species by a river, volcano, or mountain range. Even an ocean wave can separate a few individuals from the rest of their species by sweeping them out to sea and later washing them ashore on an island. This may have happened on the Galapagos Islands. Once a group becomes isolated, members of the isolated group can no longer mate with members of the rest of the species.

A new species might form when a group of individuals remains separated from the rest of its species long enough to evolve different traits. The longer the group remains isolated from the rest of the species, the more likely it is to evolve into a new species. For example, Abert's squirrel and the Kaibab squirrel live in forests in the Southwest. About 10,000 years ago both types of squirrels were members of the same species. About that time, however, a small group of squirrels became isolated in a forest on the north side of the Grand Canyon in Arizona. Over time, this group evolved into the Kaibab squirrel, which has a distinctive black belly. Scientists are not sure whether the Kaibab squirrel has become different enough from Abert's squirrel to be considered a separate species.

✓ *Checkpoint* ***How did geographic isolation affect the Kaibab squirrel?***

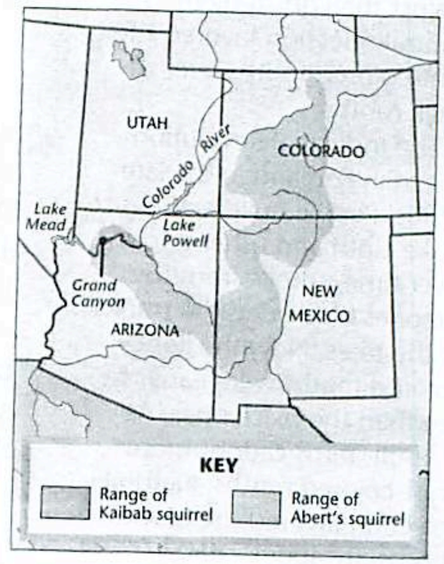


Figure 7 About 10,000 years ago, a group of squirrels became isolated from the rest of the species. As a result, the Kaibab squirrel (left) has become different from Abert's squirrel (right).
Interpreting Maps What geographic feature separates the range of the Kaibab squirrel from that of Abert's squirrel?

The Role of Genes in Evolution

Without variations, all the members of a species would have the same traits. Evolution by natural selection would not occur because all individuals would have an equal chance of surviving and reproducing. But where do variations come from? How are they passed on from parents to offspring? Darwin could not answer these questions.

Darwin did not know anything about genes or mutations. It is not surprising that he could not explain what caused variations or how they were passed on. As scientists later learned, variations can result from mutations in genes or from the shuffling of alleles during meiosis. Only genes are passed from parents to their offspring. Because of this, only traits that are inherited, or controlled by genes, can be acted upon by natural selection.

Evolution in Action

Since Darwin published his book, scientists have observed many examples of evolution in action. In a 1977 study of the finches on Daphne Major, one of the Galapagos Islands, scientists observed that beak size could change very quickly by natural selection. That year, little rain fell on the island—only 25 millimeters instead of the usual 130 millimeters or so. Because of the lack of rain, many plants died. Fewer of the seeds that the finches usually ate were available. Instead, the birds had to eat large seeds that were enclosed in tough, thorny seed pods.

Finches with larger and stronger beaks were better able to open the tough pods than were finches with smaller, weaker beaks. Many of the finches with smaller beaks did not survive the drought. The next year, more finches on the island had larger and stronger beaks. Evolution by natural selection had occurred in just one year.

Social Studies CONNECTION

The case of the English peppered moth is an example of how human actions can affect natural selection. In the late 1700s, most English peppered moths were light gray in color. The light-colored moths had an advantage over black peppered moths because birds could not see them against the light-gray trees. Natural selection favored the light-colored moths over the black moths.

The Industrial Revolution began in England in the late 1700s. People built factories to make cloth and other goods. Over time, smoke from the factories blackened the trunks of the trees. Now the light-colored moths were easier to see than the black ones. As a result, birds caught more light-colored moths. Natural selection favored the black moths. By about 1850, almost all the peppered moths were black.

In Your Journal

Since the 1950s, strict pollution laws have reduced the amount of smoke released into the air in England. Predict how this has affected the trees and the moths.

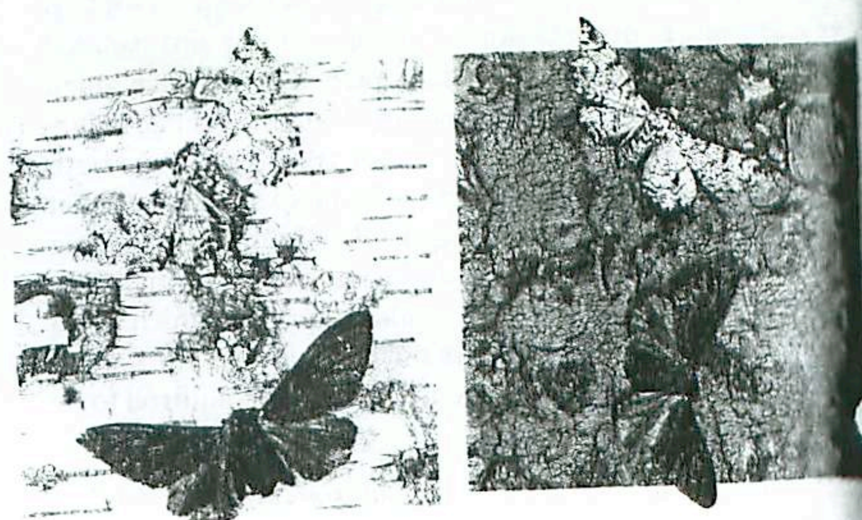


Figure 6 The Industrial Revolution affected natural selection in peppered moths in England. As pollution blackened the tree trunks, black moths became more likely to survive and reproduce.

Continental Drift

Geographic isolation has also occurred on a worldwide scale. For example, hundreds of millions of years ago all of Earth's landmasses were connected as one landmass. It formed a supercontinent called Pangaea. Organisms could migrate from one part of the supercontinent to another. Over millions of years, Pangaea gradually split apart in a process called continental drift. As the continents separated, species became isolated from one another and began to evolve independently.

Perhaps the most striking example of how continental drift affected the evolution of species is on the continent of Australia. The organisms living in Australia have been isolated from all other organisms on Earth for millions of years. Because of this, unique organisms have evolved in Australia. For example, most mammals in Australia belong to the group known as marsupials. Unlike other mammals, a marsupial gives birth to very small young that continue to develop in a pouch on the mother's body. Figure 8 shows two of the many marsupial species that exist in Australia. In contrast, few species of marsupials exist on other continents.

Figure 8 As a result of continental drift, many species of marsupials evolved in Australia. Australian marsupials include the numbat (top) and the spotted cuscus (bottom).

Section 1 Review

1. What is evolution? What did Darwin observe on the Galapagos Islands that he thought was the result of evolution?
2. Explain why variations are needed for natural selection to occur.
3. Describe how geographic isolation can result in the formation of a new species.
4. **Thinking Critically** Applying Concepts Some insects look just like sticks. How could this be an advantage to the insects? How could this trait have evolved through natural selection?

CHAPTER PROJECT

Check Your Progress

You should now be ready to submit your plans for your time lines to your teacher. Include a list of the major events you will include on your time lines. Remember, you want to emphasize the life forms that were present at each period. When your plans are approved, begin to construct your time lines. (*Hint:* You will need to divide your time lines into equal-sized intervals. For example, if you use a 12-month calendar to represent 5 billion years, calculate how many months will represent 1 billion years.)

INTEGRATING EARTH SCIENCE

SECTION 2 The Fossil Record

DISCOVER ACTIVITY

What Can Fossils Tell You?

1. Look at the fossil in the photograph. Describe the fossil's characteristics in as much detail as you can.
2. From your description in Step 1, try to figure out how the organism lived. How did it move? Where did it live?

Think It Over

Inferring What type of present-day organism do you think is related to the fossil? Why?

A crime has been committed. You and another detective arrive at the crime scene after the burglar has fled. To piece together what happened, you begin searching for clues. First you notice a broken first-floor window. Leading up to the window are footprints in the mud. From the prints, you can infer the size and type of shoes the burglar wore. As you gather these and other clues, you slowly piece together a picture of what happened and who the burglar might be.

To understand events that occurred long ago, scientists act like detectives. Some of the most important clues to Earth's past are fossils. A **fossil** is the preserved remains or traces of an organism that lived in the past. A fossil can be formed from a bone, tooth, shell, or other part of an organism. Other fossils can be traces of the organism, such as footprints or worm burrows left in mud that later turned to stone.

GUIDE FOR READING

- How do most fossils form?
- How can scientists determine a fossil's age?

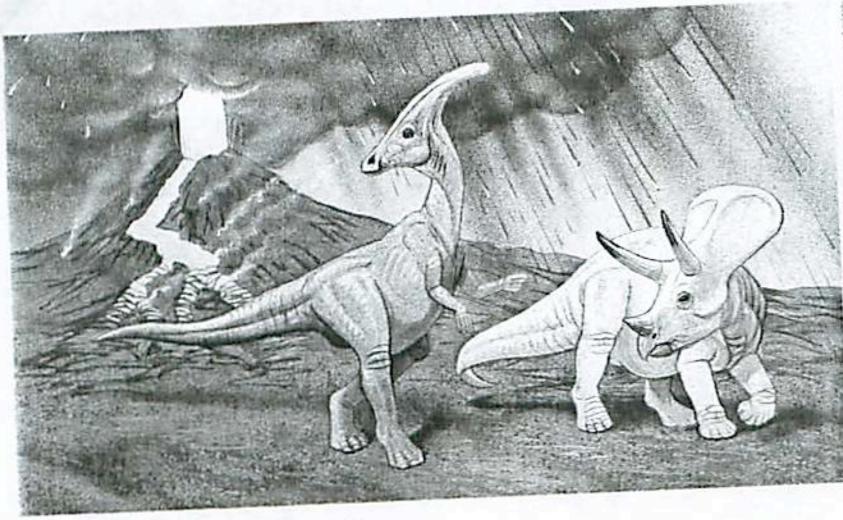
Reading Tip As you read, write four multiple-choice questions about the content in this section. Exchange questions with a partner and answer each other's questions.

A fossilized shark tooth ▼

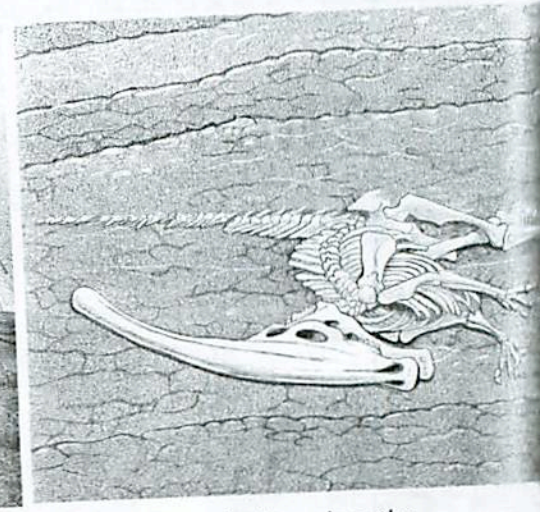
How Do Fossils Form?

Very few fossils are of complete organisms. Often when an animal dies, the soft parts of its body either decay or are eaten before a fossil can form. Usually only the hard parts of the animal, such as the bones or shells, remain. Plants also form fossils. The parts of plants that are most often preserved as fossils include leaves, stems, roots, and seeds.

The formation of any fossil is a rare event. The conditions must be just right for a fossil to form. **Most fossils form when organisms that die become buried in sediments.** Sediments are



1. Two dinosaurs are buried by ash from an erupting volcano.



2. Minerals gradually replace the remains. Over millions of years, the fossils become buried by sediments.

Figure 9 Fossils are the preserved remains or traces of organisms that lived in the past. Fossils can form when organisms that die become buried in sediments.
Interpreting Diagrams *What is one way in which a buried fossil can become uncovered?*

particles of soil and rock. When a river flows into a lake or ocean, the sediments carried by the river settle to the bottom. Layers of sediments build up and cover the dead organisms. Over millions of years, the layers harden to become **sedimentary rock.**

Petrified Fossils Some remains that become buried in sediments are actually changed to rock. Minerals dissolved in the water soak into the buried remains. Gradually, the minerals replace the remains, changing them into rock. Fossils that form in this way are called **petrified fossils.**

Molds and Casts Sometimes shells or other hard parts buried by sediments are gradually dissolved. An empty space remains in the place the part once occupied. A hollow space in sediment in the shape of an organism or part of an organism is called a **mold.**

Sometimes a mold becomes filled in with hardened minerals, forming a **cast.** A cast is a copy of the shape of the organism that made the mold. If you have ever made a gelatin dessert in a plastic mold, then you can understand how a cast forms.

Preserved Remains Organisms can also be preserved in substances other than sediments. Entire organisms, such as the huge elephant-like mammoths that lived thousands of years ago, have been preserved in ice. The low temperatures preserved the mammoths' soft parts.

The bones and teeth of other ancient animals have been preserved in tar pits. Tar is a dark, sticky form of oil. Tar pits formed when tar seeped up from under the ground to the surface. The tar pits were often covered with water. Animals that came to drink the water became stuck in the tar.

3. Running water cuts through the sedimentary rock layers, exposing the fossils.

Insects and some other organisms can become stuck in the sticky sap that some evergreen trees produce. The sap then hardens, forming amber. The amber protects the organism's body from decay.

Determining a Fossil's Age

To understand how living things have changed through time, scientists need to be able to determine the ages of fossils. They can then determine the sequence in which past events occurred. This information can be used to reconstruct the history of life on Earth. **Scientists can determine a fossil's age in two ways: relative dating and absolute dating.**

Relative Dating Scientists use **relative dating** to determine which of two fossils is older. To understand how relative dating works, imagine that a river has cut down through layers of sedimentary rock to form a canyon. If you look at the canyon walls, you can see the layers of sedimentary rock piled up one on top of another. The layers near the top of the canyon were formed most recently. These layers are the youngest rock layers. The lower down the canyon wall you go, the older the layers are. Therefore, fossils found in layers near the top of the canyon are younger than fossils found near the bottom of the canyon.

Relative dating can only be used when the rock layers have been preserved in their original sequence. Relative dating can help scientists determine whether one fossil is older than another. However, relative dating does not tell scientists the fossil's actual age.

Checkpoint *Which rock layers contain younger fossils?*

TRY THIS

Preservation in Ice

ACTIVITY

1. Place fresh fruit, such as apple slices, strawberries, and blueberries, in an open plastic container.
2. Completely cover the fruit with water. Put the container in a freezer.
3. Place the same type and amount of fresh fruit in another open container. Leave it somewhere where no one will disturb it.
4. After three days, observe the fruit in both containers.

Inferring Use your observations to explain why fossils preserved in ice are more likely to include soft, fleshy body parts.

Figure 10 The half-life of potassium-40, a radioactive element, is 1.3 billion years. This means that half of the potassium-40 in a sample will break down into argon-40 every 1.3 billion years. ***Interpreting Charts*** *If a sample contains one fourth of the original amount of potassium-40, how old is the sample?*

Decay of Potassium-40 (Half-life = 1.3 billion years)		
Time	**Amount of Potassium-40**	**Amount of Argon-40**
2.6 billion years ago	1 g	0 g
1.3 billion years ago	0.5 g	0.5 g
Present	0.25 g	0.75 g

Absolute Dating Another technique, called **absolute dating,** allows scientists to determine the actual age of fossils. The rocks that fossils are found near contain **radioactive elements,** unstable elements that decay, or break down, into different elements. The **half-life** of a radioactive element is the time it takes for half of the atoms in a sample to decay. Figure 10 shows how a sample of potassium-40, a radioactive element, breaks down into argon-40 over time.

Integrating Chemistry

Scientists can compare the amount of a radioactive element in a sample to the amount of the element into which it breaks down. As you can see in Figure 10, this information can be used to calculate the age of the rock, and thus the age of the fossil.

☑ *Checkpoint What is a half-life?*

What Do Fossils Reveal?

Like pieces in a jigsaw puzzle, fossils help scientists piece together information about Earth's past. The millions of fossils that scientists have collected are called the **fossil record.** The fossil record, however, is incomplete. Many organisms die without leaving fossils behind. Despite gaps in the fossil record, it has given scientists a lot of important information about past life on Earth.

Almost all of the species preserved as fossils are now extinct. A species is **extinct** if no members of that species are still alive. Most of what scientists know about extinct species is based on the fossil record. Scientists use fossils of bones and teeth to build models of extinct animals. Fossil footprints provide clues about how fast an animal could move and how tall it was.

Sharpen your Skills

Calculating

ACTIVITY

A radioactive element has a half-life of 713 million years. After 2,139 million years, how many half-lives will have gone by?

Calculate how much of a 16-gram sample of the element will remain after 2,139 million years.

The fossil record also provides clues about how and when new groups of organisms evolved. The first animals appeared in the seas about 540 million years ago. These animals included worms, sponges, and other invertebrates—animals without backbones. About 500 million years ago, fishes evolved. These early fishes were the first vertebrates—animals with backbones.

The first land plants, which were similar to mosses, evolved around 410 million years ago. Land plants gradually evolved strong stems that held them upright. These plants were similar to modern ferns and cone-bearing trees. Look at *Exploring Life's History* on pages 162 and 163 to see when other groups of organisms evolved.

The Geologic Time Scale

Using absolute dating, scientists have calculated the ages of many different fossils and rocks. From this information, scientists have created a "calendar" of Earth's history that spans more than 4.6 billion years. Scientists have divided this large time period into smaller units called eras and periods. This calendar of Earth's history is sometimes called the Geologic Time Scale.

The largest span of time in the Geologic Time Scale is Precambrian Time. This span of time is sometimes referred to simply as the Precambrian (pree KAM bree un). It covers the first 4 billion years of Earth's history. Scientists know very little about the Precambrian because there are few fossils from these ancient times. After the Precambrian, the Geologic Time Scale is divided into three major blocks of time, or eras. Each era is further divided into shorter periods. In *Exploring Life's History,* you can see the events that occurred during each time period.

Figure 11 Complete skeletons of animals that lived thousands of years ago have been found in the Rancho La Brea tar pits in Los Angeles, California. The photo shows a model of an elephant-like animal. Scientists created the model based on information learned from the fossils.

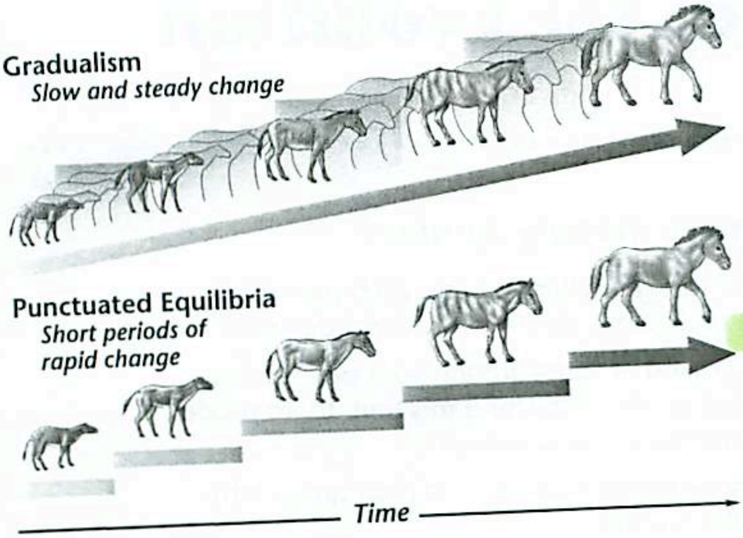


Figure 12 According to the theory of gradualism, new species of horses evolved slowly and continuously. Intermediate forms were common. According to punctuated equilibria, new species evolved rapidly during short periods of time. Intermediate forms were rare.

How Fast Does Evolution Occur?

Because the fossil record is incomplete, many questions about evolution remain unanswered. For example, scientists cannot always tell from the fossil record how quickly a particular species evolved.

One theory, called **gradualism,** proposes that evolution occurs slowly but steadily. According to this theory, tiny changes in a species gradually add up to major changes over very long periods of time. This is how Darwin thought evolution occurred.

If the theory of gradualism is correct, intermediate forms of all species should have existed. However, the fossil record often shows no intermediate forms for long periods of time. Then, quite suddenly, fossils appear that are distinctly different. One possible explanation for the lack of intermediate forms is that the fossil record is incomplete. Scientists may eventually find more fossils to fill the gaps.

Rather than assuming that the fossil record is incomplete, two scientists, Stephen Jay Gould and Niles Eldridge, have developed a theory that agrees with the fossil data. According to the theory of **punctuated equilibria,** species evolve during short periods of rapid change. These periods of rapid change are separated by long periods of little or no change. According to this theory, species evolve quickly when groups become isolated and adapt to new environments.

Today most scientists think that evolution can occur gradually at some times and fairly rapidly at others. Both forms of evolution seem to have occurred during Earth's long history.

Section 2 Review

1. Describe how fossils form in sedimentary rock.
2. Explain the process of absolute dating.
3. What is the fossil record? What does the fossil record reveal about extinct species?
4. **Thinking Critically** **Comparing and Contrasting** How are the theories of gradualism and punctuated equilibria similar? How are they different?

Science at Home

Make Your Mark With a family member, spread some mud in a shallow flat-bottomed pan. Smooth the surface of the mud. Use your fingertips to make *"footprints"* across the mud. Let the mud dry and harden, so that the footprints become permanent. Explain to your family how this is similar to the way some fossils form.

SECTION 3

Other Evidence for Evolution

DISCOVER ACTIVITY

How Can You Classify Species?

1. Collect six to eight different pens. Each pen will represent a different species of similar organisms.
2. Choose a trait that varies among your pen species, such as size or ink color. Using this trait, try to divide the pen species into two groups.
3. Now choose another trait. Divide each group into two smaller groups.

Think It Over

Classifying Which of the pen species share the most characteristics? What might the similarities suggest about how the pen species evolved?

GUIDE FOR READING

- **What evidence from modern-day organisms can help scientists determine evolutionary relationships among groups?**

Reading Tip **As you read, use the headings to make an outline about the different types of evidence for evolution.**

Do you know anyone who has had their appendix out? The appendix is a tiny organ attached to the large intestine. You might think that having a part of the body removed would cause a problem. After all, you need your heart, lungs, stomach and other body parts to live. However, this is not the case with the appendix. In humans, the appendix does not seem to have much function. In some other species of mammals, though, the appendix is much larger and plays an important role in digestion. To scientists, this information about modern-day organisms provides clues about their ancestors and their relationships.

The appendix is just one example of how modern-day organisms can provide clues about evolution. By comparing organisms, scientists can infer how closely related the organisms are in an evolutionary sense. **Scientists compare body structures, development before birth, and DNA sequences to determine the evolutionary relationships among organisms.**

Similarities in Body Structure

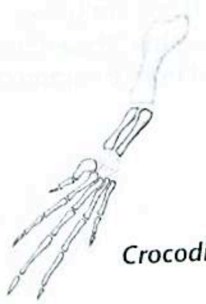
Scientists long ago began to compare the body structures of living species to look for clues about evolution. In fact, this is how Darwin came to understand that evolution had occurred on the Galápagos Islands. An organism's body structure is its basic body plan, such as how its bones are arranged. Fishes, amphibians, reptiles, birds, and mammals, for example, all have a similar body

Sharpen your Skills

Drawing Conclusions

ACTIVITY

Look at the drawing below of the bones in a crocodile's leg. Compare this drawing to Figure 13. Do you think that crocodiles share a common ancestor with birds, dolphins, and dogs? Support your answer with evidence.



structure—an internal skeleton with a backbone. This is why scientists classify all five groups of animals together as vertebrates. Presumably, these groups all inherited these similarities in structure from an early vertebrate ancestor that they shared.

Look closely at the structure of the bones in the bird's wing, dolphin's flipper, and dog's leg shown in Figure 13. Notice that the bones in the forelimbs of these three animals are arranged in a similar way. These similarities provide evidence that these three organisms all evolved from a common ancestor. Similar structures that related species have inherited from a common ancestor are called **homologous structures** (hoh MAHL uh gus).

Sometimes scientists find fossil evidence that supports the evidence provided by homologous structures. For example, scientists have recently found fossils of ancient whale-like creatures. The fossils show that the ancestors of today's whales had legs and walked on land. This evidence supports other evidence that whales and humans share a common ancestor.

☑ *Checkpoint* ***What information do homologous structures reveal?***

Similarities in Early Development

Scientists can also make inferences about evolutionary relationships by comparing the early development of different organisms. Suppose you were asked to compare an adult turtle, a chicken, and a rat. You would probably say they look quite different from each other. However, during early development, these three organisms go through similar stages, as you can see

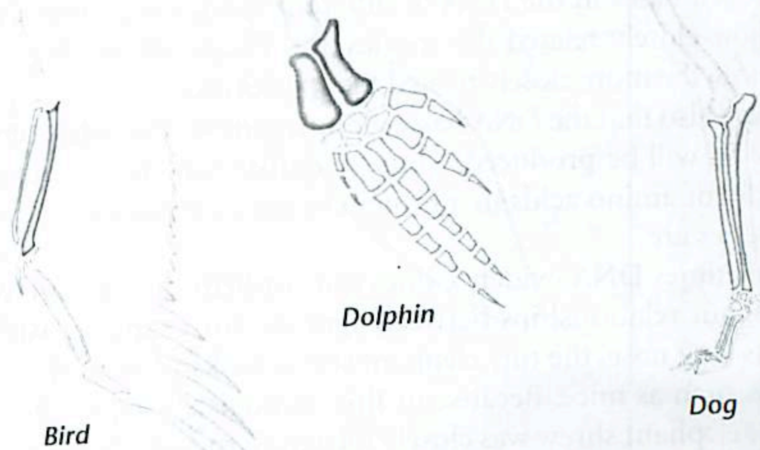


Figure 13 A bird's wing, dolphin's flipper, and dog's leg are all adapted to performing different tasks. However, the structure of the bones in each forelimb is very similar. These homologous structures provide evidence that these animals evolved from a common ancestor. *What similarities in structure do the three forelimbs share?*

Figure 14 Turtles (left), chickens (center), and rats (right) look similar during the earliest stages of development. These similarities provide evidence that these three animals evolved from a common ancestor.

in Figure 14. For example, during the early stages of development all three organisms have a tail and tiny gill slits in their throats. These similarities suggest that these three vertebrate species are related and share a common ancestor.

When scientists study early development more closely, they notice that the turtle appears more similar to the chicken than it does to the rat. This evidence supports the conclusion that turtles are more closely related to chickens than they are to rats.

Similarities in DNA

Why do related species have similar body structures and development patterns? Scientists infer that the species inherited many of the same genes from a common ancestor. Recently, scientists have begun to compare the genes of different species to determine how closely related the species are.

Recall that genes are made of DNA. By comparing the sequence of nitrogen bases in the DNA of different species, scientists can infer how closely related the species are. The more similar the sequences, the more closely related the species are.

Recall also that the DNA bases along a gene specify what type of protein will be produced. Thus, scientists can also compare the order of amino acids in a protein to see how closely related two species are.

Sometimes DNA evidence does not confirm earlier conclusions about relationships between species. For example, aside from its long nose, the tiny elephant shrew looks very similar to rodents such as mice. Because of this, biologists used to think that the elephant shrew was closely related to rodents. But when scientists compared DNA from elephant shrews to that of both

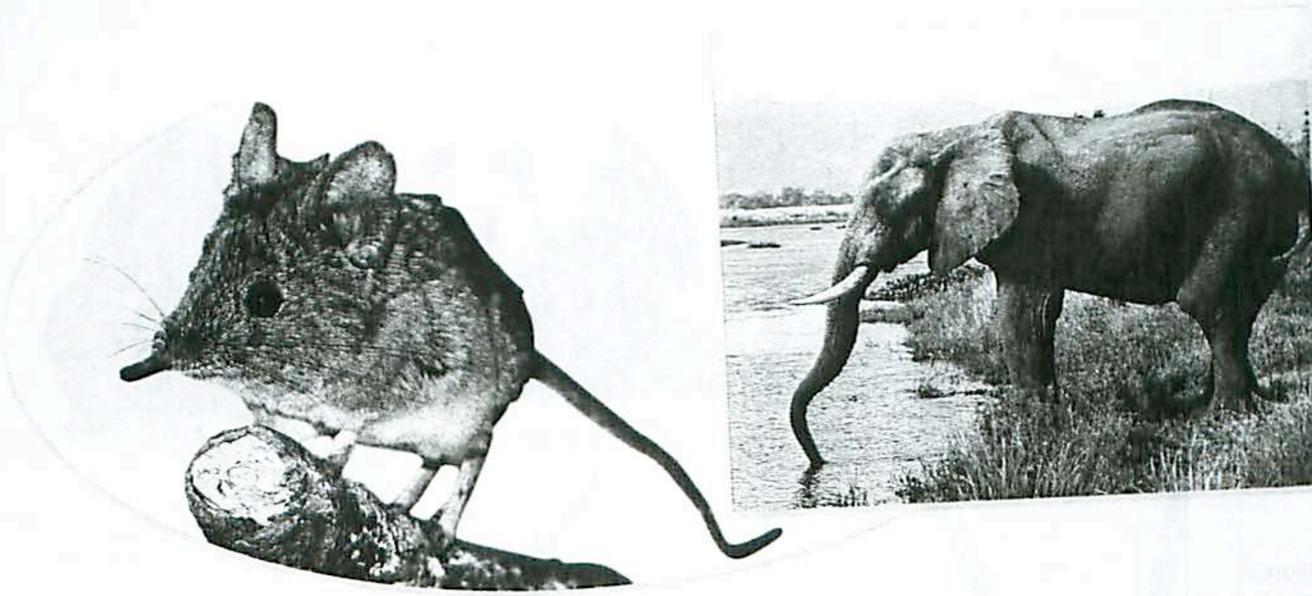


Figure 15 Because of its appearance, the tiny elephant shrew was thought to be closely related to mice and other rodents. Surprisingly, DNA comparisons showed that the elephant shrew is actually more closely related to elephants.

rodents and elephants, they got a surprise. The elephant shrew's DNA was more similar to the elephant's DNA than it was to the rodent's DNA. Scientists now think that elephant shrews are more closely related to elephants than to rodents.

Integrating Technology Recently, scientists have developed techniques that allow them to extract, or remove, DNA from fossils. Using these techniques, scientists have now extracted DNA from fossils of bones, teeth, and plants, and from insects trapped in amber. The DNA from fossils has provided scientists with new evidence about evolution.

Combining the Evidence

Scientists have combined evidence from fossils, body structures, early development, and DNA and protein sequences to determine the evolutionary relationships among species. In most cases, DNA and protein sequences have confirmed conclusions based on earlier evidence. For example, recent DNA comparisons show that dogs are more similar to wolves than they are to coyotes. Scientists had already reached this conclusion based on similarities in the structure and development of these three species.

Another example of how scientists combined evidence from different sources is shown in the branching tree in Figure 16. A **branching tree** is a diagram that shows how scientists think different groups of organisms are related. Based on similar body structures, lesser pandas were thought to be closely related to giant pandas. The two panda species also resemble both bears and raccoons. Until recently, scientists were not sure how these four groups were related. DNA analysis and other methods have shown that giant pandas and lesser pandas are not closely related. Instead, giant pandas are more closely related to bears, while lesser pandas are more closely related to raccoons.

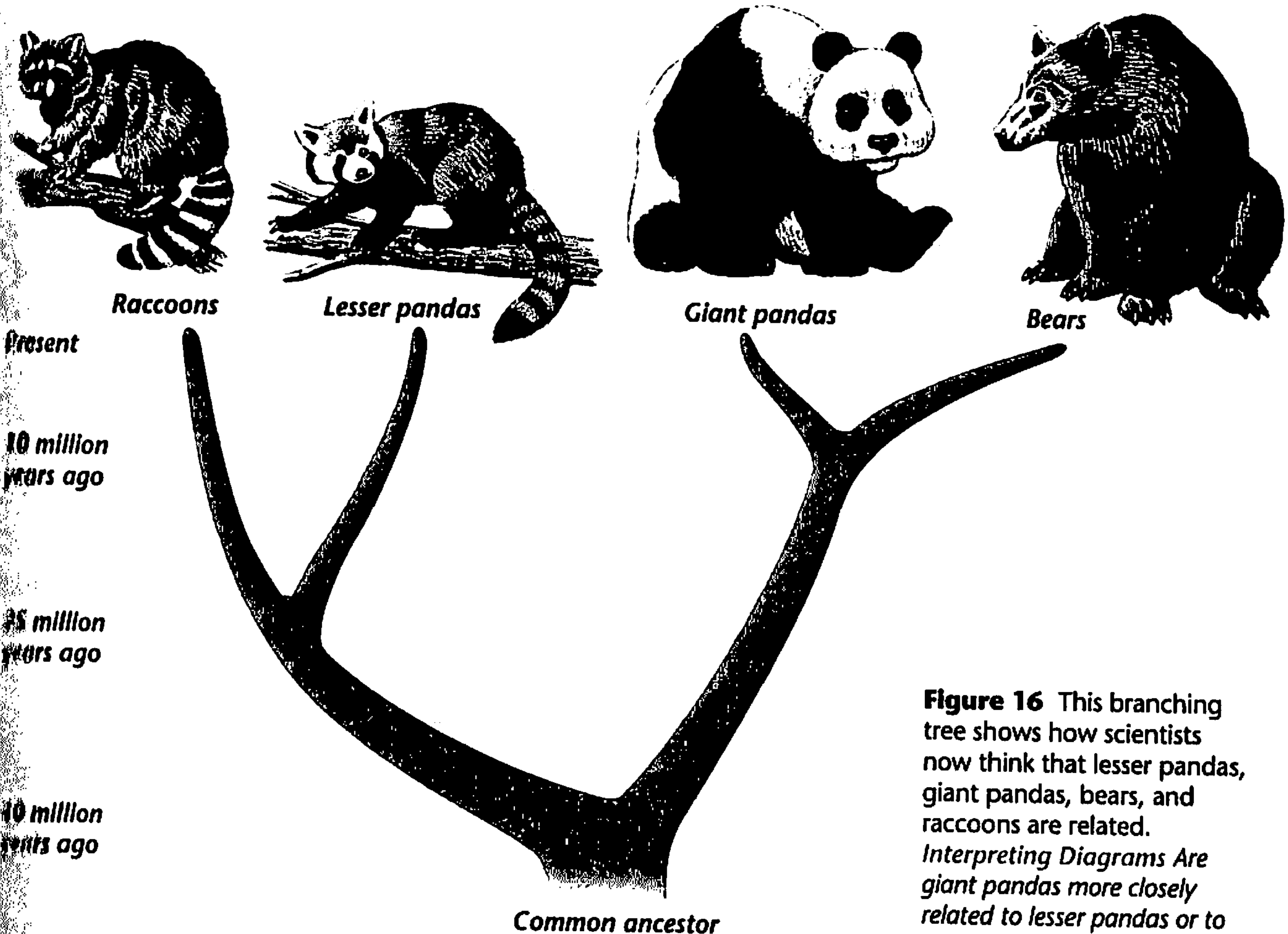


Figure 16 This branching tree shows how scientists now think that lesser pandas, giant pandas, bears, and raccoons are related. *Interpreting Diagrams Are giant pandas more closely related to lesser pandas or to bears?*

Section 3 Review

1. Name three types of evidence from modern-day organisms that scientists use to determine evolutionary relationships.
2. What are homologous structures?
3. What information did scientists learn by comparing the early developmental stages of turtles, chickens, and rats?
4. If two species are closely related, what would you expect a comparison of their DNA base sequences to reveal?
5. **Thinking Critically Making Judgments** Most scientists today consider similarities in DNA to be the best indicator of how closely two species are related. Why do you think this is the case?

CHAPTER PROJECT

Check Your Progress

You should be completing construction of the time line that covers 5 billion years. Now begin work on the time line showing 600 million years. This version is a magnified view of one part of the first time line. It will give you additional space to show what happened in the more recent years of Earth's history. (*Hint:* Prepare drawings to show how life forms on Earth were changing. Also, try to include three or more events not mentioned in the text.)

Skills Lab

TELLTALE MOLECULES

In this lab, you will compare the structure of one protein in a variety of animals. You'll use the data to draw conclusions about how closely related those animals are.

Problem

What information can protein structure reveal about evolutionary relationships among organisms?

Procedure

1. Examine the table below. It shows the sequence of amino acids in one region of a protein, cytochrome c, for six different animals. Each letter represents a different amino acid.
2. Predict which of the five other animals is most closely related to the horse. Which animal do you think is most distantly related?
3. Compare the amino acid sequence of the horse to that of the donkey. How many amino acids differ between the two species? Record that number in your notebook.
4. Compare the amino acid sequences of each of the other animals to that of the horse. Record the number of differences in your notebook.

Analyze and Conclude

1. Which animal's amino acid sequence was most similar to that of the horse? What similarities and difference(s) did you observe?
2. How did the amino acid sequences of each of the other animals compare with that of the horse?
3. Based on this data, which species is the most closely related to the horse? Which is the most distantly related?
4. For the entire cytochrome c protein, the horse's amino acid sequence differs from the other animals as follows: donkey, 1 difference; rabbit, 6; snake, 22; turtle, 11; and whale, 5. How do the relationships indicated by the entire protein compare with those for the region you examined?
5. **Think About It** Explain why data about amino acid sequences can provide information about evolutionary relationships among organisms.

More to Explore

Use the amino acid data to construct a branching tree that includes horses, donkeys, and snakes. The tree should show one way that the three species could have evolved from a common ancestor.

Section of Cytochrome c Protein in Animals

	Amino Acid Position														
Animal	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**
Horse	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Donkey	A	B	C	D	E	F	G	H	Z	J	K	L	M	N	O
Rabbit	A	B	C	D	E	Y	G	H	Z	J	K	L	M	N	O
Snake	A	B	C	D	E	Y	G	H	Z	J	K	W	M	N	O
Turtle	A	B	C	D	E	V	G	H	Z	J	K	U	M	N	O
Whale	A	B	C	D	E	Y	G	H	Z	J	K	L	M	N	O

Section 1 Darwin's Voyage

Key Ideas

- Darwin thought that species gradually changed over many generations as they became better adapted to new conditions. This process is called evolution.
- Darwin's observations led him to propose that evolution occurs through natural selection. Natural selection occurs due to overproduction, competition, and variations.
- Only traits controlled by genes can change over time as a result of natural selection.
- If a group of individuals remains separated from the rest of its species long enough to evolve different traits, a new species can form.

Key Terms

species	evolution	natural selection
adaptation	scientific theory	variation

Section 2 The Fossil Record

Integrating Earth Science

Key Ideas

- Most fossils form when organisms die and sediments bury them. The sediments harden, preserving parts of the organisms.
- Relative dating determines which of two fossils is older and which is younger. Absolute dating determines the actual age of a fossil.
- Fossils help scientists understand how extinct organisms looked and evolved.
- The Geologic Time Scale shows when during Earth's 4.6-billion-year history major groups of organisms evolved.
- Evolution has occurred gradually at some times and fairly rapidly at other times.

Key Terms

fossil	radioactive element
sedimentary rock	half-life
petrified fossil	fossil record
mold	extinct
cast	gradualism
relative dating	punctuated equilibria
absolute dating	

Section 3 Other Evidence for Evolution

Key Ideas

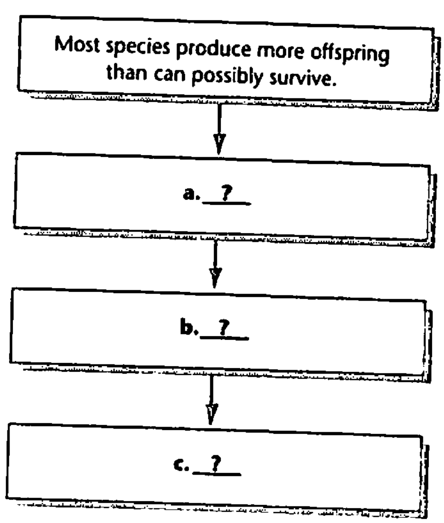
- By comparing modern-day organisms, scientists can infer how closely related they are in an evolutionary sense.
- Homologous structures can provide evidence of how species are related and of how they evolved from a common ancestor.
- Similarities in early developmental stages are evidence that species are related and shared a common ancestor.
- Scientists can compare DNA and protein sequences to determine more precisely how species are related.
- A branching tree is a diagram that shows how scientists think different groups of organisms are related.

Key Terms

homologous structure
branching tree

Organizing Information

Flowchart Copy the flowchart about natural selection onto a separate sheet of paper. Complete the flowchart by writing a sentence describing each factor that leads to natural selection. Then add a title. (For more on flowcharts, see the Skills Handbook.)



Multiple Choice

Choose the letter of the best answer.

Changes in a species over long periods of time are called
a. relative dating.
b. evolution.
c. homologous structures.
d. developmental stages.

A trait that helps an organism survive and reproduce is called a(n)
a. variation. b. adaptation.
c. species. d. selection.

The type of fossil formed when an organism dissolves and leaves an empty space in a rock is called a
a. cast. b. mold.
c. trace. d. petrified fossil.

The rate of decay of a radioactive element is measured by its
a. year. b. era.
c. half-life. d. period.

Which of these is *not* used as evidence for evolution?
a. DNA sequences
b. stages of development
c. body size
d. body structures

True or False

If the statement is true, write true. If it is false, change the underlined word or words to make the statement true.

Darwin's idea about how evolution occurs is called natural selection.

Most members of a species show differences, or variations.

A footprint of an extinct dinosaur is an example of a fossil.

The technique of relative dating can be used to determine the actual age of a fossil.

Homologous structures are similar structures in related organisms.

What role does the overproduction of offspring play in the process of natural selection?

Use an example to explain how natural selection can lead to evolution.

How are rock layers used to determine the relative ages of fossils?

According to the theory of punctuated equilibria, why does the fossil record include very few intermediate forms?

Explain why similarities in the early development of different species suggest that the species are related.

You are a young reporter for a local newspaper near the home of Charles Darwin. You have been asked to interview Darwin about his theory of evolution. Write three questions that you would ask Darwin. Then choose one question and answer it as Darwin would have.

Why did Darwin's visit to the Galapagos Islands have such an important influence on his development of the theory of evolution by natural selection?

Predict how an extreme change in climate might affect natural selection in a species.

What is the role of geographic isolation in the formation of new species?

How does relative dating differ from absolute dating?

A seal's flipper and a human arm have very different functions. What evidence might scientists look for to determine whether both structures evolved from the forelimb of a common ancestor?

Applying Skills

Radioactive carbon-14 decays to nitrogen with a half-life of 5,730 years. Use this information and the table below to answer Questions 22–24.

Fossil	Amount of Carbon-14 in Fossil	Amount of Nitrogen in Fossil	Position of Fossil in Rock Layers
A	1 gram	7 grams	bottom layer
B	4 grams	4 grams	top layer
C	2 grams	6 grams	middle layer

22. **Inferring** Use the positions of the fossils in the rock layers to put the fossils in order from youngest to oldest.
23. **Calculating** Calculate the age of each fossil using the data about carbon-14 and nitrogen.
24. **Drawing Conclusions** Do your answers to Questions 22 and 23 agree or disagree with each other? Explain.

Performance Assessment

CHAPTER PROJECT

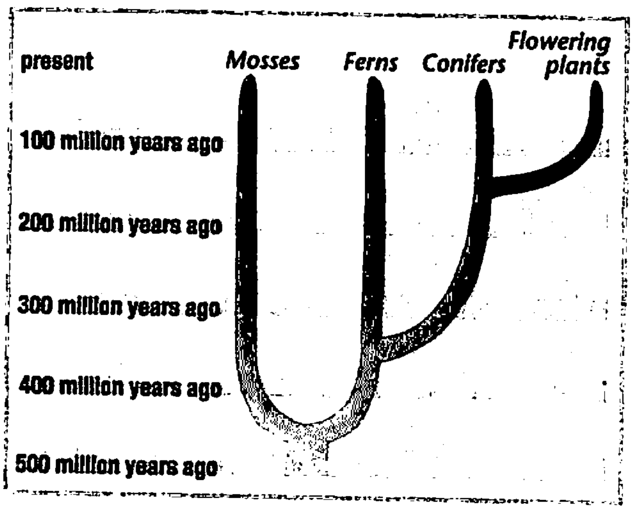
Present Your Project Display your completed time lines for the class. Be prepared to explain why you chose the scale that you did. Also, describe how your time lines are related to each other.

Reflect and Record In your notebook, describe how the time lines helped you understand the long periods involved in the evolution of life. Were you surprised to see how far apart some of the events were? What surprised you the most? What did making two time lines enable you to see that you might have missed with only one?

Test Preparation

Use these questions to prepare for standardized tests.

Use the illustration to answer Questions 25–28.



25. What is the best title for this illustration?
    a. Plant Growth Over Time
    b. Branching Tree of Plant Evolution
    c. Mosses and Ferns, the Oldest Plants
    d. Flowering Plants, the Youngest Plants
26. About how long ago did mosses evolve?
    a. 100 million years ago
    b. 150 million years ago
    c. 350 million years ago
    d. 450 million years ago
27. Which group of plants would have DNA that is most similar to the DNA of flowering plants?
    a. mosses
    b. ferns
    c. conifers
    d. They would all be equally alike.
28. Which group of plants would have DNA that is least similar to the DNA of flowering plants?
    a. mosses
    b. ferns
    c. conifers
    d. They would all be equally alike.