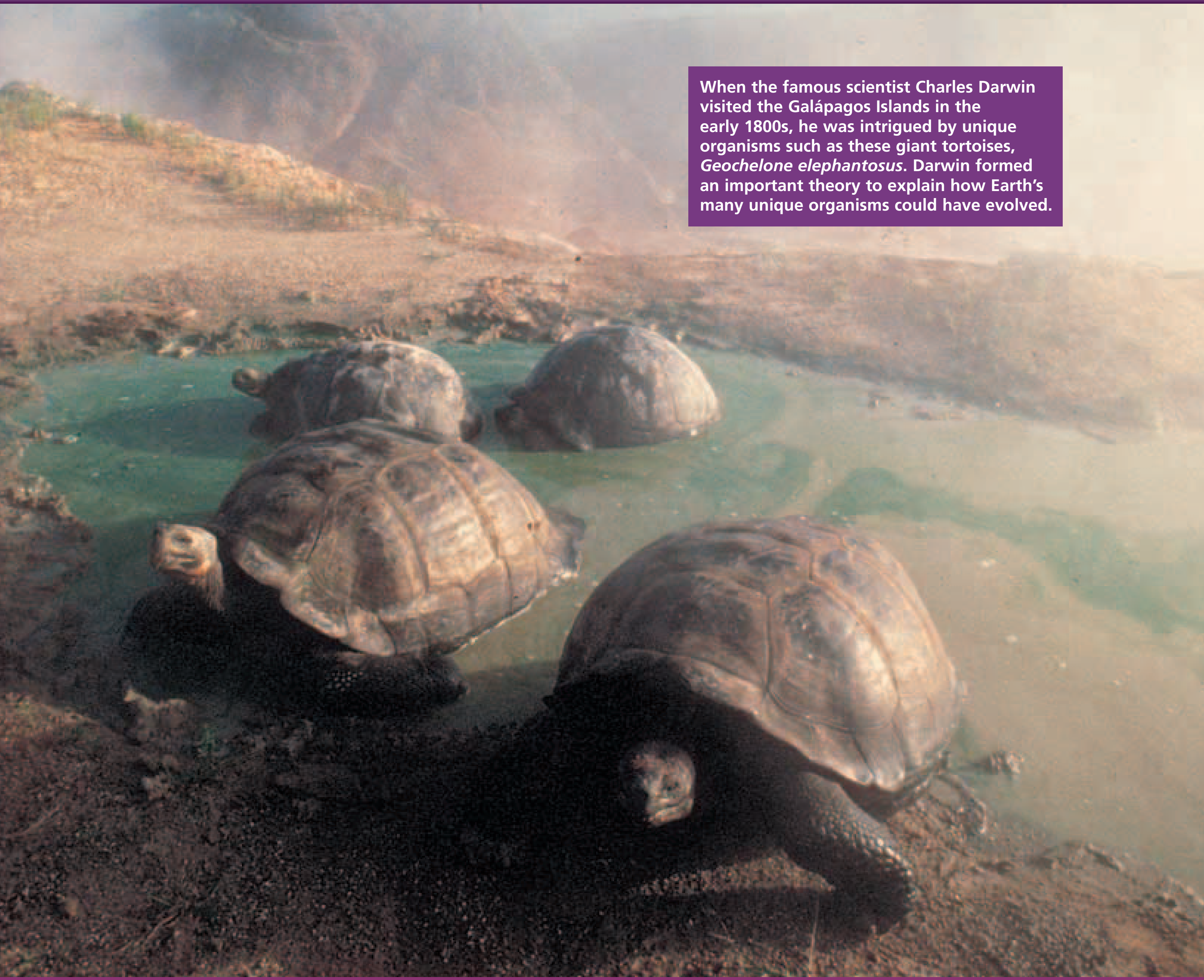
CHAPTER 15

Theory of Evolution



When the famous scientist Charles Darwin visited the Galápagos Islands in the early 1800s, he was intrigued by unique organisms such as these giant tortoises, *Geochelone elephantosus*. Darwin formed an important theory to explain how Earth's many unique organisms could have evolved.

SECTION 1 ***History of Evolutionary Thought***

SECTION 2 ***Evidence of Evolution***

SECTION 3 ***Evolution in Action***

HISTORY OF EVOLUTIONARY THOUGHT

In the1830s, the young English naturalist Charles Darwin took a trip around the world on a ship called HMS Beagle. *He was fascinated by diverse and unique organisms, such as the giant tortoises of the Galápagos Islands. Darwin went on to form one of the most important theories in biology.*

OBJECTIVES

- **Define** the biological process of evolution.
- **Summarize** the history of scientific ideas about evolution.
- **Describe** Charles Darwin's contributions to scientific thinking about evolution.
- **Analyze** the reasoning in Darwin's theory of evolution by natural selection.
- **Relate** the concepts of adaptation and fitness to the theory of natural selection.

VOCABULARY

evolution
strata
natural selection
adaptation
fitness

THE IDEA OF EVOLUTION

After visiting the Galápagos Islands, Charles Darwin (1809–1882), shown in Figure 15-1, noted that groups of animals varied from island to island. For example, the tortoises on the same island resembled each other closely, but those from neighboring islands were different. Darwin noticed similarities and differences among many organisms as he traveled around the world. He became convinced that organisms had changed over time, and he wanted to understand why.

The development of new types of organisms from preexisting types of organisms over time is called **evolution.** Modern scientists also define evolution as a heritable change in the characteristics within a population from one generation to the next. Darwin sought to present the evidence that the evolution of new organisms occurs. Furthermore, he formed a theory to explain how evolution could occur. Others had tried to form such theories earlier, but Darwin's theory became the basis for modern explanations of evolution. Remember that in science, a *theory* is a well-supported explanation for some aspect of the natural world that incorporates many observations, inferences, and tested hypotheses. In forming his theory, Darwin took years to put together data from many sources and to take account of the ideas of other scientists of his time.

FIGURE 15-1
Charles Darwin first studied to be a doctor and then a minister, but was also interested in nature. At the age of 22, he set off on a five-year voyage that became an important part of the history of science.

Ideas Of Darwin's Time

In Europe in the 18th century, most scientists thought that all species were permanent and unchanging. Furthermore, they thought that the Earth was only thousands—and not billions—of years old. However, scientists began to present evidence that the species on Earth have changed over time, and that the Earth is much older than anyone had thought.

FIGURE 15-2

The strata of the Grand Canyon contain evidence of the history of the area over millions of years of geologic time.

Ideas About Geology

By the 1800s, scientists in Europe had begun to study rock layers—called **strata**—such as those shown in Figure 15-2. They found that strata are formed as new layers of rock are deposited over time. They inferred that, in general, lower strata were formed first and are thus the oldest. The scientists also found that different rock strata hold fossils of different kinds of organisms.

French anatomist Georges Cuvier (coo-VYAY) (1769–1832) spent years reconstructing the appearance of unique organisms from fossil bones. Cuvier gave convincing evidence that some organisms in the past differed greatly from any living species and that some organisms had become *extinct*, meaning the species had ceased to live after a point in time. Cuvier also found that deeper and older strata hold fossils that are increasingly different from living species. Finally, Cuvier found many "sudden" changes in the kinds of organisms found in one rock stratum compared to the next.

To explain these observations, Cuvier promoted the idea of *catastrophism* (kuh-TAS-truh-FIZ-uhm)—the idea that sudden geologic catastrophes caused the extinction of large groups of organisms at certain points in the past. Even though scientists no longer accept all of his explanations, Cuvier contributed to scientific acceptance that geologic change and extinction had occurred.

The English geologist Charles Lyell (1797–1875) shared some of Cuvier's ideas but thought that the geologic processes that have changed the shape of Earth's surface in the past continue to work in the same ways. Lyell's idea is called *uniformitarianism* (YOON-uh-FAWRM-uh-TER-ee-uhn-IZ-um). Charles Darwin read Lyell's writings while on his trip around the world. He was excited to find how well Lyell's ideas fit with his own observations and ideas. Lyell had shown evidence from geology that fit with Darwin's evidence from biology. Darwin referred to Lyell's work in many of his writings.

Word Roots and Origins

evolution

from the Latin prefix *e-*, meaning "out," and *volvere,* meaning "to roll"

Lamarck's Ideas on Evolution

The French biologist Jean Baptiste Lamarck (1744–1829) also supported the idea that populations of organisms change over time. Lamarck put forward a new idea to explain how evolution could happen, though this idea is no longer accepted among scientists. Lamarck thought that simple organisms could arise from nonliving matter. He also thought that simple forms of life inevitably develop into more complex forms. He proposed that individuals could acquire traits during their lifetimes as a result of experience or behavior, then could pass on those traits to offspring. Lamarck's idea is called the *inheritance of acquired characteristics*. Even though Darwin himself once accepted Lamarck's idea, it was rejected by many scientists of their time and has not been supported by modern scientific study of the mechanisms of inheritance.

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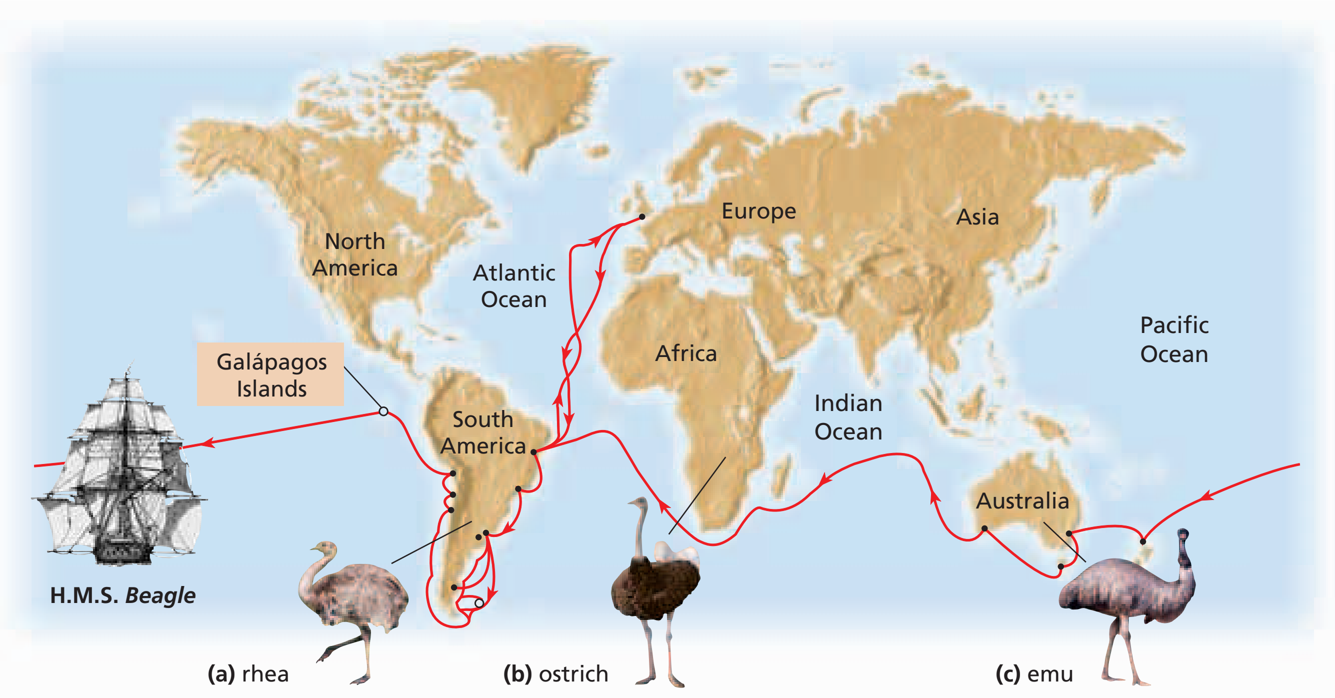

FIGURE 15-3

On his voyage, Darwin noticed the locations of similar organisms around the world. The rhea (a), ostrich (b), and emu (c), for example, are clearly related species that have similar body forms and occupy similar habitats. They occur on different continents, however. Darwin wondered what causes such distributions in nature.

DARWIN'S IDEAS

At about the same time in the mid-1800s, both Charles Darwin and the English naturalist Alfred Russel Wallace (1823–1913) formed a new theory to explain how evolution may take place. Both Darwin and Wallace had been on sea voyages around the world; Darwin's voyage is shown in Figure 15-3. In 1858, the ideas of Darwin and Wallace were presented to a prestigious group of scientists in London. The following year, Darwin published a book entitled *On the Origin of Species by Means of Natural Selection.*

Darwin had two goals in his book: first, he wanted to present the large amount of evidence that evolution occurs; and second, he wanted to explain the variety and distribution of organisms on Earth in terms of natural processes that are observable every day.

Descent with Modification

Darwin used the phrase *descent with modification* to describe the process of evolution. He carefully reviewed the evidence that every species—living or extinct—must have descended by reproduction from preexisting species and that species must be able to change over time. Darwin was not the first person to put forward the idea of descent with modification, but he was the first to argue that *all* species had descended from only one or a few original kinds of life.

Darwin saw the animals of the Galápagos Islands as evidence of descent with modification. For example, the islands are home to 13 similar species of finches. Each of these bird species has a beak that is best adapted for a certain kind of food. But Darwin suspected that all 13 species descended from and diverged from just a few ancestral finches. These ancestors could have flown to the Galápagos Islands from elsewhere sometime after the islands were formed.

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Natural Selection

Darwin proposed the theory of **natural selection** as the mechanism for descent with modification. In forming his theory, Darwin thought carefully about the forces that could cause changes in organisms over time. The following summary explains the four main parts of Darwin's reasoning, as shown in Figure 15-4:

1. **Overproduction** More offspring can be produced than can survive to maturity. For example, each female deer has one or more offspring per year for many years in a lifetime. This multiplication could increase the total number of deer in a short time. But each new deer needs food and is vulnerable to predators and disease, so not all of the deer live for very long.

   Darwin drew this part of his reasoning from a popular book about human social problems by English clergyman and economist Thomas Malthus (1766–1834). Malthus pointed out that human populations can increase more quickly than food supplies and that populations are often limited by conditions such as war, disease, or lack of food. Darwin realized that the environment limits the populations of *all* organisms by causing deaths or by limiting births.

2. **Genetic Variation** Within a population, individuals have different traits. For example, some deer may have thicker fur or longer legs than others. Also, some of this variation can be inherited. For example, deer that have thick fur tend to have offspring with thick fur. Occasionally, new traits may appear in a population.

3. **Struggle to Survive** Individuals must compete with each other in what Darwin called a "struggle for existence." Some variations improve an individual's chance to survive and reproduce, but some variations reduce this chance. For example, deer that have thick fur may survive in the cold better than deer that have thin fur. A trait that makes an individual successful in its environment, such as thick fur in cold climates, is called an **adaptation.**

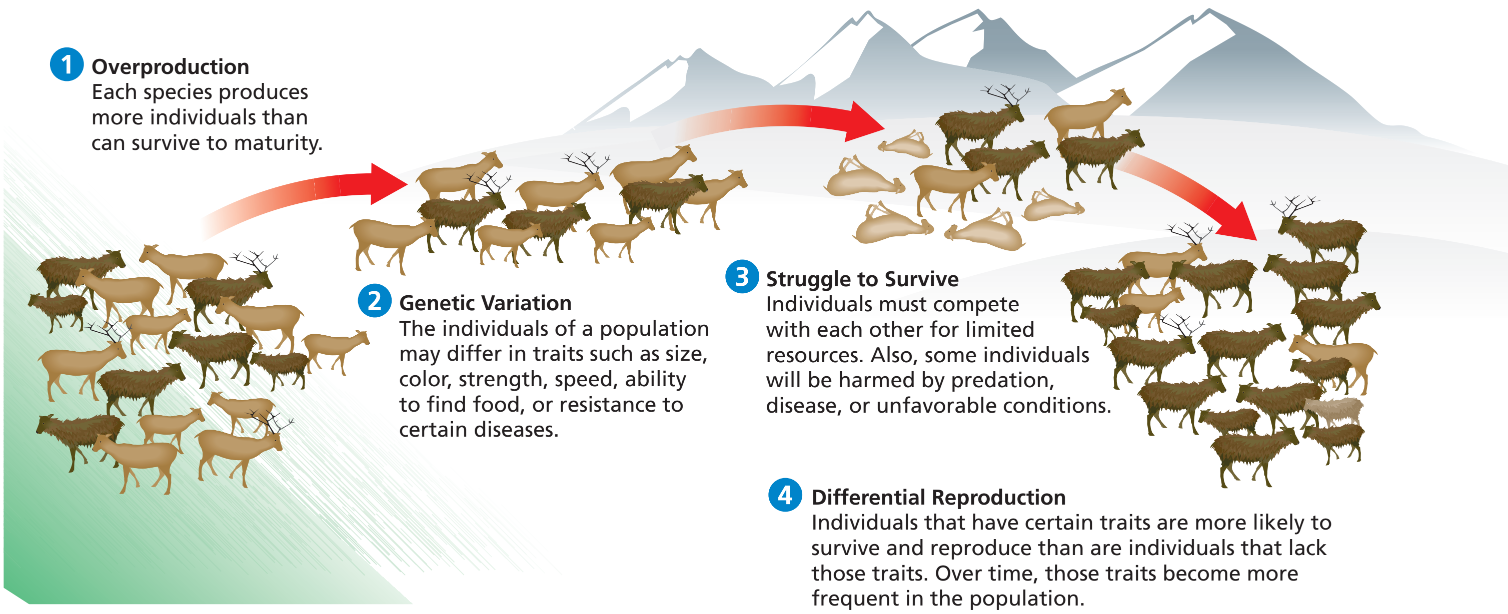

FIGURE 15-4
This diagram represents the process of natural selection explained by Charles Darwin as the mechanism for evolution.

4 Differential Reproduction Darwin concluded that organisms with the best adaptations are most likely to survive and reproduce. And through inheritance, the adaptations will become more frequent in the population. So, populations may begin to differ as they become adapted to different environments, even if they descended from the same ancestors. This conclusion is the core idea of Darwin's theory.

Darwin explained that natural selection could account for descent with modification as species become better adapted to different environments. That is, the theory of natural selection proposes that nature changes species by selecting traits. The environment "selects" the traits that may increase in a population by selecting the parents for each new generation.

Darwin sometimes used the phrase "survival of the fittest" to describe natural selection. In evolutionary terms, **fitness** is a measure of an individual's hereditary contribution to the next generation. This kind of fitness is more than simply living a long time. A fit individual is one that has offspring that also live long enough to reproduce in a given environment. For example, if thick fur is an advantage for a deer living in the mountains, then deer that have thick fur are more likely to live long enough to reproduce and pass on the genes for thick fur. If a certain trait increases an individual's fitness, the proportion of individuals with that trait is likely to increase over time. So, adaptations are those traits that increase the fitness of individuals, and populations tend to be well adapted to survive the conditions in which they live.

In evolutionary theory, the term *adaptation* is also used to describe changes in traits in populations over time. This meaning is different from that of short-term adaptation by an individual to a temporary condition. Also, long-term adaptation in populations is not the same as acclimatization in individuals. *Acclimatization* is a short-term process in which physiological changes take place in a single being in its own lifetime. An example of acclimatization is an animal adjusting to a new climate by growing thicker fur.

Eco Connection

Galápagos Islands

The unique ecosystems of the Galápagos Islands have been in danger since the discovery of the islands by Europeans in 1535. For 400 years, the islands were a favorite stopping place for pirates and whalers. Sailors valued the large native tortoises as a meat source because the tortoises could live for long periods aboard a ship with little or no food or water. Over the years, the number of native tortoises was severely reduced. Three of the 14 original subspecies of tortoises are now extinct. However, since 1936, the government of Ecuador and scientists from many countries have taken steps to preserve and restore the islands' native species and habitats. In 1965, the Charles Darwin Research Station began to breed and reintroduce the tortoises and other species.

SECTION 1 REVIEW

1. Explain Darwin's use of the phrase *descent with modification* to describe the process of evolution.
2. Describe two scientists' ideas about geology that influenced ideas about evolution in the 1800s.
3. Explain the difference between an acquired characteristic and an inherited characteristic.
4. In what ways was Darwin an important scientist?
5. Describe the four parts of reasoning in Darwin's theory of evolution by natural selection. Use examples in your answer.

CRITICAL THINKING

6. **Inferring Meaning** Explain why some biologists say that "fitness is measured in grandchildren."
7. **Analyzing Processes** Suppose that an individual has a new trait that makes it live longer than others in its population. Does this individual have greater fitness? Explain your answer.
8. **Applying Information** What have you learned about heredity and genetics that could support Darwin's theory of natural selection?

SECTION 2

EVIDENCE OF EVOLUTION

OBJECTIVES

- **Relate** several inferences about the history of life that are supported by evidence from fossils and rocks.
- **Explain** how biogeography provides evidence that species evolve adaptations to their environments.
- **Explain** how the anatomy and development of organisms provide evidence of shared ancestry.
- **Compare** the use of biological molecules with other types of analysis of evolutionary relationships.
- **Describe** the ongoing development of evolutionary theory.

VOCABULARY

fossil
superposition
relative age
absolute age
biogeography
homologous structure
analogous structure
vestigial structure
phylogeny

Many kinds of evidence give insight into the history of life on Earth and the patterns of change among organisms. Fossils that are different from organisms living today are strong evidence that organisms on Earth can change over time. But evidence of evolution is also found inside living organisms.

THE FOSSIL RECORD

A **fossil** is the remains or traces of an organism that died long ago. Fossils of many kinds of organisms can be formed under a number of different conditions, as shown in Figure 15-5. Fossils show that different types of organisms appeared at different times and places on Earth. Some fossils are of organisms that have become *extinct*, meaning the species is no longer alive. Fossils are among the most powerful evidence of evolution.

The Age of Fossils

In 1669, Danish scientist Nicolaus Steno (1638–1686) proposed the principle of **superposition.** This principle states that if the rock strata at a location have not been disturbed, the lowest stratum was formed before the strata above it. Successive strata are newer, and the most recent stratum is on the top. Geologists in the 1700s and 1800s built on Steno's ideas by comparing strata in different places and by comparing the fossils found in different strata. The geologists began to put together a timeline for the order in which different groups of rocks and fossils were formed. This timeline is commonly known as the *geologic time scale* (a simple version of this table appears in the Appendix). Today, geologists often can tell a fossil's **relative age**—its age compared to that of other fossils—by referring to the geologic time scale and to records of known fossils.

FIGURE 15-5
These fossils of pterosaur bones (a), fern leaves (b), and trilobite exoskeletons (c) were buried in ancient sediment. The insect (d) was trapped in ancient tree sap. In each case, the surrounding material later became rock.

(a) (b) (c) (d)

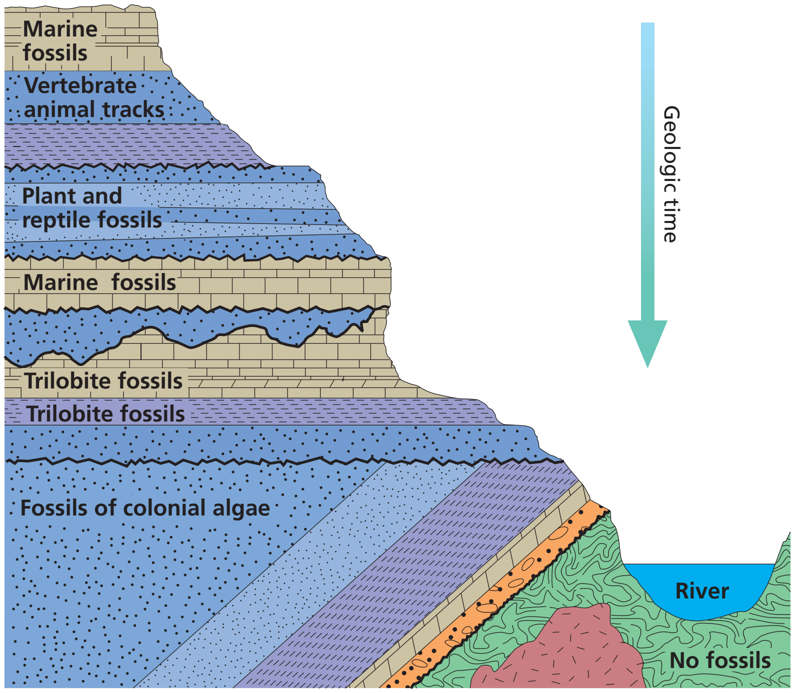

FIGURE 15-6

Erosion has exposed layer after layer of sedimentary rock in the Grand Canyon. Fossils trapped in the layers show that organisms changed over time as conditions on the surface changed over time. Deeper and older layers often contain fossils of organisms, such as trilobites, that no longer live on Earth.

For certain rocks, scientists can estimate the time since formation, or the **absolute age** of the rock, by techniques such as *radiometric dating.* Scientists use both relative and absolute dating as they compare fossils around the world. In this way, scientists try to make their history of life on Earth as precise as possible. However, the fossil record is an incomplete history of life because not all organisms have left fossil evidence. Most fossils are formed only by rare events. For example, a fossil could form if an organism died in a place where it did not fully decay and where rock later formed over the remains. Then, if the fossil escapes destruction over time, humans will discover it only by chance. Nevertheless, Earth is rich with fossil evidence of organisms that lived in the past.

The Distribution of Fossils

A number of additional inferences can be made from the fossil record. First, we can infer that different organisms lived at different times. For example, the rock strata shown in Figure 15-6 hold different kinds of fossils in successive layers. Second, we can infer that today's organisms are different from those of the past. Trilobites, for example, were unlike any organism alive today. Third, we can infer that fossils found in adjacent layers are more like each other than to fossils found in deeper or higher layers. In other words, organisms that lived during closer time periods are more alike than organisms that lived in widely separated time periods. Different species of trilobites appear in nearby strata, whereas deeper and older strata do not hold trilobites but hold other kinds of organisms. Fourth, by comparing fossils and rocks from around the planet, we can infer when and where different organisms existed. Each fossil provides evidence about the environment in which the organism existed and for which the organism had become adapted.

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Transitional Species

Finally, we can infer from the fossil record that species have differed in a gradual sequence of forms over time. This inference is based on *transitional species,* which have features that are intermediate between those of hypothesized ancestors and later descendant species. For example, evolutionary scientists have hypothesized that modern marine mammals, such as whales, evolved from early mammals in the fossil record that walked with four legs on land. This hypothesis predicts that there should be fossils that share characteristics of both ancient land-dwelling mammals and modern whales.

Indeed, scientists have found several fossils, such as those in Figure 15-7, that form a sequence of transitional forms. Comparing these fossils with each other and with modern whales reveals a sequence of differences in the structure of the hind limbs, forelimbs, vertebrae, and skull of each species. Scientists explain these differences as increasing adaptations for life in water. For example, hind limbs were smaller in later species and are absent in modern whales except for tiny pelvic bones. The hypothesis of whale evolution from land mammals is strongly supported by these fossil finds. However, there are other groups of organisms for which fossils of hypothesized transitional species have not been found.

FIGURE 15-7

The fossil skeletons below form a sequence of transitional forms that support the hypothesis that whales evolved from four-legged, land-dwelling mammals.

1. ***Pakicetus* (pak-uh-SEE-tuhs)**
Scientists think that whales evolved from land-dwelling mammals. One of these ancestors may have belonged to the genus *Pakicetus,* which lived about 50 million years ago. The fossil skeleton of a pakicetid is shown here.

2. ***Ambulocetus* (am-byoo-loh-SEE-tuhs)**
This genus of mammal lived in coastal waters about 49 million years ago. It could swim by kicking its legs and using its tail for balance. It could also waddle on land with its short legs.

3. ***Dorudon* (DOH-roo-don)**
This genus of mammal lived in the oceans about 40 million years ago. It resembled a giant dolphin and propelled itself with a massive tail. It had forelimbs that were flippers and tiny hind limbs that could not have been used for walking or swimming.

4. **Modern toothed whales**
Modern whales have forelimbs that are flippers. They also have tiny, nonfunctioning hip bones at the rear of their bodies.

BIOGEOGRAPHY

Biogeography is the study of the locations of organisms around the world. When traveling, Charles Darwin and Alfred Russel Wallace saw evidence of evolution in the distribution of organisms. Both Darwin and Wallace observed animals that seemed closely related yet were adapted to different environments in nearby regions. However, they also observed animals that seemed unrelated but that had similar adaptations to similar environments in regions that were far apart. Again, the model of descent with modification provides an explanation for these patterns of distribution.

The mammals of the continent of Australia provide a striking example of biogeographic evidence of evolution. There are native Australian animals that resemble wolves, cats, mice, moles, or anteaters. However, most Australian mammals are marsupials, mammals that have pouches in their bodies for carrying their young. A possible explanation for this pattern is that these animals evolved in isolation on the Australian continent.

Word Roots and Origins

homologous

from the Greek *homo,* meaning "equivalent to" and *logos,* meaning "relation" or "reason"

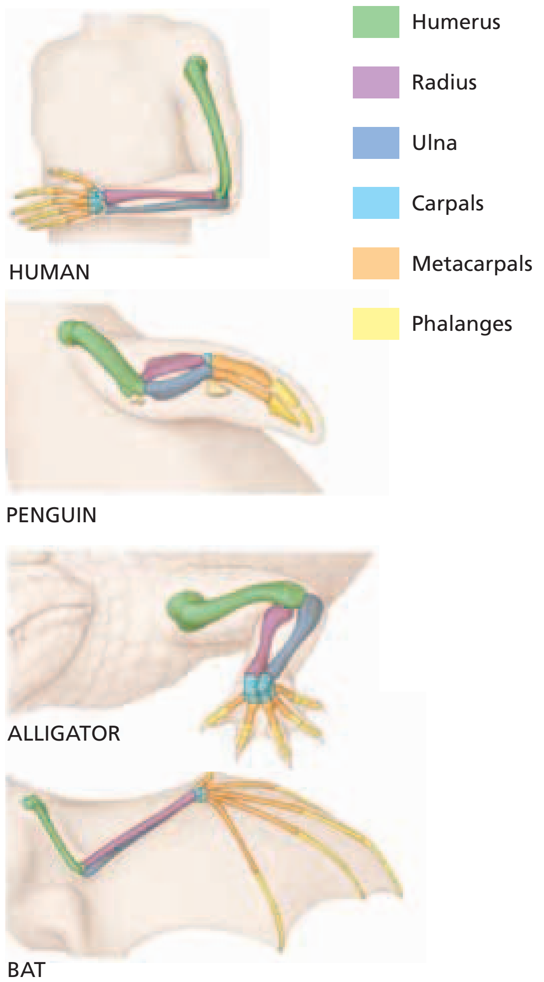
ANATOMY AND EMBRYOLOGY

Descent with modification also predicts the findings of *anatomy*—the study of the body structure of organisms—and *embryology*—the study of how organisms develop. Look at the bones in the forelimbs of humans, penguins, alligators, and bats shown in Figure 15-8. These forelimbs are used in different ways in each animal, yet each limb has a similar bone structure. One explanation for the commonalities among the forelimb bones of the four animals is that an early ancestor shared by all these vertebrates had a forelimb with a similar bone structure. As generations passed, different populations of descendants adapted to different environments. Bones inherited from ancestors may have become modified for different tasks.

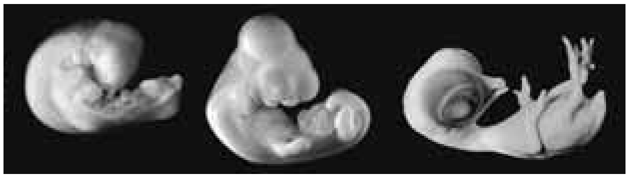
Biologists define **homologous structures** as anatomical structures that occur in different species and that originated by heredity from a structure in the most recent common ancestor of the species. Homologous organs often have a related structure even if their functions differ between species. On the other hand, **analogous structures** have closely related functions but do not derive from the same ancestral structure. For example, even though birds, bats, and moths have wings, their wings have very different underlying structures. Scientists think that wings evolved independently in each of these groups of animals.

FIGURE 15-8

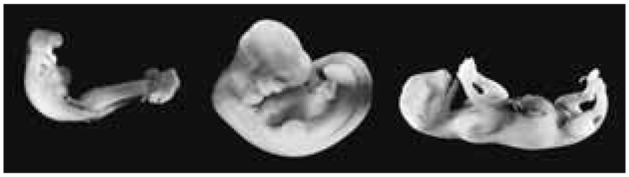
Humans, penguins, alligators, and bats each have forelimbs with homologous parts.



(a) dogfish, *Squalus acanthias*



(b) chicken, *Gallus gallus*



(c) cat, *Felis catus*

FIGURE 15-9

Modern analysis of vertebrate embryos shows that fish, chick, and cat embryos are remarkably similar at certain stages. This pattern would be expected if all were descended from a common ancestor. Processes occurring later in development then modify the ancestral body structures.

Further evidence of evolution is found in structures called **vestigial structures** that seem to serve no function but that resemble structures with functional roles in related organisms. For example, the human tailbone, or coccyx, is made up of four fused vertebrae that resemble the bones in an animal's tail. Other examples of vestigial structures are the pelvic bones of modern whales and the human appendix.

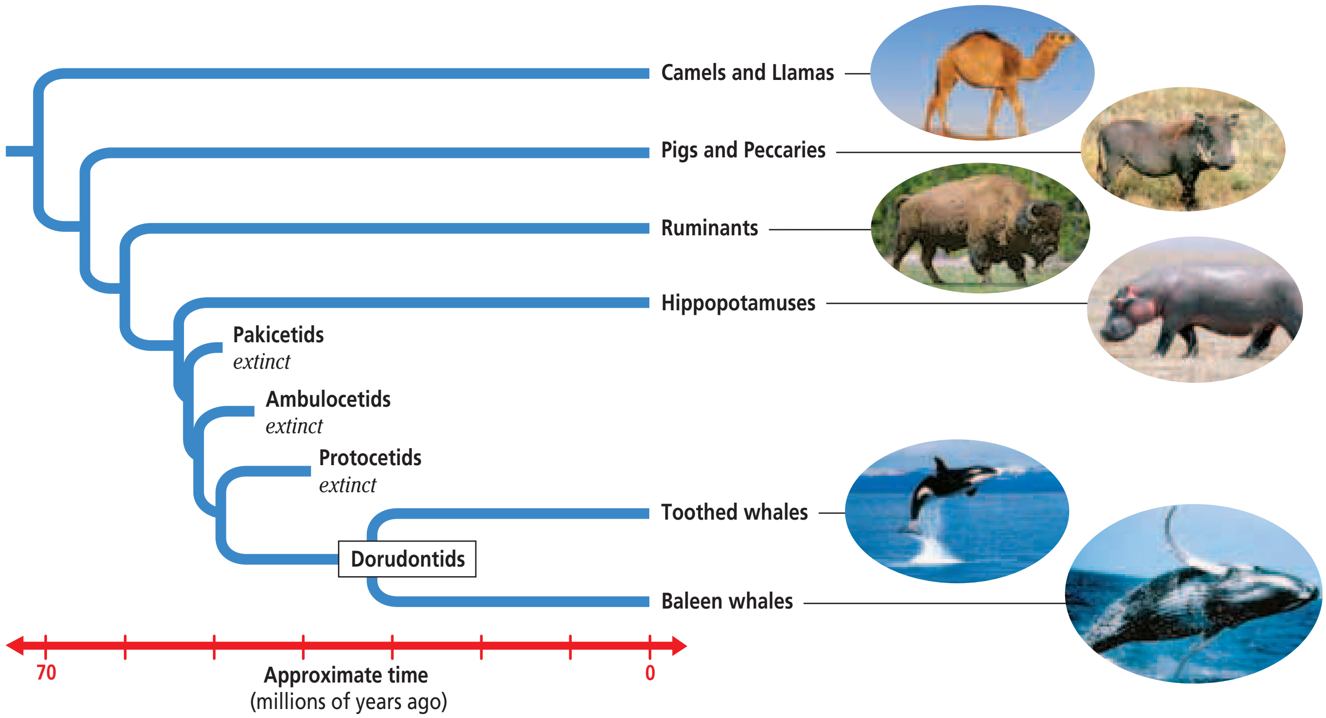
The development of animal embryos is also evidence of descent with modification. As shown in Figure 15-9, some stages of vertebrate embryo development are very alike, although the similarities fade as development proceeds. One possible explanation for these similarities is that vertebrates share a common ancestor and have inherited similar stages of development.

BIOLOGICAL MOLECULES

Organisms that share many traits should have a more recent common ancestor than organisms that share fewer traits. Darwin made this prediction by studying anatomy, but modern studies of biological molecules also support this prediction. In all species, DNA and RNA are the molecular basis for inheritance of traits. Furthermore, DNA affects traits encoding the amino acid sequences that form proteins. Biologists can compare the DNA, RNA, proteins, and other biological molecules from many different organisms. Then, they can look for similarities and differences among the data for each species. The greater the number of similarities between any given species, the more closely the species are related through a common ancestor. However, because the study of biological molecules is still relatively new, scientists continue to debate how to interpret this kind of evidence.

DEVELOPING THEORY

Not until the mid-1900s did scientists begin to integrate the theory of natural selection with new understandings of genetics. This blending has been called the *modern synthesis* of evolutionary theory. As in all areas of science, hypotheses and theories about evolution continue to be formed, challenged, and revised. Many aspects of evolution remain poorly understood, and some observations remain unexplained. Altough modern evolutionary theory, like all theories in science, can never be "proven," it is widely accepted and applied by scientists because it explains the broadest range of observations and makes useful predictions.



For example, scientists try to model **phylogeny,** the relationships by ancestry among groups of organisms. To do so, they must analyze many kinds of evidence. Sometimes, different evidence supports different models. Figure 15-10 shows a phylogenetic diagram, or "tree," which models a hypothesized phylogeny. This particular phylogeny was based on an analysis of biological molecules in animals that seem closely related to whales. The "trunk" represents a past species that could have been the ancestor of all these animals. Each "branch" over time represents a separate population or lineage. More closely related groups appear closer to each other on a branch. For example, whales are more closely related to hippopotamuses than to camels. Hypotheses such as these are supported when independent anatomical and biochemical data match the same model.

FIGURE 15-10

This phylogenetic diagram, or "tree," shows one hypothesis of the ancestral relationships among whales and the group of hoofed mammals known as *artiodactyls*. Scientists construct models such as these by comparing the anatomical or biochemical traits of many organisms. For updates on phylogenetic information, visit **go.hrw.com** and enter the keyword **HM6 Phylo.**

SECTION 2 REVIEW

1. Relate several inferences about the history of life that are supported by geologic evidence.
2. What evidence supports the hypothesis that whales evolved from land-dwelling mammals?
3. Compare the concepts of homologous structures, analogous structures, and vestigial structures.
4. Explain the evidence of evolution presented by the mammals of Australia.
5. Compare the use of biological molecules to other types of analysis of phylogeny.

CRITICAL THINKING

6. **Analyzing Theories** Does natural selection act on vestigial structures? Support your answer.
7. **Analyzing Models** If the DNA of a whale, a hippopotamus, and a camel were compared, what finding would support the model in Figure 15-10 above?
8. **Inferring Relationships** Fly embryos and frog embryos differ from each other more than frog embryos and ape embryos do. What does this imply about how these groups may be related?

SECTION 3

OBJECTIVES

- **Describe** how convergent evolution can result among different species.
- **Explain** how divergent evolution can lead to species diversity.
- **Compare** artificial selection and natural selection.
- **Explain** how organisms can undergo coevolution.

VOCABULARY

convergent evolution
divergent evolution
adaptive radiation
artificial selection
coevolution

EVOLUTION IN ACTION

Evolution is a continuous process. Evolution is going on today in populations of living species and can be observed, recorded, and tested. Patterns of evolution repeat in different times and places. Interactions between species, including humans, affect their ongoing evolution.

CASE STUDY: CARIBBEAN ANOLE LIZARDS

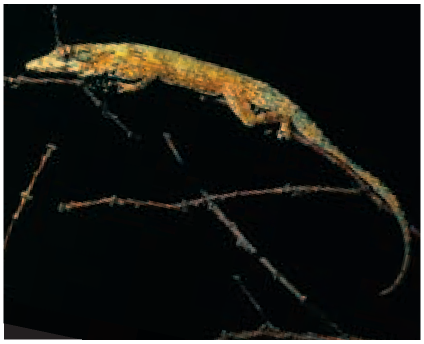
Often, when scientists compare groups of species, the scientists find patterns that are best explained as evolution in progress. An example is the comparison of anole lizard species (genus *Anolis*) on the Caribbean islands of Cuba, Hispaniola, Jamaica, and Puerto Rico. Among these lizards, each species' body type correlates with the habitat in which the species lives, as shown in Figure 15-11. For example, anole species that live mainly on tree trunks have stocky bodies and long legs. In contrast, those that reside on slender twigs have thin bodies, short legs and tails, and large toe pads. Grass-dwelling anoles tend to be slender and have very long tails. In all, there are at least six anole body types that are each adapted to their environment in a unique way. Also, distinct species of anoles with the same body types occur on different islands. For example, a distinct species of twig-dwelling anole is found on each island.

Many different hypotheses could explain these observations. Two possibilities are that (1) an ancestral anole species specialized for living on twigs originally lived on one island and later migrated to other islands or that (2) each twig-dwelling species evolved independently on each island from distinct ancestor anole species.

FIGURE 15-11

Each of these lizards is a member of the genus *Anolis* and lives on the island of Hispaniola in the Caribbean. One species (a) dwells mainly on tree trunks and on the ground and has much longer legs than a species (b) that mostly inhabits tree branches. Another species (c) stays mainly in the grass and has a long tail.

(a) *Anolis cybotes*



(b) *Anolis insolitus*

(c) *Anolis pulchellus*

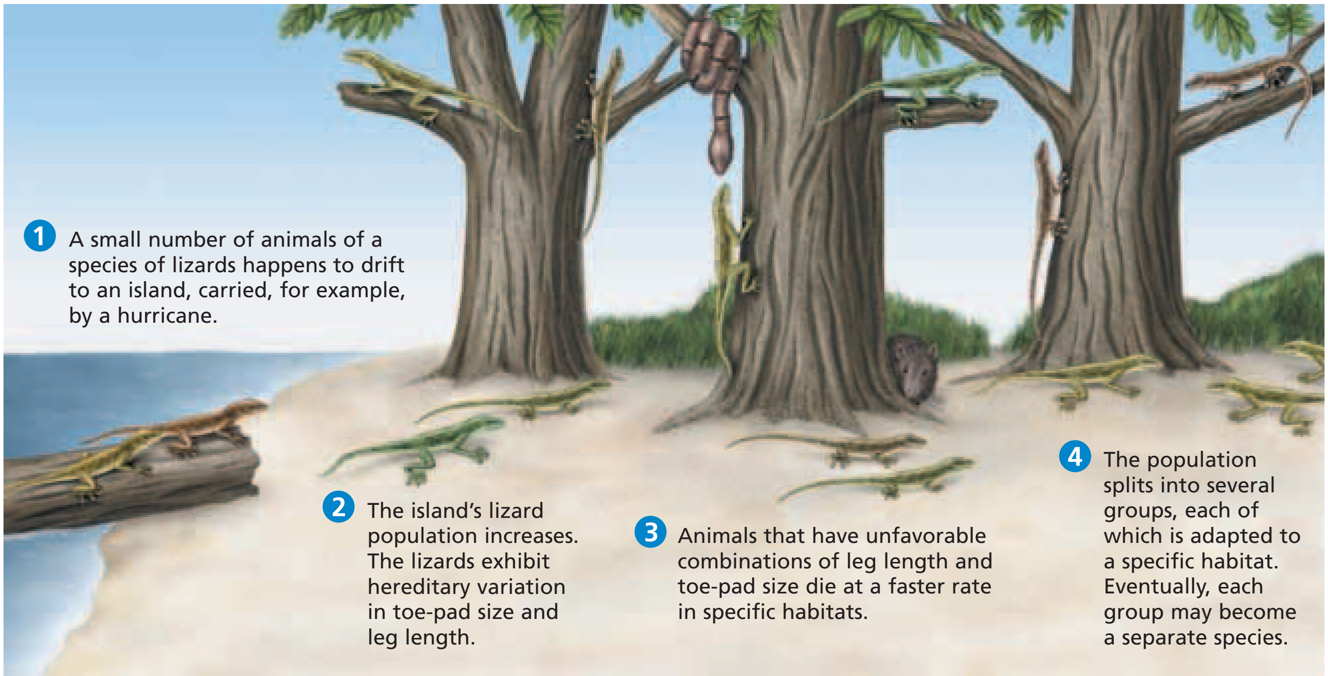


FIGURE 15-12

This diagram shows a possible scenario to explain, through natural selection, the evolution of a variety of anole lizard species in the Caribbean islands by descent from common ancestors.

Biologists tested these hypotheses by comparing DNA from various species to look for closely related species. The DNA evidence supported hypothesis 2—twig-dwelling species evolved independently on each island. In other words, each twig-dwelling species came from different ancestors but evolved similar adaptations to similar habitats. The process by which different species evolve similar traits is called **convergent evolution.** Many other examples of convergent evolution can be found in nature.

Divergence and Radiation

A model of Caribbean anole evolution must also explain how the lizards became adapted to their particular habitats. Studies showed that long-legged trunk-dwelling species could run faster on flat surfaces than short-legged twig-dwelling species, but the twig-dwelling species could cling to twigs better and did not fall as often. However, both kinds of lizards on each island were closely related.

The best explanation for this pattern of phylogeny is that divergent evolution occurred on each island. **Divergent evolution** is a process in which the descendants of a single ancestor diversify into species that each fit different parts of the environment. Lizards with genes for large toe pads and short legs ran so slowly on the trunk and ground that predators often caught them, and lizards with long legs and small toe pads often slipped if they climbed thin branches.

Sometimes, a new population in a new environment, such as an island, will undergo divergent evolution until the population fills many parts of the environment. This pattern of divergence is called **adaptive radiation.** Figure 15-12 illustrates a possible scenario for the evolution of Caribbean anole lizards. Fossil evidence suggests many cases of adaptive radiation on the geologic time scale.

Quick Lab

Observing Adaptations Around You

Materials paper and pencil

Procedure Observe organisms around your school grounds or around your home. Describe any traits that seem to be adaptations to a particular environment or way of life. Also, look for and describe variations within groups of organisms that you see. Explain your reasoning for each inference you make about adaptations.

Analysis Which variations in the traits that you observed might increase or decrease the fitness of the organisms? Explain your reasoning.

FIGURE 15-13

Recent DNA evidence shows that despite the enormous variation among domestic dogs, all varieties descended from Asian wolves. By artificially selecting the dogs that will be the parents of the next generation, people have increased the rate of divergent evolution among domestic dogs.

ARTIFICIAL SELECTION

Darwin started his famous book with a chapter on **artificial selection.** This process occurs when a human breeder chooses individuals that will parent the next generation. For example, humans may choose to breed oat plants that yield more grain per stalk or greyhounds that run faster. Because of the immense differences among varieties of dogs, as shown in Figure 15-13, Darwin doubted that all domestic dog breeds arose from the same wild species. But in the 2000s, geneticists analyzed DNA from 654 dog breeds, including ancient dog remains. Their findings indicated that all breeds of dogs share DNA similarities with wolves in East Asia. These findings support the hypothesis that humans first selected domestic dogs from a wolf population about 15,000 years ago.

COEVOLUTION

It is important to keep in mind that evolution is ongoing and that in a given environment, many species may be evolving at once. Each species is part of the forces of natural selection that act upon the other species. When two or more species have evolved adaptations to each other's influence, the situation is called **coevolution.**

Through coevolution, some species have evolved strategies to avoid being eaten, while the animals that eat them have evolved strategies to keep eating them. Many flowering plants have evolved such that specific insects carry pollen to other plants. Some microbes have evolved to live within certain animals, while these animals have adapted to either benefit from or avoid the microbes.

Humans are also involved in many cases of coevolution. For example, humans have developed and used antibiotics, such as penicillin, to kill disease-causing bacteria. But as antibiotic use has increased, many populations of bacteria have evolved adaptations to resist the effects of some antibiotics. This kind of adaptation is called *resistance.* Similarly, the evolution of resistance to pesticides is observed among populations of insects in agricultural settings.

SECTION 3 REVIEW

1. Explain how the anole lizard species on Caribbean islands demonstrate both convergent and divergent evolution.
2. What are the key differences and similarities between natural selection and artificial selection?
3. Give examples of species that are likely to be coevolving. Describe how each species influences the evolution of the other species.

CRITICAL THINKING

4. **Inferring Meaning** What is the meaning of *radiation* as used in the term *adaptive radiation*?
5. **Constructing Models** Draw a phylogenetic tree to match each of the two proposed hypotheses for the evolution of the anole lizards.
6. **Analyzing Patterns** Propose a reason why some Caribbean islands lack lizard species.

CHAPTER HIGHLIGHTS

SECTION 1 History of Evolutionary Thought

- Evolution is the process of change in the inherited characteristics within populations over generations such that new types of organisms develop from preexisting types.
- Scientific understanding of evolution began to develop in the 17th and 18th centuries as geologists and naturalists compared geologic processes and living and fossil organisms around the world.
- Among geologists, Cuvier promoted the idea of catastrophism, and Lyell promoted uniformitarianism. Among naturalists, Lamarck proposed the inheritance of acquired characteristics as a mechanism for evolution.
- After making many observations and considering ideas of other scientists, both Darwin and Wallace proposed the theory of natural selection to explain evolution.
- Darwin wrote *On the Origin of Species,* in which he argued that descent with modification occurs, that all species descended from common ancestors, and that natural selection is the mechanism for evolution.
- Organisms in a population adapt to their environment as the proportion of individuals with genes for favorable traits increases. Those individuals that pass on more genes are considered to have greater fitness.

Vocabulary

evolution (p. 297)
strata (p. 298)
natural selection (p. 300)
adaptation (p. 300)
fitness (p. 301)

SECTION 2 Evidence of Evolution

- Evidence of evolution can be found by comparing several kinds of data, including the fossil record, biogeography, anatomy and development, and biological molecules. Evolutionary theories are supported when several kinds of evidence support similar conclusions.
- Geologic evidence supports theories about the age and development of Earth. The fossil record shows that the types and distribution of organisms on Earth have changed over time. Fossils of transitional species show evidence of descent with modification.
- Biogeography, the distribution of organisms, shows evidence of descent with modification.
- In organisms, analogous structures are similar in function but have different evolutionary origins. Homologous structures have a common evolutionary origin. A species with a vestigial structure probably shares ancestry with a species that has a functional form of the structure. Related species show similarities in embryological development.
- Similarity in the subunit sequences of biological molecules such as RNA, DNA, and proteins indicates a common evolutionary history.
- Modern scientists integrate Darwin's theory with other advances in biological knowledge. Theories and hypotheses about evolution continue to be proposed and investigated.

Vocabulary

fossil (p. 302)
superposition (p. 302)
relative age (p. 302)
absolute age (p. 303)
biogeography (p. 305)
homologous structure (p. 305)
analogous structure (p. 305)
vestigial structure (p. 306)
phylogeny (p. 307)

SECTION 3 Evolution in Action

- Ongoing examples of evolution among living organisms can be observed, recorded, and tested.
- In divergent evolution, related populations become less similar as they respond to different environments. Adaptive radiation is the divergent evolution of a single group of organisms in a new environment.
- In convergent evolution, organisms that are not closely related resemble each other because they have responded to similar environments.
- The great variety of dog breeds is an example of artificial selection.
- The increasing occurrence of antibiotic resistance among bacteria is an example of coevolution in progress.

Vocabulary

convergent evolution (p. 309)
divergent evolution (p. 309)
adaptive radiation (p. 309)
artificial selection (p. 310)
coevolution (p. 310)

Using Vocabulary

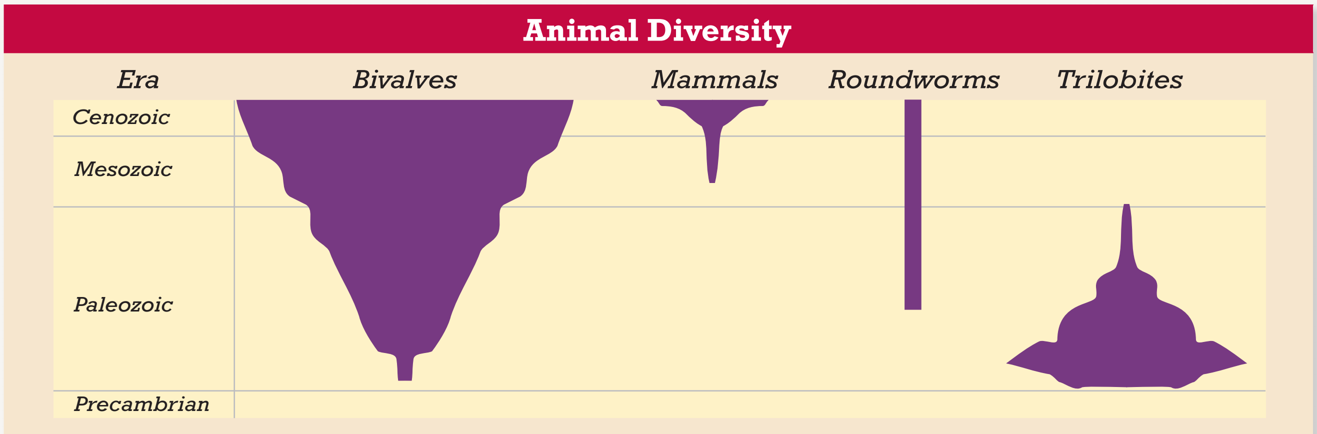
1. Use the following terms in the same sentence: *evolution, natural selection, adaptation,* and *fitness*.
2. For each pair of terms, explain how the meanings of the terms differ.
   a. *acquired trait* and *inherited trait*
   b. *homologous structure* and *analogous structure*
   c. *relative age* and *absolute age*
   d. *divergent evolution* and *convergent evolution*
   e. *artificial selection* and *natural selection*
3. **Word Roots and Origins** The word *radiation* is derived from the Latin *radius,* which means "rod" or "ray." Using this information, explain the meaning of *adaptive radiation*.

Understanding Key Concepts

4. **Define** the biological process of evolution.
5. **Contrast** Cuvier's catastrophism with Lyell's uniformitarianism.
6. **Describe** how the finch species of the Galápagos Islands illustrate descent with modification.
7. **List** the steps of reasoning that Darwin gave to explain the process of natural selection.
8. **Identify** several factors that could limit the growth of populations.
9. **Relate** the roles of adaptation and fitness in the theory of natural selection.
10. **State** several inferences about evolution that are supported by fossil evidence.
11. **Describe** evidence from biogeography that species evolve adaptations to their environments.
12. **Identify** an example of a vestigial structure.
13. **Explain** how biological molecules indicate relatedness between species.
14. **Summarize** the examples of convergent and divergent evolution seen in Caribbean lizards.
15. **Describe** an example of coevolution.
16. **Explain** why antibiotics are not consistently effective against infections of bacteria.
17. **CONCEPT MAPPING** Use the following terms to create a concept map: *struggle to survive, theory, inheritable variation, Darwin, overpopulation, natural selection,* and *successful reproduction*.

Critical Thinking

18. **Analyzing Concepts** Could a characteristic that is not controlled by heredity be subject to natural selection? Explain your answer.
19. **Making Predictions** Suppose that an island in the Pacific Ocean was just formed by a volcano. Describe a possible scenario for the kinds of species that could be found on this island over the next million years.
20. **Interpreting Graphics** The graph below shows the diversity among different groups of animals over time. Of the four eras listed, the Cenozoic era is the most recent. The changing width of the bar for each group reflects the changing number of known subgroups over geologic time. Use the graph to answer the following questions:
    a. Which group most recently evolved?
    b. Which group is or was the most diverse? the least diverse?
    c. Which group diversified rapidly soon after it first appeared?
    d. Which group(s) became extinct?



Standardized Test Preparation

DIRECTIONS: Choose the letter of the answer choice that best answers the question.

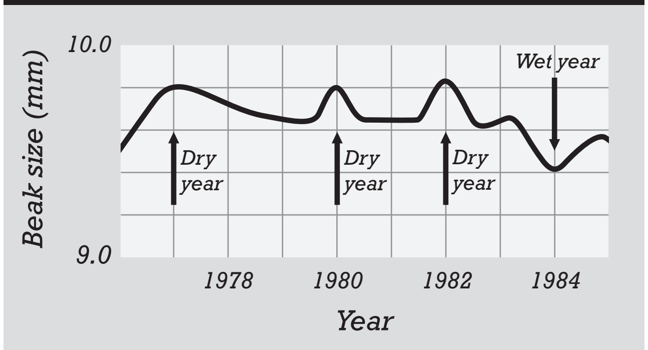
1. What is the term for the idea that geologic processes occurring now on Earth are much the same as those that occurred long ago?
A. catastrophism
B. uniformitarianism
C. adaptive radiation
D. convergent evolution

2. What is the term for the biological process by which the kinds of organisms on Earth change over time?
F. evolution
G. superposition
H. biogeography
J. uniformitarianism

3. When the internal structures of two species are very similar, what can be inferred about both species?
A. They share similar environments.
B. They evolved in similar environments.
C. They have similar external structures.
D. They evolved from a common ancestor.

INTERPRETING GRAPHICS: The graph below shows the variation in average beak size in a group of finches in the Galápagos Islands over time. These finches eat mostly seeds. Use the graph to answer the question that follows.

Average Beak Size in Galápagos Finches

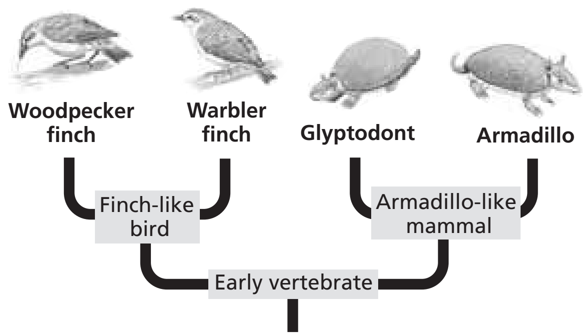


4. Beak size in these finches is correlated to the size of seeds they can eat. What can be inferred from the graph?
F. In wet years, the finches that survive are mostly those that can eat larger seeds.
G. In dry years, the finches that survive are mostly those that can eat larger seeds.
H. In all years, the finches that survive are mostly those that can eat larger seeds.
J. In all years, the finches that survive are mostly those that can eat smaller seeds.

DIRECTIONS: Complete the following analogy.

5. vestigial : functional :: vacated :
A. used
B. visceral
C. broken
D. occupied

INTERPRETING GRAPHICS: The diagram below shows possible evolutionary relationships between some organisms. Use the diagram to answer the question that follows.



6. What does the diagram imply about warbler finches and armadillos?
F. They are unrelated.
G. They are equally related to glyptodonts.
H. They share a common ancestor.
J. They did not evolve from older forms of life.

SHORT RESPONSE

The human body has a tailbone but no tail. It also has an organ called the appendix, which is attached to the intestines but does not serve a function in digestion.

How would an evolutionary biologist explain the presence of these structures in the human body?

EXTENDED RESPONSE

An example of an acquired characteristic is large leg muscles built up in an individual by frequent running. An example of an inherited characteristic is the maximum height to which an individual can grow.

Part A Explain the difference between inherited and acquired characteristics.

Part B Contrast two historical theories that explained evolution, based on either acquired characteristics or inherited characteristics.

Test TIP When answering questions based on graphs, look for answers that are supported by evidence from the graphs.

Modeling Selection

OBJECTIVES

- Simulate the generation of variation.
- Model the selection of favorable traits in new generations.

PROCESS SKILLS

- observing
- testing
- measuring

MATERIALS

- construction paper
- cellophane tape
- soda straws
- penny, or other coin
- six-sided die
- scissors
- meterstick or tape measure
- metric ruler

Background

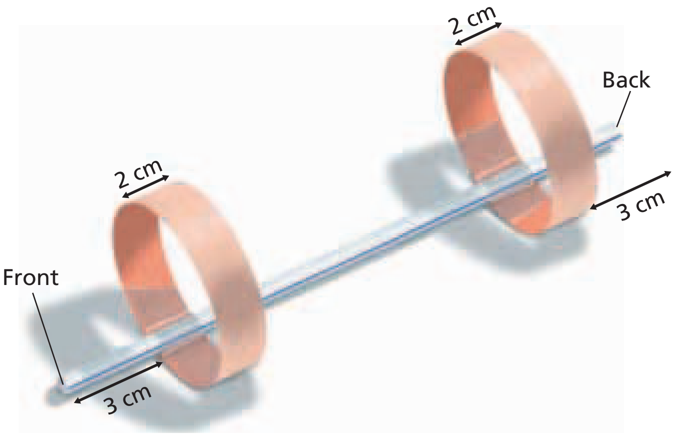
1. The fictitious Egyptian origami bird (*Avis papyrus*) lives in arid regions of North Africa. Only the birds that can fly the long distances between oases live long enough to breed successfully.
2. Successful evolution requires the generation of inheritable variations by mutation and then selection by the environment of the most-fit individuals.

PART A Parent Generation

1. Make a "parent bird." First, cut two strips of paper, 2 cm × 20 cm each. Make a loop with one strip of paper, letting the paper overlap by 1 cm, and tape the loop closed. Repeat for the other strip. Tape one loop 3 cm from each end of the straw, as shown in the figure. Mark the front end of the bird with a felt-tip marker. This "bird" will represent the parent generation.
2. In your lab report, prepare a data table like the one shown below.

DATA TABLE

Bird	Coin flip (H or T)	Die throw (1–6)	Anterior wing (cm)			Posterior wing (cm)			Average distance flown (m)
			Width	Circum.	Distance from front	Width	Circum.	Distance from back	
Parent	NA	NA	2	19	3	2	19	3	
Generation 1									
Chick 1									
Chick 2									
Chick 3									
Generation 2									
Chick 1									
Chick 2									
Chick 3									



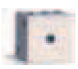
3. Test how far your parent bird can fly by releasing it with a gentle overhand pitch. Test the bird twice. Record the bird's average flight distance in your data table.

PART B First (F_1) Generation

4. Model the breeding of offspring. Each origami bird lays a clutch of three eggs. Assume that the first chick is a clone of the parent. Fill in the table with data for this chick.
5. Assume that the next two chicks have mutations. Follow steps A–C below to determine the effects of each mutation.

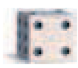
Step A Flip a coin to determine which part of the bird is affected by the mutation.
Heads = anterior (front)
Tails = posterior (back)

Step B Throw a die to determine how the mutation affects the wing.

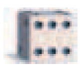

(1) = The wing position moves 1 cm toward the end of the straw.


(2) = The wing position moves 1 cm toward the middle of the straw.


(3) = The circumference of the wing increases 2 cm.


(4) = The circumference of the wing decreases by 2 cm.


(5) = The width of the wing increases by 1 cm.


(6) = The width of the wing decreases by 1 cm.

Step C A mutation is lethal if it results in a wing falling off or a wing with a circumference smaller than that of the straw. If you get a lethal mutation, disregard it, and breed another chick. Record the mutations and the dimensions of each offspring in your data table. The circumference of the wings can be calculated by measuring the length of the strips of paper used to form the wings and subtracting 1 cm for the overlap.

6. Test the birds. Release each bird with a gentle overhand pitch. It is important to release the birds as uniformly as possible. Test each bird at least twice.
7. The most successful bird is the one that flies the farthest. Record the flight distance of each offspring bird in your data table.

PART C Subsequent Generations

8. Assume that the most successful bird in the F_1 generation is the sole parent of the next (F_2) generation. Continue to breed, test, and record data for 8 more generations.
9.   Clean up your materials before leaving the lab.

Analysis and Conclusions

1. Did your selection process result in birds that fly better?
2. Describe two aspects of this investigation that model evolution of biological organisms.
3. Your most successful bird may have a different lineage from the most successful bird of your neighboring groups. Compare your winning bird with those of your neighbors. How does it differ?
4. What might happen to your last bird if the environmental conditions change?
5. How might this lab help explain the observations Darwin made about finches on the Galápagos Islands?

Further Inquiry

A flock of origami birds is blown off the mainland and onto a very small island. These birds face little danger on the ground, but they experience significant risk when flying because they can be blown off the island. Birds that cannot fly at all are most likely to survive and reproduce. Continue the experiment for several generations, selecting birds that can't fly.