CHAPTER 13

Evolution: Evidence of Change



In the past, animals that resemble your worst nightmares walked the Earth. Some were peaceful creatures content to nibble soft grasses. Others were fierce carnivores, looking to make a meal of weaker, or more gentle, animals.

A grazing animal lifts its head; its three horns form a peculiar silhouette against the evening sky. Another type of grazer scratches itself with the forked horn on the end of its nose. Suddenly, a pack of sleek, bearlike predators bursts from the underbrush. The herds of grazers erupt into a flurry of moving hooves and horns. The predators pursue, single out their quarry, and close in. Their prey kicks and slashes with its triple horns, but to no avail. It is over in moments. The pack begins to feed.

Even though this scene is imaginary, the strange, remarkable animals were not. They lived some 7 million years ago in what is now Texas. How do we know of these ancient animals? Where did they come from? And why are they no longer alive? In this chapter you will learn about methods scientists use to reconstruct a picture of ancient life.

CHAPTER OUTLINE

13–1 Evolution and Life's Diversity
- Darwin's Dilemma
- The Diversity of Life
- Fitness: To Survive and Reproduce

13–2 The Age of the Earth
- Evidence in Stone
- The Geologic Time Scale: A Clock in the Rocks
- Radioactive Dating

13–3 The Fossil Record
- How Fossils Form
- Fossil Evidence: Problems in Assembling the Puzzle
- What the Fossil Record Tells Us

13–4 Evidence from Living Organisms
- Similarities in Early Development
- Similarities in Body Structure
- Similarities in Chemical Compounds
- What Homologies Tell Us

13–1 Evolution and Life's Diversity

Section Objectives

- Relate Darwin's observations to his explanation of evolution.
- Explain how fitness is related to adaptation.

The idea that life on Earth has changed over time, or evolved, is very old. But just believing that change occurs is not enough to make evolution a science. In science, you will recall, observation, questioning, and constant testing of hypotheses must replace belief. Scientists have accumulated considerable evidence to show that organisms alive today have been produced by a long process of change over time. The process by which modern organisms have descended from ancient organisms is called **evolution**.

One man, Charles Darwin, contributed more to our understanding of the process of evolution than anyone else. For this reason, we will begin this chapter by looking at the natural phenomena that convinced Darwin that evolution occurred.

Darwin's Dilemma

Two days after Christmas in 1831, a young Englishman named Charles Robert Darwin (1809–1882) set sail on HMS *Beagle* for a cruise around the world. Although no one knew it then, this voyage would revolutionize scientific thought.

Darwin was well educated and had a strong interest in natural history. He also had keen powers of observation and an

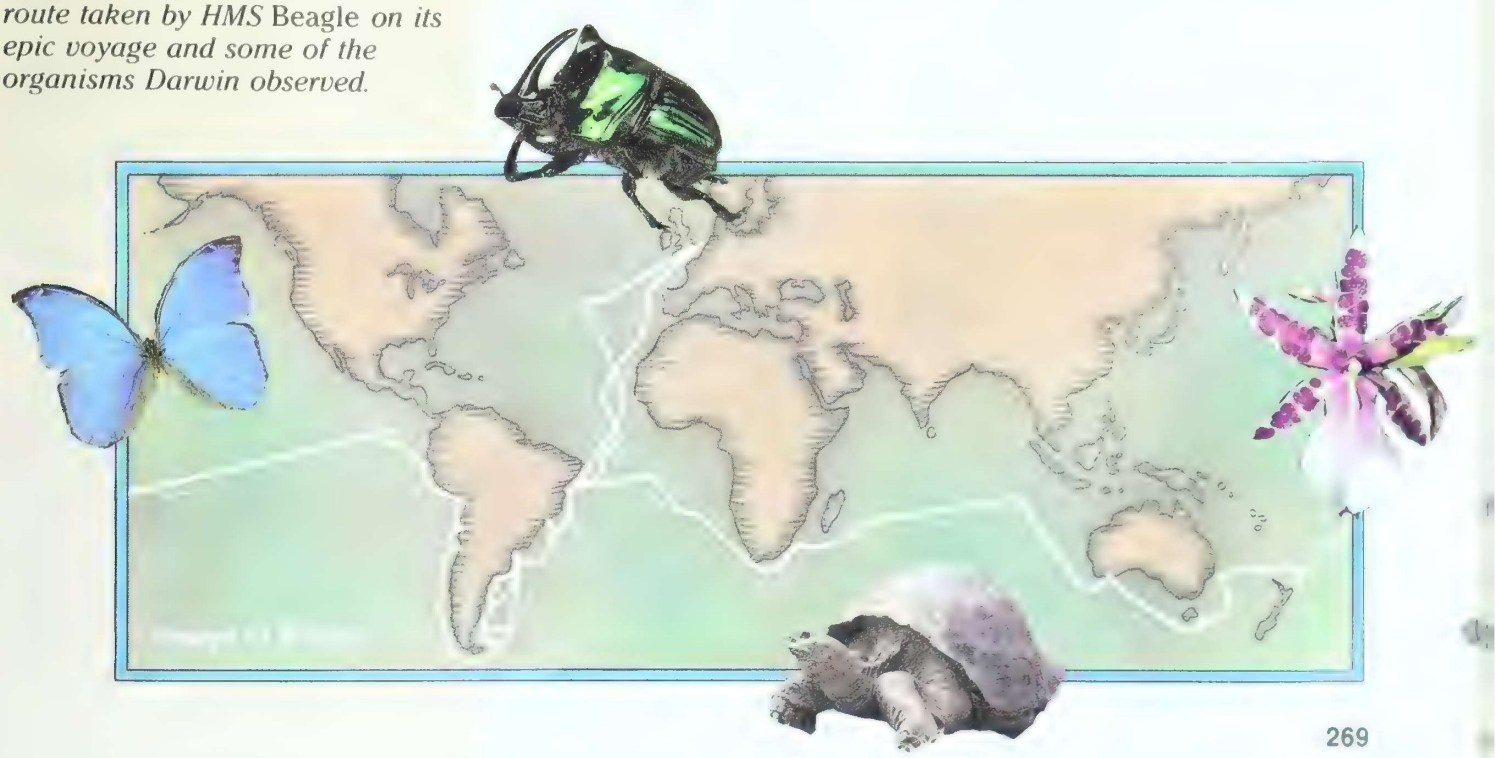


Figure 13–1 *This map shows the route taken by HMS* Beagle *on its epic voyage and some of the organisms Darwin observed.*



Figure 13–2 *Roxie Laybourne is one of the world's experts on birds. These file drawers at the Smithsonian Institution are only a small part of the museum's collection of specimens. The specimens are used to compare birds collected in the wild with named species.*

Figure 13–3 *Reproductive behaviors can contribute to a species' survival. A female cuckoo laid her egg and abandoned it in this bird's nest. After the cuckoo hatched, it killed its foster brothers and sisters by pushing them out of the nest. Now alone and constantly hungry, it demands all the attention of its foster parents.*



analytical mind. Over five years' time, the *Beagle* took Darwin to several continents and many remote islands. Darwin went ashore whenever the ship anchored. At each new place, he collected animal and plant specimens that he added to an ever-growing collection. At sea, between bouts of seasickness, Darwin examined his specimens and filled notebooks with his thoughts and observations. He also spent many hours reading the most current scientific books.

Throughout the voyage, Darwin witnessed countless wonders of nature for which his bright young mind demanded an explanation. Those same mysteries of life will spark your curiosity, too, if you stop to think about them.

The Diversity of Life

Our planet houses living organisms of every imaginable shape, size, and habit. This variety of living things is called the diversity of life. Only a tiny fraction of these organisms lived in Darwin's England—or in your hometown. But if you travel to or read about different countries, you will discover, as Darwin did, that the diversity of life is staggering.

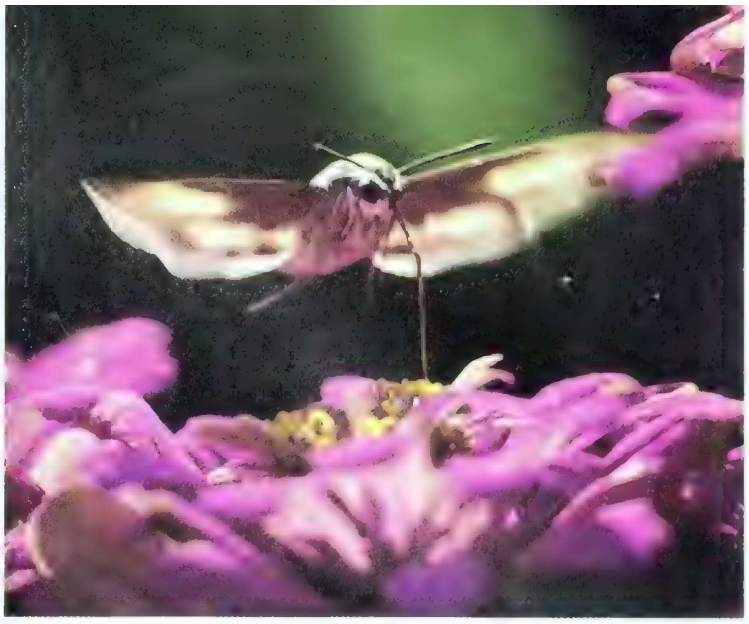
When Darwin visited tropical South America, countless species of plants, mammals, birds, and insects passed before his eyes. In just one day in a Brazilian forest, Darwin collected 68 different species of beetles! This discovery amazed Darwin because he was not specifically looking for beetles. Darwin realized that the number of living species was enormous. Scientists now estimate that there are as many as 10 million species of organisms alive today.

Darwin soon realized that the diversity of life he observed was only one part of a much larger puzzle. For as he traveled, he found evidence that even more organisms had vanished from the Earth. Today, researchers estimate that of all the species that have at some time lived on Earth, more than 99.9 percent are now extinct! If that estimate is correct, several hundred million species have come and gone during Earth's long history. Where have all the marchers in this endless parade of life come from? Why have so many of them disappeared over time? These are two of the questions Darwin tried to answer.

Fitness: To Survive and Reproduce

Darwin was also impressed by the many different ways in which organisms survive and produce offspring. He noted that most animals and plants seem remarkably well designed to do the things they do. **The combination of physical traits and behaviors that helps organisms survive and reproduce in their environment Darwin called fitness.** How did all of these organisms develop the structures that give them their **fitness**? And why is there such an extraordinary variety of techniques for survival?





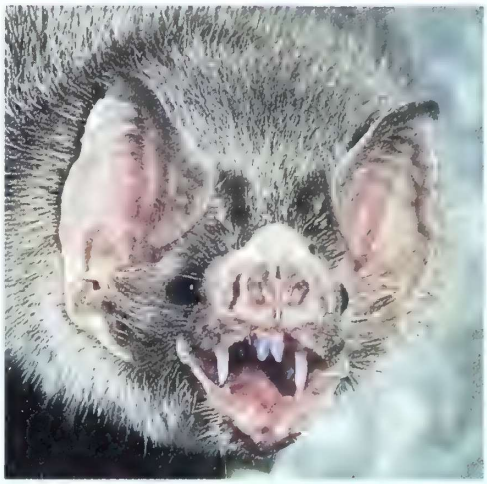


Figure 13–4 *The giraffe dines on leaves of trees out of the reach of even the tallest zebra's head. The sphinx moth uses a long feeding tube to reach the nectar in a flower. The vampire bat punctures the skin of another animal with its razor-sharp teeth and then greedily laps up blood from the wound.*

These are very difficult questions, so it is not surprising that Darwin wasn't able to provide answers overnight. It was not until 1859, nearly 30 years after he began his voyage on the *Beagle*, that Darwin published his explanations in a book called *The Origin of Species by Means of Natural Selection.* This book changed the way people think about the living world.

In *The Origin of Species,* Darwin maintained that modern organisms have been produced through evolution. Evolution is a long, slow process of change in species over time. Darwin argued that just as each new organism comes from preexisting organisms, each species has descended from other species over time. If you look back far enough in time, you will see that all species have shared, or common, ancestors. Since species have descended from common ancestors, Darwin called this principle **common descent.**

Darwin also argued that fitness arises through a process called **adaptation**. Successful adaptations enable organisms to become better suited to their environment, better able to survive and reproduce. Darwin also used the word adaptation to describe any inherited characteristic that increases an animal's or plant's fitness for survival. Thus, the long neck and legs of a giraffe are adaptations that permit giraffes to feed on the leaves of trees. With these adaptations, giraffes can eat leaves too high for most grazing animals to eat and thus are better able to survive and reproduce, passing their genes on to their young.

13–1 SECTION REVIEW

1. How did Darwin's voyage on the *Beagle* influence his thoughts about life on Earth?
2. Define diversity of life. How is the diversity of life related to evolution?
3. How is adaptation related to fitness?

Section Objectives

- Discuss how scientists determined that the Earth was much more than a few thousand years old.
- Distinguish between relative and absolute dating.
- Explain how radioactive elements in the Earth's rocks act as a natural clock.

13–2 The Age of the Earth

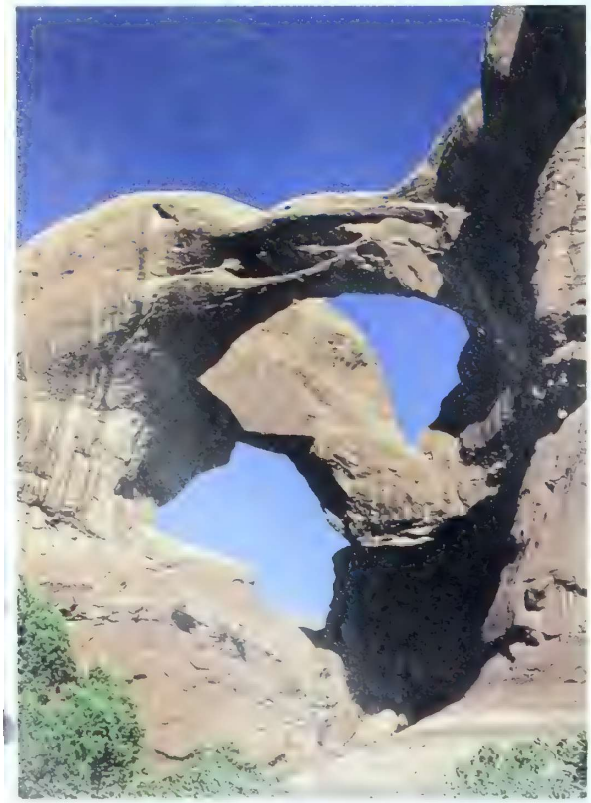
Darwin and other scientists have accumulated a vast amount of evidence that proves that evolution has occurred. Some of the evidence certifies that planet Earth is more than 4 billion years old. Other evidence makes it clear that both Earth and the life on it have changed dramatically over time. Still other evidence supports the principle of common descent and emphasizes the importance of adaptation to the environment. Much of the evidence is found in the rocks of the Earth itself. And it is this evidence that we will now examine.

Evidence in Stone

In the past, many people believed the Earth was relatively young—only a few thousand years old. They also believed that the Earth had remained unchanged over this time. Rocks and major geological features, they thought, had been produced suddenly by catastrophic events that humans rarely (if ever) witnessed and, even if they did, could not understand. But other people have offered a different explanation, an explanation based on evidence stored in the rocks of the Earth itself.

In the eighteenth and nineteenth centuries, scientists began to examine the Earth in great detail. And they offered the hypothesis that the Earth was indeed very old and had changed slowly over a long period of time by natural forces like weather. It was the work of these scientists that profoundly influenced Darwin's thoughts.

Figure 13–5 *These delicate stone arches were formed by the relentless forces of nature. Tiny particles of windborne sand constantly strike the rock face and wear it away.*



Evidence that supported the idea that the Earth was very old first came from geologist James Hutton in 1788. Hutton proposed that rocks, mountains, and valleys had been changed gradually by rain, heat, cold, the activity of volcanoes, and other natural forces. Because most of these processes operate slowly, Hutton argued, the Earth had to be much more than a few thousand years old.

In 1830, just before Darwin began his voyage, the geologist Charles Lyell carried these arguments further. Lyell agreed that the Earth had changed slowly and gradually over time. Lyell also argued that scientists must always explain past events in terms of events and processes they could observe themselves. That, Lyell insisted, was the only way the scientific method could work. Lyell's work, as you will discover in the next chapter, was an important influence on Darwin's thinking.

The evidence proved to Hutton and Lyell that the Earth was very old. Further evidence suggested to them that the land is constantly moving and shifting: Forces beneath the Earth's surface twist and bend some rock layers, bury others, and even push up some parts of the sea floor into mountain ranges. For these scientists, the Earth had indeed changed over the long period of its existence.

At the same time, other scientists found evidence that life on Earth had also changed over time. While examining the Earth's rocks, geologists—professional and amateur—began to

make some startling discoveries. In the stones they examined they found **fossils**. Fossils are the preserved remains of ancient organisms. Some of these fossils resembled organisms still alive. Others did not. These fossils raised many questions that would remain unanswered for some time. Even though they could not explain the meaning of all the fossils they found, these early geologists made a great contribution. They created an interest in and a sense of wonder about the Earth and the life that lived upon it.

The Geologic Time Scale: A Clock in the Rocks

Earth's story is not complete without a "clock" to tell us when things happened. Both biologists and geologists date the



Figure 13–6 *This illustration represents changes that occurred in the evolution of the camel. Provided that the order of layers has not been disturbed, the "camels" in the lower layers are older than those in the layers above.*

Earth's past with the help of a record in the rocks called the **geologic time scale**.

More than 100 years ago, researchers noticed that certain layers of rock often appeared in the same vertical order wherever they were found. It is the position of the layers relative to each other that determines their age. This knowledge helped geologists assemble a column of rocks in which each layer represented a different period of time. Geologists knew that the lower rock layers were deposited before the upper layers. Thus, lower layers are older than upper layers, provided that the layers have not been disturbed since they were formed. In addition, fossils found in lower layers are older than fossils found in the layers above them. **Relative dating** is a technique that is used by scientists to determine the age of fossils relative to other fossils in different layers of rock. However, because geologists did not know the amount of time it took for the different layers to form, they could not determine the actual age of the fossils.

Radioactive Dating

Near the middle of this century, our growing understanding of radioactivity provided scientists with a tool that could determine the actual age of rocks. Rocks are made up of many different elements. In certain rocks, some of these elements are radioactive. **Radioactive elements** decay, or break down, into nonradioactive elements at a very steady rate. Scientists measure this rate of radioactive decay in a unit called a **half-life**. A half-life is the length of time required for half the radioactive atoms in a sample to decay. This means that after one half-life, one half of the radioactive atoms in a sample have decayed. At the end of the next half-life, one half of the remaining radioactive atoms have decayed. In other words, one quarter of the original number of radioactive atoms remain after the second half-life reduces the remaining radioactive atoms by half.

Decay of a Radioactive Element with a Half-Life of 1 Million Years in a Fossil

Time		Amount of Radioactive Element	Amount of Decay Element
4 million years ago, when fossil formed		1 kg (1)	0 kg (0)
3 million years ago		0.5 kg ($\frac{1}{2}$)	0.5 kg ($\frac{1}{2}$)
2 million years ago		0.25 kg ($\frac{1}{4}$)	0.75 kg ($\frac{3}{4}$)
1 million years ago		0.125 kg ($\frac{1}{8}$)	0.875 kg ($\frac{7}{8}$)
Present		0.0625 kg ($\frac{1}{16}$)	0.9375 kg ($\frac{15}{16}$)

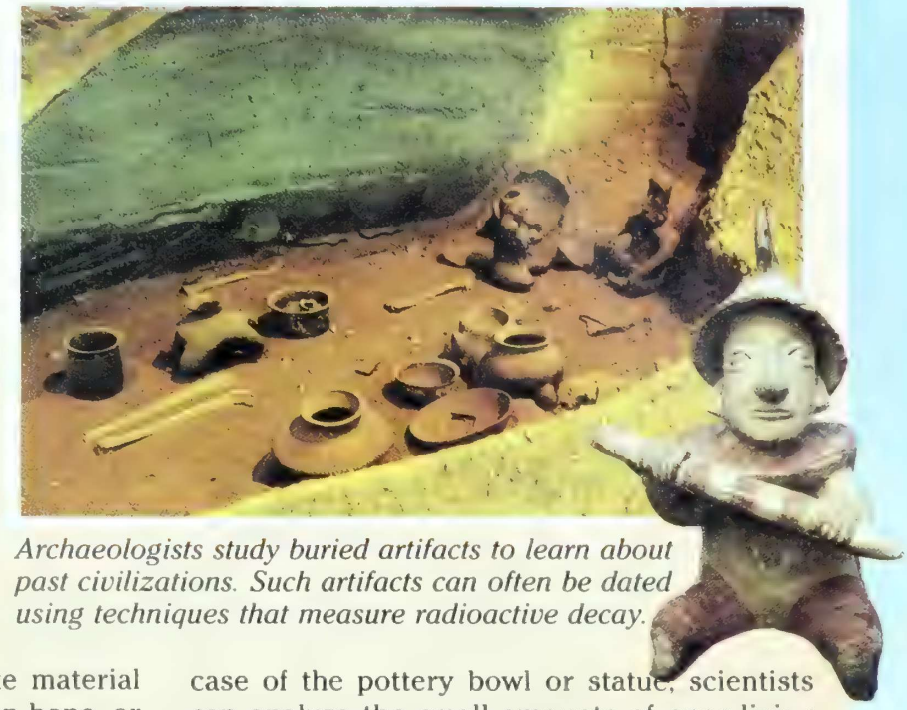
= Radioactive element = Decay element

Figure 13–7 Scientists use the natural decay of radioactive elements to date certain fossils. It is the constancy of an element's half-life that makes radioactive dating accurate.

Dating with Carbon-14

Many collectors buy art and objects made by ancient people. In some cases, clever forgeries of ancient material have been made by individuals eager to cheat unsuspecting collectors or museums. But scientists have a way to date these artifacts and protect people from making expensive mistakes.

A common radioactive element, carbon-14, is often used to date fossils that are younger than about 60,000 years old. Carbon-14 has a half-life of about 5770 years. After about 60,000 years, or approximately ten half-lives, there is too little carbon-14 left to measure with accuracy.



Archaeologists study buried artifacts to learn about past civilizations. Such artifacts can often be dated using techniques that measure radioactive decay.

Scientists use carbon-14 to date material that was once alive, such as a human bone, or to date an object that contains some once-living material.

For example, a pottery bowl or statue often contains a bit of straw that was used to hold the clay together when the bowl or statue was made. The straw contains enough carbon-14 to make radioactive dating possible.

Because it is present in the atmosphere, all living things take in carbon-14 while they are alive. The carbon-14 present in the body decays into nitrogen-14 at a fixed rate. In the case of the pottery bowl or statue, scientists can analyze the small amounts of once-living material, like straw, that are contained in the clay. They can then compute the ratio of carbon-14 to nitrogen-14 in the straw and determine how long ago the straw died. They assume, of course, that the straw was alive until shortly before it was used in the construction of the pottery.

Thus carbon-14 can be used to catch thieves and forgers of ancient art. Radioactive materials can make a pottery bowl or statue confess its true age.

Each radioactive element has a different half-life. For example, potassium-40 has a half-life of 1.3 billion years. During that time, one half of the potassium-40 atoms in a rock sample decay to argon-40. Uranium-238 has a half-life of 4.5 billion years. During that time, one half of the uranium-238 atoms in a rock sample decay into lead-206. Geologists can measure the amounts of uranium-238 and lead-206 present in a rock sample. By determining how much lead has been produced by decay since the rock was formed and by knowing the half-life of uranium, geologists can calculate the rock sample's age.

Half-Lives of Radioactive Elements	
Element	**Half-life**
Rubidium-87	50 billion years
Thorium-232	13.9 billion years
Uranium-238	4.5 billion years
Potassium-40	1.3 billion years
Uranium-235	713 million years
Carbon-14	5770 years

Figure 13–8 *As you can see from this chart, the half-lives of many radioactive elements are much longer than a human's whole life.*

Uranium-238 and potassium-40 are used to date rocks millions of years old. The different radioactive elements, each with its own half-life, thus provide a useful series of natural clocks that help date the rocks in which they are found.

Using radioactive dating, researchers can calculate the actual age of a rock sample. Because radioactive dating is so accurate, scientists call this method **absolute dating**. By using techniques of absolute dating, scientists have compiled an accurate history of the Earth. With a reliable radioactive clock, scientists have divided the Earth's history into units called **eras**. Eras are divided into **periods**, which in turn are divided into **epochs**. See Figure 13–9.

Through radioactive dating and the examination of rates of geological processes such as the breaking down of rocks by weather and other natural forces, scientists have determined that the Earth is about 4 1/2 billion years old.

13–2 SECTION REVIEW

1. Compare relative and absolute dating.
2. How might relative dating provide inaccurate data?

Figure 13-9 **GEOLOGIC HISTORY OF THE EARTH**

Era	Period	Epoch	End Date (millions of years ago)	Notes
Cenozoic	Quaternary	Recent		Humans are the dominant form of life; civilization begins and spreads
		Pleistocene	0.01	"The Ice Age"; modern humans present; mammoths and other animals become extinct
	Tertiary	Pliocene	2.5	Fossils of ancient humans near end of epoch; many birds, mammals, and sea life similar to modern types; climate cools
		Miocene	5	Many grazing animals; flowering plants and trees resemble modern types
		Oligocene	25	Fossils of primitive apes; elephants, camels, and horses develop; climate generally mild
		Eocene	38	Fossils of "dawn horse" (*Hyracotherium*); grasslands and forests present; many small mammals; larger mammals such as whales, rhinoceroses, and monkeys begin to develop

Era	Period	Epoch	End Date (millions of years ago)	Notes
Cenozoic	Tertiary	Paleocene	55	Beginning of "Age of Mammals."; flowering plants and small mammals abundant; many different climates exist
Mesozoic	Cretaceous		65	First flowering plants; placental mammals develop; dinosaurs die out, as do many marine animals, at end of period
	Jurassic		135	The Rocky Mountains rise; first birds; palms and cone-bearing trees dominant; largest dinosaurs thrive; primitive mammals develop
	Triassic		195	"Age of Reptiles" begins; first dinosaurs; first mammals; corals, insects, and fishes resemble modern types
Paleozoic	Permian		245	First cone-bearing plants; ferns, fishes, amphibians, and reptiles flourish; many marine invertebrates, including trilobites, die out
	Carboniferous		285	Ice covers large areas of the Earth; swamps cover lowlands; first mosses; great coal-forming forests form; seed ferns grow; first reptiles and winged insects appear
	Devonian		345	First forests grow in swampy areas; fishes flourish; first amphibians, sharks, and insects develop
	Silurian		400	"Age of Fishes" begins; coral reefs form; jawed fishes develop; first land plants appear; first air-breathing animals, including land arthropods
	Ordovician		430	First fishes (jawless) appear; invertebrates flourish in the sea
	Cambrian		500	"Age of Invertebrates" begins; trilobites, brachiopods, sponges, and other marine invertebrates are present
Precambrian			580	Earth's history begins; first life forms in the sea; first prokaryotes (bacteria) appear; as time passes, first eukaryotes appear

Section Objectives

- Describe how sedimentary rocks are formed.
- Explain how fossils provide evidence of evolution.
- Discuss why there may be problems in interpreting fossil evidence.

13–3 The Fossil Record

Since the early nineteenth century, biologists have learned about animals and plants that lived long ago by examining preserved traces of those organisms, or fossils. As you can see in Figure 13–10, there are many different kinds of fossils. A fossil can be as large and complete as an entire perfectly preserved animal or plant, or it might be as small and incomplete as a tiny fragment of a jawbone or leaf. There are fossil footprints, fossil eggs, and even fossilized animal droppings. Some of the fossils Darwin found in South America represented animals so strange that they resemble creatures from science fiction films more than they do any plant or animal alive today. How did these organisms leave their remains in stone? How do fossil remains help explain the history of life on Earth?

How Fossils Form

Fossils have been formed in a variety of ways, all of which depend a great deal on chance. In cold places, animals sometimes fell into crevasses in ice or became trapped in snow fields. Insects and other small animals were occasionally trapped in the sticky tree sap that eventually hardened into amber. Still other fossils were formed when animals became mired in peat bogs, certain kinds of quicksand, or tar pits. In all these cases, the material that surrounded the dead animal helped to protect it from decay and acted to preserve it as evidence of past life.

Most fossils are found in **sedimentary rock**. Sedimentary rocks are formed when exposure to rain, heat, and cold breaks down existing rocks into small particles of sand, silt, and clay.



Figure 13–10 *This hatchling dinosaur did not live to become an adult, but its bones and even the delicate shell of its egg remain. The trilobite remains illustrate two kinds of fossils, a cast (center) and a mold (right).*

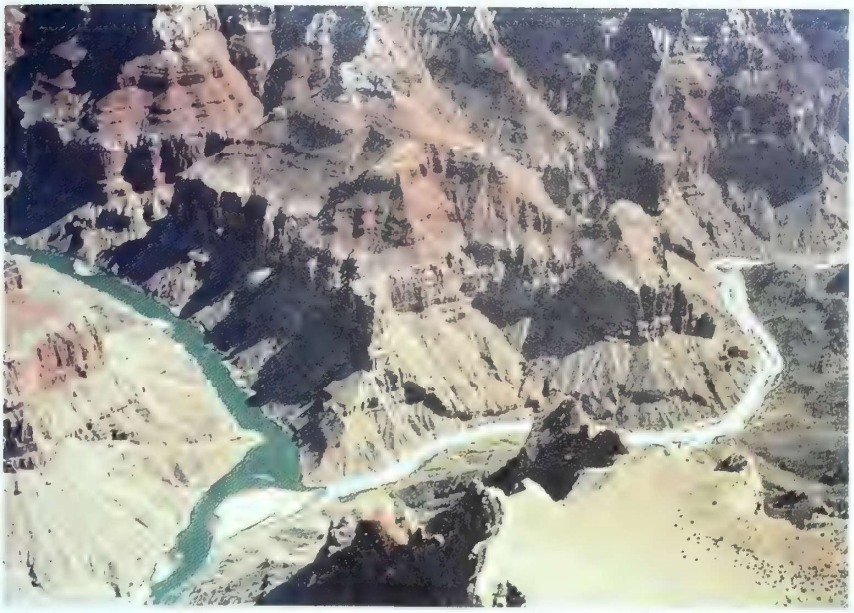
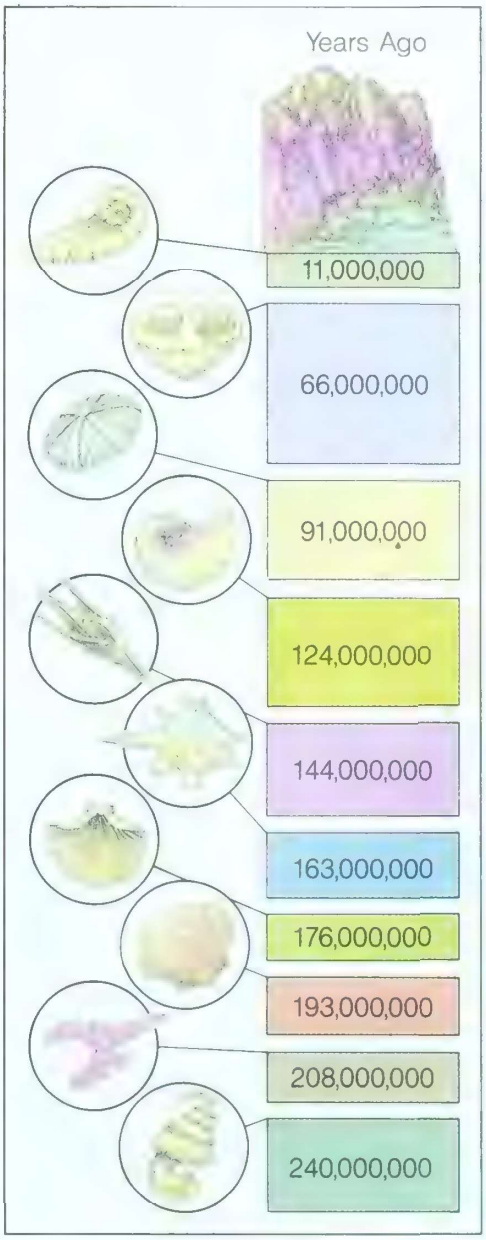


Figure 13–11 *The Colorado River, flowing along the bottom of the Grand Canyon, has cut through layer upon layer of rock over millions of years, exposing fossils long buried in sedimentary rock.*

Figure 13–12 *Fossils are usually found in sedimentary rocks. Because lower sedimentary rock layers are older than upper rock layers, scientists can determine the sequence of changes in life forms on the Earth.*



These particles are carried by streams and rivers into lakes or seas. Because the particles are heavier than water, they eventually settle to the bottom of the lake or sea. Here they build up in layer upon layer of sediments. Dead organisms, carried in the water, also eventually fall to the bottom. The organisms can become embedded in the sediment layers. As sediments pile up, pressure on the lower layers compresses the sediments and slowly turns them into rock, which thus preserves the remains of the dead organisms.

In some cases the small particles of rock that buried plant or animal remains preserved the organism's soft parts. In other cases, the hard parts of plants or animals were preserved when wood, shells, or bones were replaced with long-lasting mineral compounds. These fossils are petrified, or turned to rock.

Fossil Evidence: Problems in Assembling the Puzzle

You might think of fossils as pieces of a jigsaw puzzle. All the pieces, assembled correctly, would provide a complete picture of the history of life on Earth. But we do not have all the pieces, and we probably never will.

The chancy process by which organisms are fossilized means that the fossil record is not as complete as we would like it to be. For every organism that leaves a proper fossil, many die and vanish without leaving a trace. Because sedimentary rocks form only in certain bodies of water, organisms that live in mountains and deserts may never become part of the fossil record.

Finding fossils embedded in tons of rock is difficult, if not impossible. However, the natural forces that help make sedimentary rock may reveal hidden fossils. Rocks that contain

fossils may be exposed by weather. Bit by bit, the upper, younger layers are worn away by wind and rain, and the older layers beneath are exposed. The Grand Canyon is an example of a place where many layers of rock have been exposed—in this case, by the moving water of the Colorado River. When a fossil is exposed, a fortunate (and observant) scientist may happen along at the right time and remove it for study.

The quality of fossil preservation also varies. Some fossils are preserved so perfectly that we can see the microscopic structure of tiny bones and feathers. Other fossils are not preserved as well and so raise fascinating questions about their meaning and importance. Often scientists must reconstruct an extinct species from a few fossil bits and pieces of bone, leaves, or stems. Fossil reconstruction requires a thorough knowledge of the anatomy of living animals and plants as well as a great amount of skill.

Dating fossils can also present difficulties. The long half-lives of some radioactive elements, such as uranium, make the elements useless for dating fossils younger than 100,000 years. In such cases, scientists must use radioactive elements with shorter half-lives to date the fossils. Carbon-14, with a half-life of 5770 years, is one radioactive element used to date "young" fossils. While they are alive, organisms take up radioactive carbon-14 from their environment along with nonradioactive carbon-12 and carbon-13. Carbon-14 decays to form nitrogen-14. By comparing the proportions of carbon-14 and nitrogen-14 within a fossil, researchers can date the relatively young bones of early humans. Because of its short half-life, however, carbon-14 is not useful in dating fossils more than about 60,000 years old.

What the Fossil Record Tells Us

Scientists who study fossils are called **paleontologists** (pay-lee-uhn-TAHL-uh-jihsts). Over the years, paleontologists



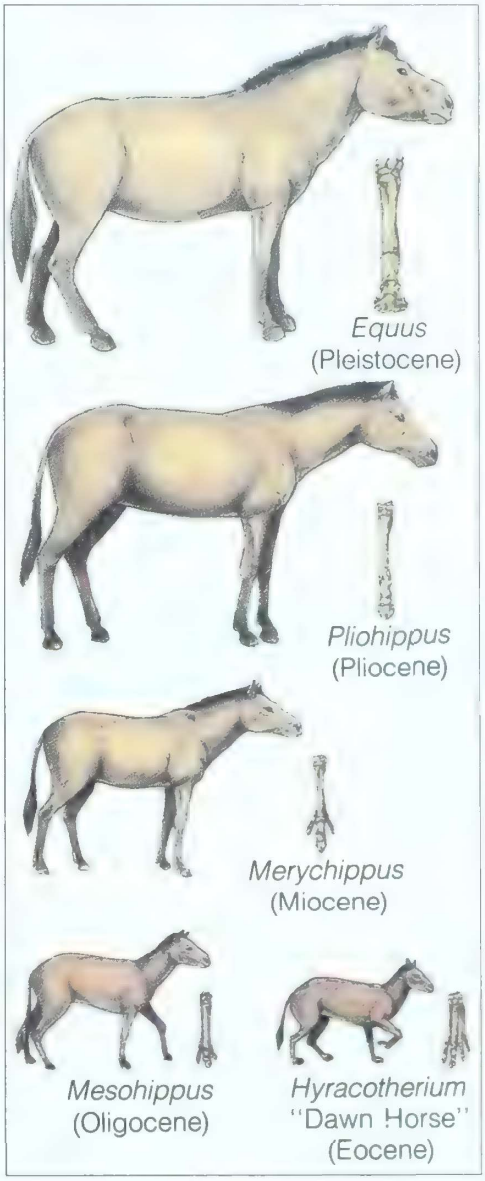


Figure 13–13 *Amber forms when sap flowing from a wound in the bark of a tree fossilizes. If the sticky sap traps an unsuspecting animal, as it did in the case of this tiny lizard, the animal's remains are preserved (left). Notice the minute details of the lizard's skin. Fossils can also provide evidence of the unseen world, such as these microfossils of bacteria preserved in gunflint chert (right). These tiny fossils have been magnified 24,000 times.*



Figure 13–14 *Approximately 310 million years ago, places on Earth looked like this. At that time the dragonfly had a wingspan of about one meter. Compare this to a modern dragonfly that flits delicately above the surface of a pond.*

Figure 13–15 *The first horse was actually quite small, about the size of a small dog. This illustration shows the first horse, as well as several of the intermediate ancestors of today's horse.*



have collected millions of fossils to make up the **fossil record**. The fossil record represents the preserved collective history of the Earth's organisms. Although incomplete, the fossil record has long inspired scientists. As the naturalist Loren Eisley once wrote, " . . . every bone that one holds in one's hands is a fallen kingdom, a veritable ruined world, a unique object that will never return through time."

Our picture puzzle of ancient life has many missing pieces. But in spite of the missing pieces, paleontologists can offer a relatively clear picture of the evolution of many organisms. One example is the series of fossils that shows the development of the modern horse over 50 million years. You can see from Figure 13–15 that the "dawn horse" resembled a modern horse in only the most superficial ways. The evolutionary changes in the horse have been remarkable and quite dramatic.

The fossil record also tells of major changes that occurred in Earth's climate and geography. Fossil shark teeth have been found in Arizona, indicating that the deserts of the American Southwest were once covered by ancient seas. Giant fossil ferns found in Canada show that North America once had a much warmer, tropical climate. Every period, every epoch in Earth's history had a different climate and contained different kinds of organisms that were adapted to it.

But species do not last forever. As Earth's environments changed over time, many species died out. In the very spot where you now sit and read this book, giant dragonflies with wings that measured almost a meter across may have flitted over swamps filled with giant ferns. Dinosaurs appeared, thrived for a time, and eventually disappeared into Earth's fossil record. The huge fossil skeletons they left behind, when reconstructed, still have the power to amuse and amaze us. **The fossil record shows that change followed change on Earth.**

PROBLEM SOLVING IN BIOLOGY

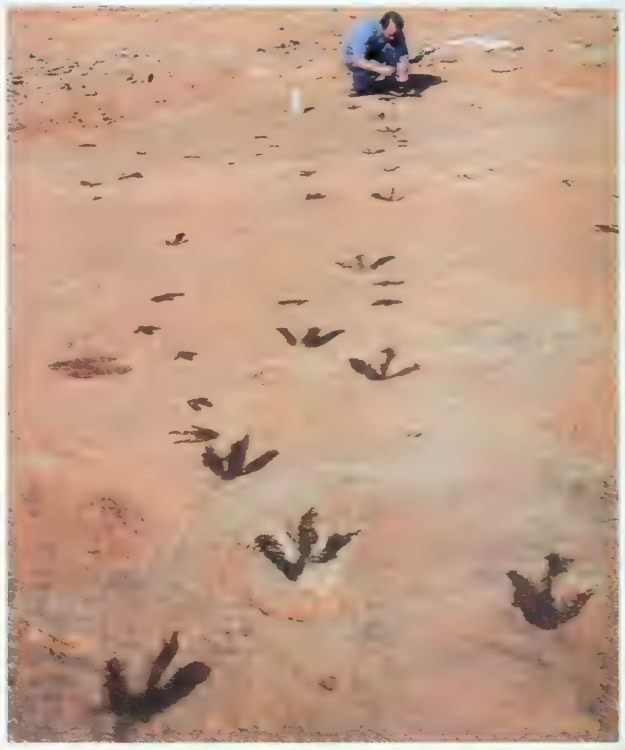
RADIOACTIVE DATING

You are a famous paleontologist and an expert in radioactive-dating techniques. One day, two visitors to your laboratory present you with two different fossils. One fossil is a dinosaur footprint, the other a human jawbone. Both were found at the bottom of a deep valley cut by a stream through cliffs of sedimentary rock. Your guests are very excited. Because they found these fossils next to each other near the stream bed, they feel they have found conclusive evidence that humans and dinosaurs lived at the same time. You are asked to date the samples to confirm their claims.

You first test the human jawbone. You determine that it now contains 1/16 the amount of carbon-14 it contained when alive. How old is the jawbone?

You next examine the fossil footprint. You discover that the fresh mud that the dinosaur stepped in had just been covered with a thin layer of volcanic ash. You study the amount of potassium-40 and argon-40 in the ash. The ratio shows that 1/10 of one potassium-40 half-life has passed since the footprint was made. How old is the footprint?

Were your visitors' conclusions about these fossils' ages correct? If they were not, how could you explain the fact that they were found together at the bottom of the valley? Refer to Figures 13–7 and 13–8 and pages 274 and 276 for helpful information.



13–3 SECTION REVIEW

1. Describe how sedimentary rocks are formed.
2. What is a fossil? How are fossils formed?
3. How is radioactive dating used to determine the age of fossils?
4. What kind of changes are reflected in the fossil record?
5. Explain why the fossil record is incomplete.

13–4 Evidence from Living Organisms

Section Objectives

- Describe how similarities in embryos support the concept of common descent.
- Explain how homologous and vestigial structures indicate that evolution has occurred.
- Discuss how biochemical similarities are evidence of evolution.

Fossils of extinct organisms are not the only evidence that shows the ongoing process of evolution. All living organisms carry within their bodies traces of the history that links them to their ancestors.

Similarities in Early Development

In the late nineteenth century, scientists noticed that the **embryos** of many different animals looked so similar that it was difficult to tell them apart. Embryos are organisms at early stages of development. Today, no scientist would say that a human embryo is identical to a fish or a bird embryo. However, as you can see in Figure 13–16, all of these embryos are similar in appearance during early stages of development. But why are they so similar? And what do these similarities tell us?

Similarities in early development indicate that similar genes are at work. All genes in an organism are not active at the same time. But those that are active during the early development of fish, birds, humans, and related animals are the shared heritage from a common ancestor. The common ancestor of these different animals had a particular sequence of genes that controlled its early development. And this sequence of genes has been passed on to the species that descended from it.

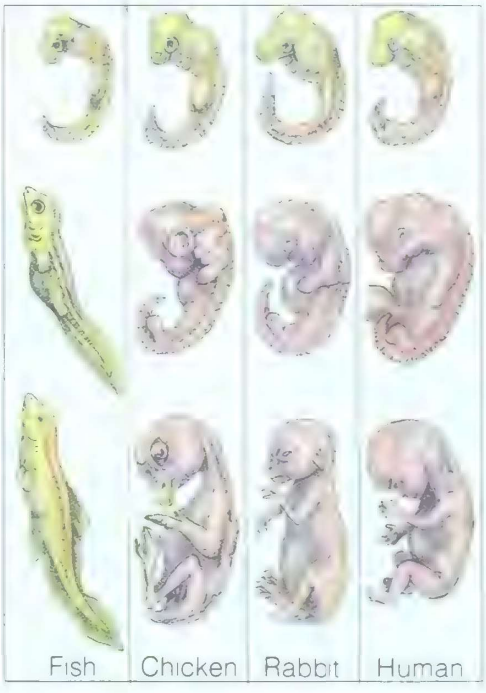
As they grow and develop, the embryos gradually become more and more dissimilar. These differences in form are caused by genes that have changed during the course of evolution. Changes in form are produced by mutations, or changes in the genetic blueprint contained within an organism's DNA. Remember that this DNA blueprint is very complicated. Mutations that affect early stages of development are likely to be lethal, or deadly. An organism carrying such a mutation dies while it is an embryo, and its genes are not passed on. As a consequence, the portions of DNA that control the early stages of development remain relatively unchanged. Thus the embryos of different kinds of animals resemble each other.

Mutations that cause less drastic, as well as potentially useful, changes in structure are likely to occur at later stages of growth and development. Thus the later stages in the development of related organisms begin to show marked differences. An organism with this kind of mutation may survive to reproduce and pass the changes in its DNA to its offspring.

Similarities in Body Structure

In the embryos of many animals—humans, birds, horses, and whales, for example—the clumps of cells that develop into limbs look quite similar. But as the embryos mature, the limbs grow into arms, wings, legs, and flippers that differ greatly in form and function. These different forelimbs evolved in a series

Figure 13–16 *During certain embryological stages, vastly different organisms show similarities. During later stages of development, profound changes occur. Thus the adults bear little resemblance to one another.*



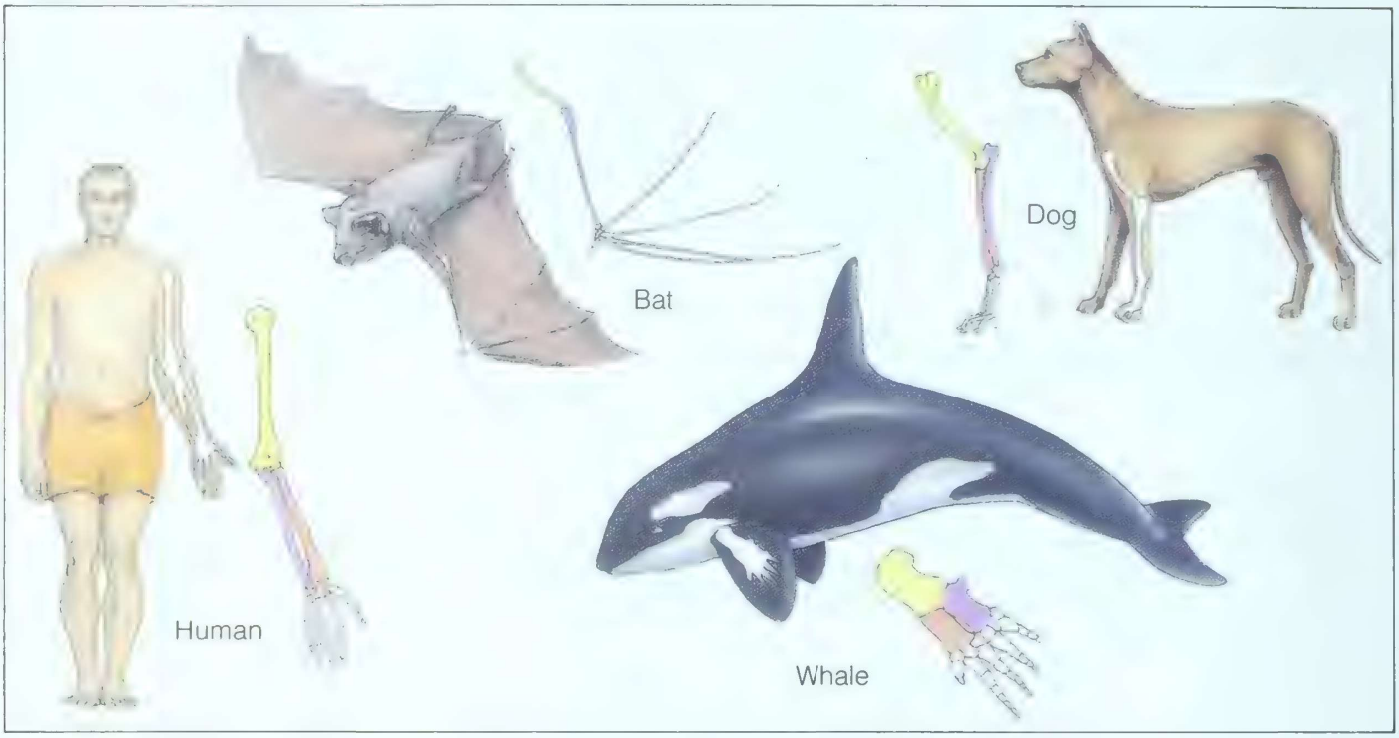


Figure 13–17 *Superbly adapted to performing different tasks, the limbs of various organisms are remarkably similar in structure. Here you can see the homologous limbs of four mammals. How is the form of each limb adapted for different movements?*

Figure 13–18 *Albinism (lack of color) is the result of a gene mutation. In this photograph a normally colored penguin is "chatting" with an albino penguin. Perhaps it's scolding its pale companion for being out of uniform.*



of evolutionary changes that altered the structure and appearance of the arm and leg bones of ancient animals. As you can see in Figure 13–17, the changes in the final structure of the limbs of different species are adaptations that enable each organism to survive in a different environment. Structures such as these that develop from the same body parts are called **homologous structures**.

Many animals have organs that look like miniature arms, legs, tails, or other structures. These organs are **vestigial organs.** Vestigial organs seem to serve no useful purpose at all. You may wonder why organs that are not needed are still present in an organism.

As you will see in the next chapter, evolutionary change occurs as species show new adaptations to their environment. The changes that occur may involve the modification of primitive limbs into wings or flippers. But evolution may also involve the loss or reduction of body structures that are no longer necessary. Structures that are not used may become smaller and smaller but may never disappear completely.

For example, we believe that snakes evolved from ancestors that had four legs. Today, species of pythons and boa constrictors still have useless tiny bones left over from those legs. See Figure 13–19. These tiny bones have no function. However, they act as reminders of the snake's early ancestors.

Humans, too, have vestigial organs. Examples of these are a set of tailbones at the base of the spine and, in most people, the muscles that move the ears. We also have an appendix that leads off the large intestine. This appendix does not seem to serve a useful purpose today. In fact, an appendix can cause medical problems and sometimes must be removed surgically.

Today, a large functioning appendix is found in some animals, such as the koala, that eat primarily plant materials. So it is probable that our appendix is left over from a time during which our ancestors needed this organ to digest their food.

Similarities in Chemical Compounds

All organisms—from bacteria to humans—share many biochemical details. All organisms use DNA and/or RNA to carry information from one generation to the next and to control growth and development. The DNA of all eukaryotic organisms always has the same basic structure and replicates in the same way. The RNAs of various species may act a little differently, but all RNAs are similar in structure from one species to the next. Remember, too, that ATP (adenosine triphosphate) is an energy carrier found in all living systems. A wide variety of complicated proteins, such as cytochrome *c*, are also shared by many organisms.

The more closely related two species are, the more closely their important chemical compounds resemble each other. In Chapter 15 we will discuss the importance of similar proteins in studying evolutionary relationships among species.

What Homologies Tell Us

Similarities in structure and biochemistry provide powerful evidence that all living things evolved from common ancestors. **The structural and biochemical similarities among living organisms are best explained by Darwin's conclusion: Living organisms evolved through gradual modification of earlier forms—descent from a common ancestor.** In a previous chapter you learned that life's chemical pathways are extremely complex. In a later chapter you will learn that tissues and organs are equally complex. If organisms had arisen independently of one another, there would be very little chance that they would have similar structures and biochemistries. The very complexity of life and its processes supports Darwin's conclusion.





Figure 13–19 *If you look closely, you can see the vestigial leg bones of this python, which serve no function—the snake can move quite well without them! Another example of a vestigial organ is the human appendix. In a Koala bear, however, the appendix is a functioning organ that helps the animal digest leaves.*

13–4 SECTION REVIEW

1. What are homologous structures?
2. What is a vestigial organ? Name a vestigial organ in a human.
3. How does evidence from embryology support the concept that all animals evolved from common ancestors?
4. How does biochemistry support the idea that all living things evolved from common ancestors?

LABORATORY INVESTIGATION

EXAMINING HOMOLOGOUS STRUCTURES

PROBLEM

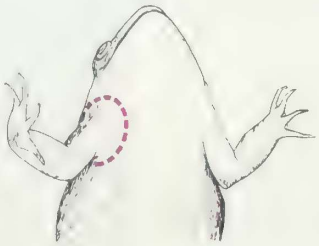
How do homologous structures support the theory of common descent?

MATERIALS *(per group)*

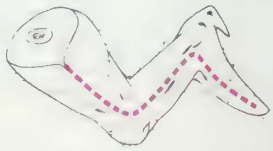
preserved frog	dissecting pan
chicken wing	scalpel
human skeleton (model or chart)	scissors
	forceps

PROCEDURE

1. Put a preserved frog in a dissecting pan. Using your scissors, cut the skin around the base of the frog's arm where it joins the body. See the accompanying figure. Then grasp the cut edge of the skin with forceps and pull it down the arm until the skin is removed. The skin should come off the arm easily.



2. Pull the frog's arm up toward the head. Use your scissors to cut the muscles around the base of the arm. When you have completed your cut, the bones of the arm and shoulder should be visible. Pull back on the arm. The arm should come loose from the shoulder, but you may have to use your scissors to cut the connections that hold the arm in place.
3. With your scissors, cut the ends of the muscles away from the bone on the severed frog arm. Use your forceps to peel the muscles away from the bones. Remove as much of the muscles from the frog's arm as you can. Then, using a scalpel, gently and carefully scrape the bones clean. **CAUTION:** *Use care when using a scalpel. Always cut or scrape away from your body.*
4. Draw a diagram that shows the arrangement of the bones in a frog's arm.
5. Put a chicken wing in a dissecting pan. Use your scissors to cut the skin toward the wingtip. The dotted line in the accompanying figure indicates where you should cut. Using the forceps, remove all the skin from the chicken wing.



6. Carefully cut the muscles away from the bones using your scissors. With a scalpel, carefully scrape the bones clean. **CAUTION:** *Use care when using a scalpel. Always cut or scrape away from your body.*
7. Draw a diagram that shows the arrangement of the bones in a chicken wing.
8. Use the model or chart of the human skeleton to draw the arrangement of the bones in the human arm.

OBSERVATIONS

1. How many bones did you find in each of the limbs?
2. In what ways are the structures of the limbs similar?
3. In what ways are the shapes of the bones similar?

ANALYSIS AND CONCLUSIONS

1. List some functions of each of the three different limbs you have examined.
2. Even though the limbs of these organisms are very different in outward appearance and function, their internal structure is remarkably similar. How can you explain this observation?
3. From an evolutionary standpoint, what would it mean if these bones were very different in structure?

STUDENT STUDY GUIDE

SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

13–1 Evolution and Life's Diversity

- The observation of the diversity of living things on Earth contributed to the formation of Darwin's theory of evolution.
- Fitness is the combination of physical traits and behaviors, or adaptations, that help organisms survive.

13–2 The Age of the Earth

- Scientists use the decay of radioactive elements to date the Earth's rocks.
- The position of rock layers as well as the decay of radioactive elements have enabled scientists to set up a geological time scale.
- Dating techniques have shown that the Earth is about 4 1/2 billion years old.

13–3 The Fossil Record

- Fossils, the remains of ancient organisms, are preserved in sedimentary rock layers.
- Although the fossil record is not complete, fossil evidence shows that life on Earth has changed over time.

13–4 Evidence from Living Organisms

- Similarities in the structure and development of embryos provide evidence of descent from a common ancestor.
- Homologous structures and vestigial organs are additional evidence of descent from a common ancestor.
- The biochemistries of living organisms support the hypothesis that these organisms evolved from a common ancestor.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meanings. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review its definition.

13–1 Evolution and Life's Diversity	13–2 The Age of the Earth	13–3 The Fossil Record	13–4 Evidence from Living Organisms
evolution	fossil	sedimentary rock	embryo
fitness	geologic time scale	paleontologist	homologous structure
common descent	relative dating	fossil record	vestigial organ
adaptation	radioactive element		
	half-life		
	absolute dating		
	era		
	period		
	epoch		

CHAPTER REVIEW

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

1. The length of time it takes for one half of a radioactive element to decay is a (an)
   a. era. c. year.
   b. half-life. d. epoch.
2. Another term for radioactive dating is
   a. relative dating.
   b. geologic time scale.
   c. calendar dating.
   d. absolute dating.
3. The ability of an organism to survive and reproduce is known as
   a. fitness. c. diversity.
   b. evolution. d. adaptation.
4. Fitness arises through a process called
   a. common descent. c. homologous change.
   b. half-life. d. adaptation.
5. Evidence for the age of the Earth is provided by all of the following except
   a. fossils.
   b. radioactive dating.
   c. the rate of sediment formation.
   d. vestigial organs.
6. Most fossils are found in
   a. sedimentary rock. c. ice.
   b. amber. d. tar pits.
7. A vestigial organ is
   a. always useful.
   b. useless.
   c. not evidence for evolution.
   d. sometimes useful.
8. Change in species over time is called
   a. fitness. c. diversity.
   b. evolution. d. relative dating.

True or False

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

1. Paleontologists are scientists who study fossils.
2. The ability of an organism to survive and reproduce is known as diversity.
3. In the Earth's history, periods are divided into eras.
4. Embryos are early stages in an organism's development.
5. Relative dating is the same as radioactive dating.
6. Today, scientists have evidence that shows that the Earth is 1 million years old.
7. The theory that organisms share a common ancestor is known as common descent.
8. A human's arm and a dog's leg are examples of vestigial organs.

Word Relationships

A. *In each of the following sets of terms, three of the terms are related. One term does not belong. Determine the characteristic common to three of the terms and then identify the term that does not belong.*

1. appendix, tailbones, ear muscles, heart
2. absolute dating, double dating, radioactive dating, relative dating
3. half-life, era, epoch, period
4. diversity, fitness, fossil, adaptation

B. *An analogy is a relationship between two pairs of words or phrases generally written in the following manner: a:b::c:d. The symbol : is read "is to," and the symbol :: is read "as." For example, cat:animal::rose:plant is read "cat is to animal as rose is to plant."*

In the analogies that follow, a word or phrase is missing. Complete each analogy by providing the missing word or phrase.

5. biologist:organism::paleontologist:_____
6. era:periods::sedimentary rock:_____
7. half-life:absolute dating::rock position:_____
8. appendix:vestigial organ::bat wing and whale flipper:_____

CONCEPT MASTERY

Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

1. Explain how radioactivity is used to date rock samples.
2. What is the geologic time scale? How was it developed?
3. What is a vestigial organ? Give an example of a vestigial organ in humans.
4. What does the phrase common descent mean?
5. What is a fossil?
6. How is sedimentary rock formed?

CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

1. **Summarizing information** Evolutionary biologists say that there is good reason for gaps in the fossil record. Can you explain why some extinct animals and plants were never fossilized?
2. **Applying concepts** A giraffe's long neck enables it to eat the leaves of trees. How does this adaptation help the giraffe survive?
3. **Sequencing events** How did the work of geologists help Darwin formulate his theory of evolution?
4. **Applying technology** Discuss the limitations of radioactive dating.
5. **Making inferences** How did the diversity of life that Darwin observed during the five-year voyage of the *Beagle* contribute to the development of his theory?
6. **Using the writing process** You have been given the opportunity to become the first person to travel back in time to the age when dinosaurs roamed the Earth. Describe your feelings as you observe these ancient creatures walk through the area you now call home.
7. **Using the writing process** This time you will travel forward in time several million years. Use your imagination to describe the kinds of organisms now living on Earth. (*Hint:* Remember that any organism you describe must be well adapted to the environment of Earth in the distant future.)