Chapter

13 Evolution: Evidence of Change

The striking patterns of diversity among organisms of the Galapagos Islands, such as these Sally Light-foot crabs, were instrumental in helping Charles Darwin develop his theory of evolution.

Chapter Inquiry Comparing

1. Examine the wings of the different types of animals provided by your teacher.

2. Compare and contrast wing structures and functions among all the animals. Based on the wing structures only, which animals do you think are closely related? Explain the criteria you used to determine those relationships.

Connect to the Main Ideas

Organisms that share many characteristics are often closely related. How might the principles of evolution explain this pattern?

CHAPTER PREVIEW

Main Ideas

In this chapter, you will learn about Charles Darwin's travels that led him to develop the theory of evolution. You will also investigate the age of the Earth by examining the geologic record, the fossil record, and the relationships of living organisms.

Reading Strategy

Organizing Information As you read this chapter, list the different methods that scientists use to date the Earth and its fossils. Write a sentence explaining each method.

Journal Activity

Biology and Your World Darwin kept voluminous notes in the diary he recorded during his five-year-long voyage. His diary helped him remember details he later used to write his books. Keep a record of your observations for a period of time. Note the people you met, what they wore, what you ate, what you thought. As with Darwin, you may have a book in your future!

13–1 Evolution and Life's Diversity

Guide For Reading

- What is "fitness"?
- How do adaptations contribute to fitness?

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 analytical mind. Over five years' time, the *Beagle* took Darwin to several continents and many remote islands. Darwin went

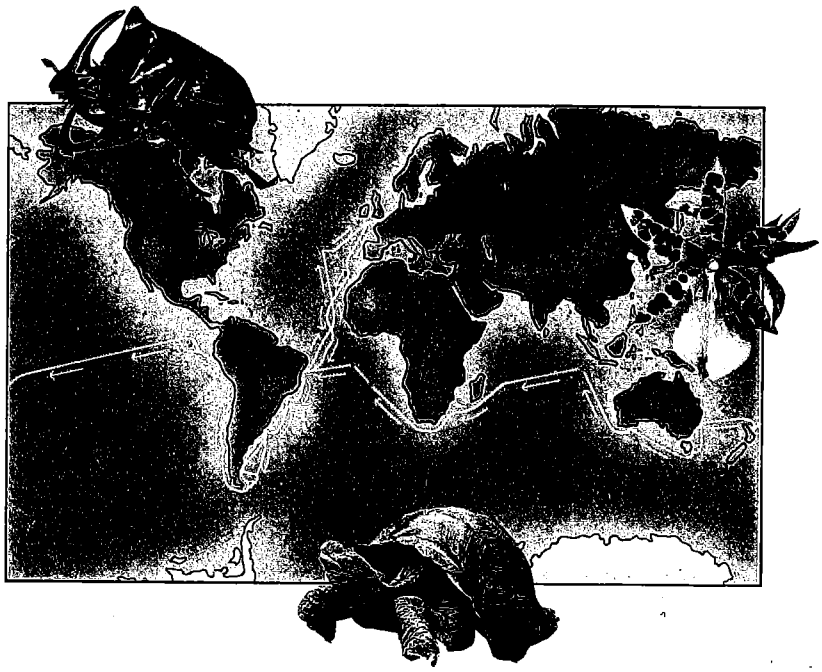


Figure 13–1 *This map shows the route taken by the HMS* Beagle *on its epic voyage.*

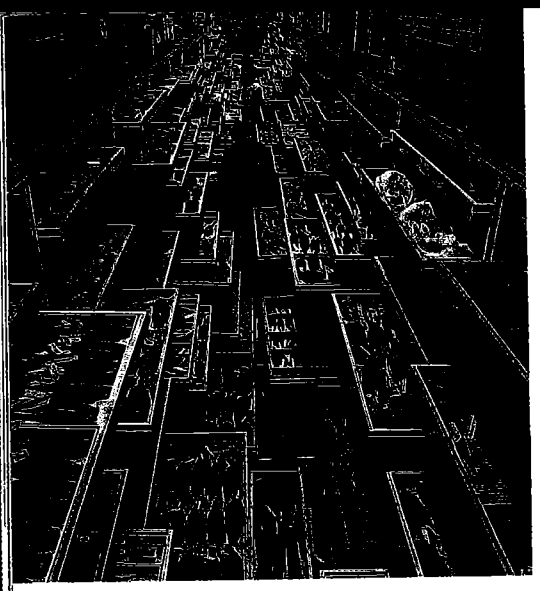


Figure 13–2 *Roxie Laybourne is one of the world's experts on birds. She stands amidst file drawers that contain only a small part of the Smithsonian Institution's collection of specimens. As large as this collection is, however, it represents only a small fraction of the species of birds alive today. 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. The behavior patterns of this female spider ensure that her egg sack will be carefully placed on leaves where her offspring will have the greatest chance of survival.*

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 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 traveled in South America, he found more different forms of life than he had ever dreamed of. For example, in just one day spent in a Brazilian forest he collected 68 different species of beetles—even though he wasn't really looking for beetles! Darwin's observations helped him to realize that an enormous number of species inhabit the Earth. Even today, as scientists search land, water, and air, there is no precise count of the number of different kinds of organisms that exist. Estimates range from 3 million to more than 20 million different living species.

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 have body parts and behaviors that do certain things very well. **The physical traits and behaviors that enable organisms to survive and reproduce in their environment give them what Darwin called fitness.** But how did all these organisms develop the structures that give them their fitness? And why are there so many different techniques for survival?

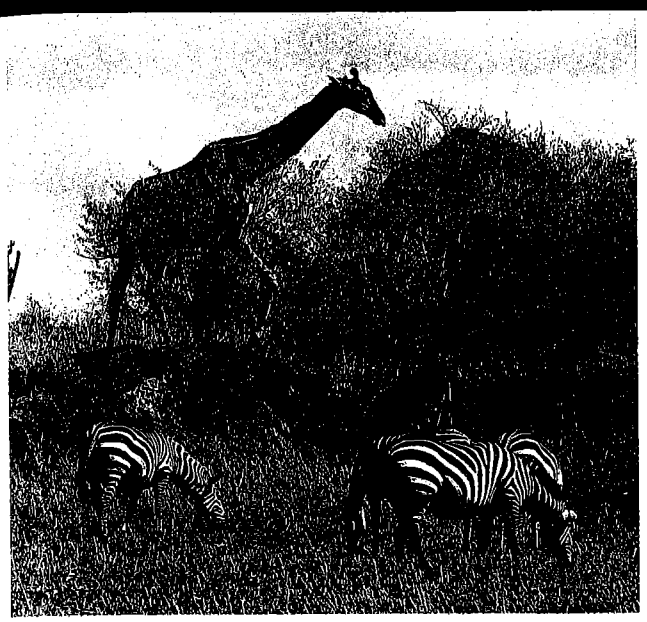


Figure 13–4 *The giraffe dines on leaves of trees out of the reach of even the tallest zebra's head. The sphinx moth uses a long feeding tube to reach the nectar in a flower. The vampire bat punctures the skin of another animal with its razor-sharp teeth and then greedily laps up blood from the wound.*

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 were produced by a process called evolution. Evolution is a 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. What is fitness?
2. How did Darwin's voyage on the *Beagle* influence his thoughts about life on Earth?
3. How is the diversity of life related to evolution?
4. **Critical Thinking—Relating Concepts** How is adaptation related to fitness?

Guide For Reading

- What is the age of the Earth?
- What is the difference between relative and absolute dating?
- What is a half-life?

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.

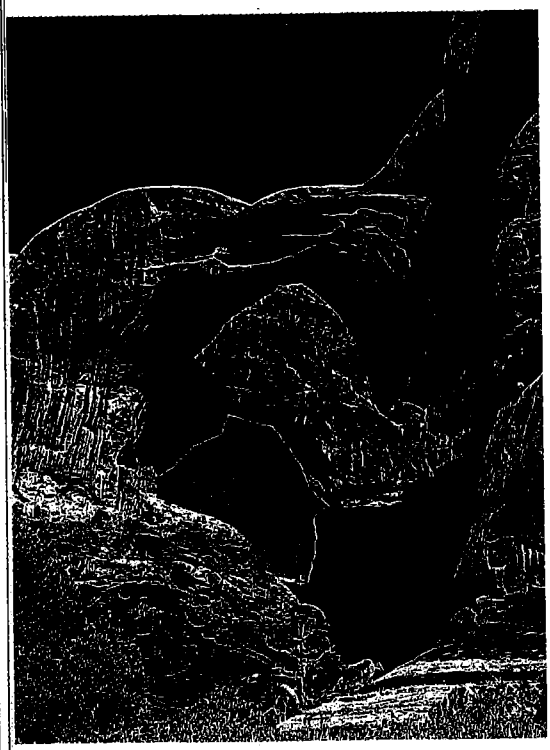
Evidence that supported the idea that the Earth was very old first came from geologist James Hutton in 1788. Hutton proposed that rocks, mountains, and valleys had been changed gradually by rain, heat, cold, the activity of volcanoes, and other natural forces. Because most of these processes operate 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

Figure 13–5 *These stone arches were formed by the relentless forces of nature. Tiny particles of windblown sand constantly hit the rock and wear it away. Darwin learned from his reading that most geological changes do not happen overnight—or even during a single human lifetime. Instead, they take many, many years.*



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

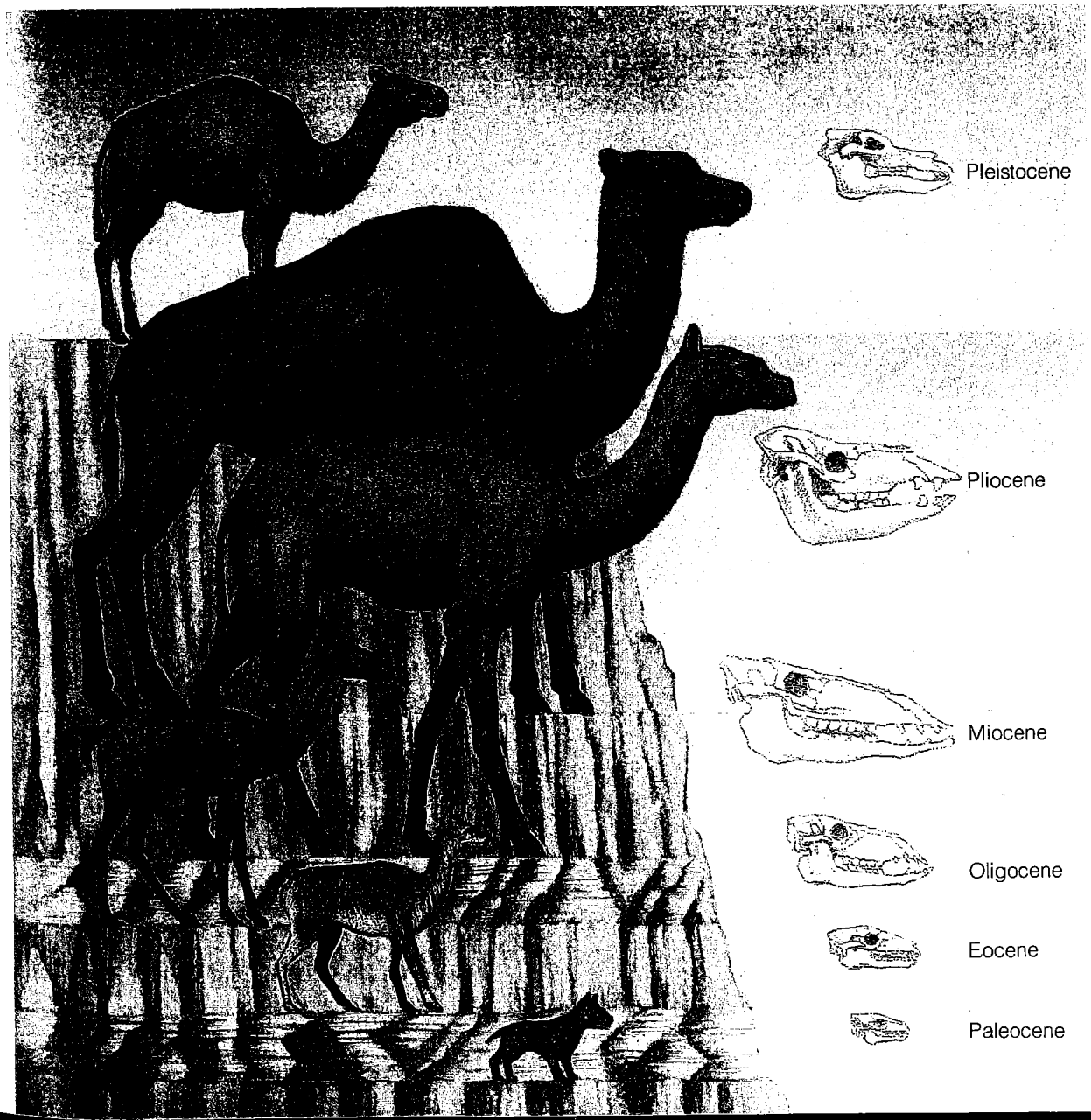


Figure 13–6 *These ancient, fossilized relatives of the modern camel have been arranged in chronological order according to the layers of rock in which their bones were found. Provided that the order of the layers has not been disturbed, fossils found in lower layers are older than those found in the layers above.*

Quick Lab

To reinforce the **Main Idea** of dating rocks and fossils, perform the Quick Lab activity called Comparing Half-Lives on p. 1088.

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 used by scientists to determine the age of fossils relative to other fossils in different layers of rock. However, because geologists did not know how long it took for the 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.

Each radioactive element has a different half-life. Uranium-238, for example, 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. Potassium-40 has a half-life of 1.3 billion years. During that time, one half of the potassium-40 atoms decay to argon-40, an inert gas that remains trapped inside the potassium crystals. Still another radioactive element, carbon-14, has a much shorter half-life of about 5770 years. During that period, half the carbon-14 decays to nitrogen-14.

Elements with different half-lifes provide natural "clocks" that "tick" at different rates. When properly interpreted, these clocks help scientists date rocks and specimens of different ages. Here is how this process works.

Suppose geologists have uncovered what they think is a very old piece of rock—one that might date back to the birth of our planet. To determine the age of their sample, they measure and compare the amounts of uranium-238 and lead-206 it contains. Next, they determine how much lead has been

Figure 13–7 *Scientists use the natural decay of radioactive elements to date certain fossils. (The bracketed numbers give a fractional representation of the radioactive element and its decay element in the sample.) It is the constancy of a radioactive element's decay that makes radioactive dating accurate.*

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

Time (millions) of years ago)	Amount of Radioactive Element (kg)	Amount of Decay Element (kg)
4	1 [1]	0 [0]
3	0.5 [1/2]	0.5 [1/2]
2	0.25 [1/4]	0.75 [3/4]
1	0.125 [1/8]	0.875 [7/8]
Present	0.0625 [1/16]	0.9375 [15/16]

= Radioactive element

= Decay element