10.4 Evidence of Evolution

KEY CONCEPT Evidence of common ancestry among species comes from many sources.

MAIN IDEAS

- Evidence for evolution in Darwin's time came from several sources.
- Structural patterns are clues to the history of a species.

VOCABULARY

biogeography, p. 311
homologous structure, p. 312
analogous structure, p. 313
vestigial structure, p. 314

CALIFORNIA STANDARDS

8.d *Students know* reproductive or geographic isolation affects speciation.

Review Life Science
7.3.c *Students know* how independent lines of evidence from geology, fossils, and comparative anatomy provide the bases for the theory of evolution.

Connect How genetic inheritance works was not known while Darwin was working on his theory of natural selection. However, Darwin documented natural selection from every angle available at the time. His thoroughness was important. It left no doubt in the minds of scientists that all organisms have a past history. Today, the concept of evolution ties together all fields of biology.

MAIN IDEA

Evidence for evolution in Darwin's time came from several sources.

Darwin found evidence from a wide range of sources to support his argument for evolution. The most important and convincing support came from fossils, geography, embryology, and anatomy.

Fossils

Even before Darwin, scholars studying fossils knew that organisms changed over time. Scientists who study fossils study more than just the fossil itself. They also think about its age, its location, and what the environment was like when the organism it came from was alive.

In the late 1700s, geologists wondered why certain types of fossils were found in some layers of rock and not others. Later studies suggested that the fossil organisms in the bottom, or older, layers were more primitive than those in the upper, or newer, layers. Geologists were interested in fossil sequences as a record of events such as earthquakes that disturb rock strata, not as proof of evolution. However, these and other findings in the fossil record supported Darwin's concept of descent with modification.

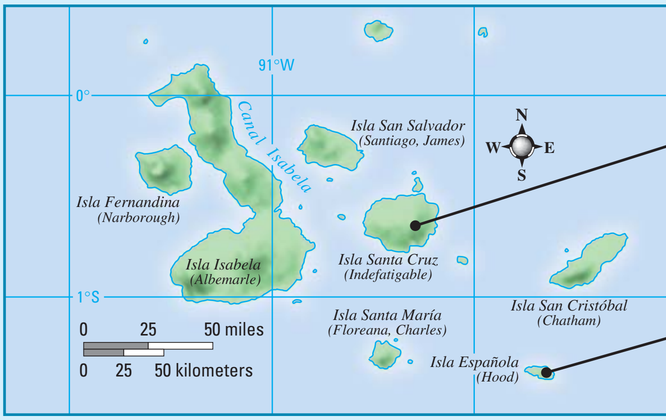
Geography

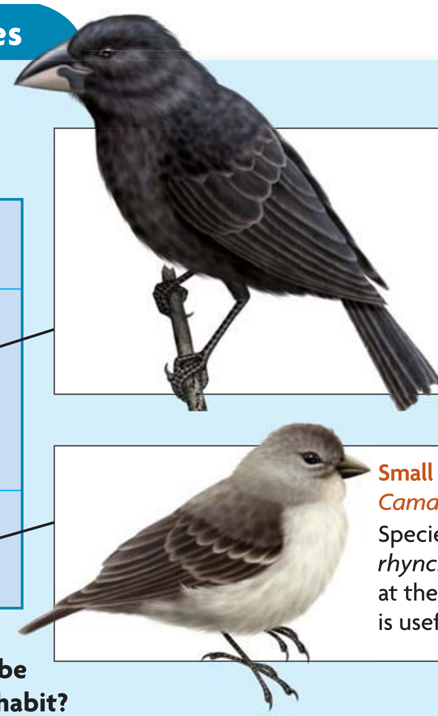
Recall that during the *Beagle* expedition Darwin saw that island plants and animals looked like, but were not identical to, species on the South American continent. He extended this observation, proposing that island species most closely resemble species on the nearest mainland. He hypothesized that at some point in the past, some individuals from the South American mainland had migrated to the islands.

FIGURE 10.8 This trilobite, an early marine invertebrate that is now extinct, was found in this loose rock bed in Ohio. Although far from modern-day oceans, this site is actually the floor of an ancient sea.

FIGURE 10.9 Variation in Galápagos Finches

Finches on certain Galápagos Islands live in different environments and have beaks of different sizes and shapes.





Large cactus finch
Geospiza conirostris
Species in the genus *Geospiza* have thick beaks and can feed on large, hard seeds that require strength for crushing.

Small tree finch
Camarhynchus parvulus
Species in the genus *Camarhynchus* have biting strength at the tips of their beaks, which is useful for tearing vegetation.

Infer What different environmental conditions might be found on the islands that these two species of finch inhabit?

Different ecosystems on each island—with different plants, climates, and predators—had favored different traits in these migrants. Over time, these new traits became well established in the separate island populations, since the islands were too far apart for mating to occur.

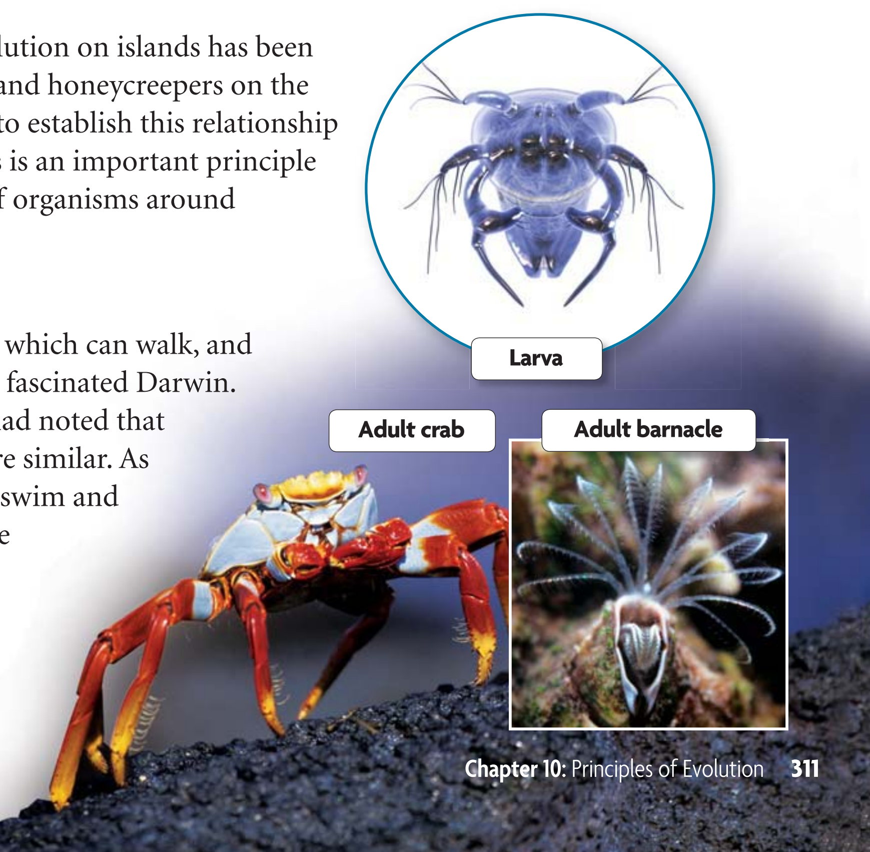
One clear example of local adaptation is found in what are now known as Darwin's finches. The finches from the Galápagos Islands, shown in **FIGURE 10.9**, have distinct-looking beaks, as well as different habits, diets, and behaviors that evolved after generations of adaptation to specific island habitats. However, they all share a common ancestor from the South American mainland.

Since Darwin's time, the same pattern of evolution on islands has been studied in many living things, such as fruit flies and honeycreepers on the Hawaiian Islands. Darwin was the first scientist to establish this relationship between island and mainland species. Today this is an important principle of **biogeography,** the study of the distribution of organisms around the world.

Embryology

A study proposing a relationship between crabs, which can walk, and barnacles, which are fixed in one place as adults, fascinated Darwin. He had collected barnacles for many years and had noted that immature crabs and barnacles, called larvae, were similar. As **FIGURE 10.10** shows, barnacle and crab larvae both swim and look alike, but the adult animals look and behave very differently.

FIGURE 10.10 Although adult crabs and barnacles look and behave very differently, they can look identical as larvae. This suggested to Darwin that they share a common ancestor.



Like larvae, embryos of vertebrates can be hard to tell apart. For example, fish, birds, reptiles, and mammals all have gill slits as embryos. The gill slits become gills in adult fish. In mammals, the gill slits develop into structures of ears and throats. These observations formed an important part of Darwin's evidence for common descent. The similar features of embryos in very different organisms suggest evolution from a distant common ancestor.

Anatomy

Some of Darwin's best evidence came from comparing the body parts of different species. Chief among such evidence were homologous structures. **Homologous structures** (huh-MAHL-uh-guhs) are features that are similar in structure but appear in different organisms and have different functions. Their appearance across different species offers strong evidence for common descent. It would be unlikely for many species to have such similar anatomy if each species evolved independently.

VOCABULARY

A tetrapod is a four-limbed animal. *Tetra-* means "four," and *-pod* means "foot."

The most common examples of homologous structures are the forelimbs of tetrapod vertebrates. The forelimbs of humans, bats, and moles are compared in **FIGURE 10.11.** In all of these animals, the forelimbs have several bones that are very similar to each other despite their different functions. Notice also how the same bones vary in different animals. Homologous structures are different in detail but similar in structure and relation to each other.

In using homologous structures as evidence of evolution, Darwin posed a logical question: If each of these groups descended from a different ancestor, why would they share these homologous structures? A simple answer is that they share a common ancestor.

FIGURE 10.11 Homologous Structures

Homologous structures, though they often have differing functions, are the result of a common ancestor.

Notice that each of these homologous structures uses the same bones in relation to the others.

Apply **What body part of a dolphin is homologous to the structures shown above?**

The idea of common descent provides a logical explanation for how homologous structures appeared in diverse groups. Having similar structures doesn't always mean two species are closely related, however. Some structures found in different species have the same functions but did not evolve from a common ancestor.

Suppose two organisms have similar needs caused by the environment. For example, two different organisms need to be able to fly. Both can develop similar adaptations using different body parts. Think about the wings of bats and the wings of flying insects. Clearly these organisms differ in more ways than they are similar. Insects are arthropods, while bats are mammals. The wings of bats and insects are called analogous structures, as shown in **FIGURE 10.12**. **Analogous structures** (uh-NAL-uh-guhs) are structures that perform a similar function—in this case, flight—but are not similar in origin. Bat wings have bones. In contrast, insect wings do not have bones, only membranes. The similar function of wings in bats and flying insects evolved separately. Their ancestors faced similar environmental challenges and came upon similar solutions.

Analyze **Using the terms *homologous* and *analogous*, identify which group of structures provides evidence for a common ancestor. Explain.**

FIGURE 10.12 ANALOGOUS STRUCTURES

Analogous structures evolved separately and are not evidence of a common ancestor. A bat's wing has bones, whereas insect wings do not.

QUICK LAB **INFERRING**

Piecing Together Evidence

Evolutionary biologists and paleontologists rarely get all of the pieces of what they are studying. In this activity, you will receive pieces of "evidence" about a picture in order to make observations, inferences, and predictions about it.

PROBLEM How are inferences modified when new information is obtained?

MATERIALS

picture cut into strips

PROCEDURE

1. Using the three strips that your teacher has provided, write down all observations and inferences that you can make about this picture.
2. Make a prediction about the picture's topic, using your observations as supporting evidence for your prediction.
3. Record observations, inferences, and a prediction for each remaining strip of "evidence" that you receive from your teacher.

ANALYZE AND CONCLUDE

1. **Analyze** What inferences did you modify as you gathered more evidence from your teacher?
2. **Provide Examples** What type of evidence might paleontologists find that would allow them to see the big picture of a species' evolutionary past?

CALIFORNIA STANDARDS

IE.1.d Formulate explanations by using logic and evidence.
IE.1.k Recognize the cumulative nature of scientific evidence.

FIGURE 10.13 Vestigial structures, such as the wings of an ostrich, are organs or structures that are greatly reduced from the original ancestral form and have little or no current use.

MAIN IDEA

Structural patterns are clues to the history of a species.

Some organisms have structures or organs that seem to lack any useful function, or at least are no longer used for their original purpose. For example, snakes have tiny pelvic bones and stumplike limbs, even though snakes don't walk. Underdeveloped or unused features are called vestigial structures. **Vestigial structures** (veh-STIHJ-ee-uhl) are remnants of organs or structures that had a function in an early ancestor. As vertebrates, snakes share a common ancestor with tetrapods such as lizards and dogs. The tiny pelvic bones and hind limbs in many snakes are homologous to the pelvic bones of tetrapods.

The wings of ostriches are another example of vestigial structures. Ostriches have wings that they use for balance but not to fly, as shown in **FIGURE 10.13**. Over generations, their increasingly large bodies and powerful long legs may have been enough to avoid predators. If ostriches that lived long ago could escape by running or by kicking viciously, their large wings would no longer have been useful. Thus, the genes coding for large wings were not preserved over generations.

Examples of vestigial structures are found in many organisms. In humans, the appendix is an example of a vestigial structure. The appendix is a remnant of the cecum, which makes up a large part of the large intestine in plant-eating mammals. It helps to digest the cellulose in plants. As omnivores, humans do not eat much cellulose. The human appendix does not have the ability to digest cellulose. In fact, it performs no known function at all.

Vestigial structures did not get smaller in one individual organism. It took many generations for those organs to shrink. Today, biologists consider vestigial structures among the most important examples demonstrating how evolution works.

Summarize **What are vestigial structures, and how do they demonstrate common ancestry?**

10.4 ASSESSMENT

REVIEWING MAIN IDEAS

1. Describe the four sources of evidence for evolution upon which Darwin based his ideas on common descent. **8.d, IE.1.k, 7.3.c**
2. Why are **vestigial structures** considered critical evidence of evolution?

CRITICAL THINKING

3. **Hypothesize** Describe how some of the Galápagos finch species, which traditionally were seed eaters, evolved over generations to prefer insects over seeds.
4. **Apply** How can a bat's wing be considered both a **homologous structure** and an **analogous structure**?

Connecting CONCEPTS

5. **Human Biology** Wisdom teeth are a third set of molars that usually appear in humans between the ages of 17 and 25, and often need removing because they crowd out other teeth. Explain why wisdom teeth are vestigial structures.

10.5 Evolutionary Biology Today

KEY CONCEPT New technology is furthering our understanding of evolution.

MAIN IDEAS

- Fossils provide a record of evolution.
- Molecular and genetic evidence support fossil and anatomical evidence.
- Evolution unites all fields of biology.

VOCABULARY

paleontology, p. 316

CALIFORNIA STANDARDS

8.f* *Students know* how to use comparative embryology, DNA or protein sequence comparisons, and other independent sources of data to create a branching diagram (cladogram) that shows probable evolutionary relationships.

IE.1.l Analyze situations and solve problems that require combining and applying concepts from more than one area of science.

VOCABULARY

Paleontology is the study of prehistoric life forms. *Paleo-* means "ancient," and *-ology* means "the study of."

Connect Darwin had spent many years collecting evidence of evolution from different fields of science before publishing his results. Since that time, technology has greatly advanced. Scientists can now examine evidence only dreamed about in the 1800s. In particular, the relatively new fields of genetics and molecular biology have added strong support to Darwin's theory of natural selection. They have shown how hereditary variation occurs.

MAIN IDEA

Fossils provide a record of evolution.

Paleontology (PAY-lee-ahn-TAHL-uh-jee), the study of fossils or extinct organisms, continues to provide new information and support current hypotheses about how evolution occurs. The fossil record is not complete, because most living things do not form into fossils after they die, and fossils have not been looked for in many areas of the world. However, no fossil evidence that contradicts evolution has ever been found.

In Darwin's time, paleontology was still a new science. Darwin worried about the lack of transitional fossils between groups of organisms. Since Darwin's time, however, many transitional forms have been discovered between species. Many of the large gaps in the fossil record have been filled in. The fossil record today includes many thousands of species that show the change in forms over time that Darwin outlined in his theory. These "missing links" demonstrate the evolution of traits within groups as well as the common ancestors between groups.

Although scientists classify organisms into groups, the mix of traits in transitional species often makes it difficult to tell where one group ends and another begins. One example of transitional species in the evolution of whales is shown in **FIGURE 10.14.** *Basilosaurus isis* had a whalelike body but also still had the limbs of land animals.

Infer **Why are fossils such as *Basilosaurus isis* considered transitional fossils?**

FIGURE 10.14 This skeleton of *Basilosaurus isis* was found in a desert in Egypt in 2005. It lived 40 million years ago and has characteristics of both land and marine animals.

MAIN IDEA

Molecular and genetic evidence support fossil and anatomical evidence.

As with homologous traits, very different species have similar molecular and genetic mechanisms. Because all living things have DNA, they share the same genetic code and make most of the same proteins from the same 20 amino acids. DNA or protein sequence comparisons can be used to show probable evolutionary relationships between species.

DNA sequence analysis As you learned in Chapter 9, the sequences of nucleotides in a gene change over time due to mutations. DNA sequence analysis depends on the fact that the more related two organisms are, the more similar their DNA will be. Because there are thousands of genes in even simple organisms, DNA contains a huge amount of information on evolutionary history.

Pseudogenes Sequences of genes known as pseudogenes also provide evidence of evolution. Pseudogenes are like vestigial structures. They no longer function but are still carried along with functional DNA. They can also change as they are passed on through generations, so they provide another way to figure out evolutionary relationships. Functioning genes may be similar in organisms with similar lifestyles, such as a wolf and a coyote, due to natural selection. Similarities between pseudogenes, however, must reflect a common ancestor.

VOCABULARY

A pseudogene is a DNA sequence that resembles a gene but seems to have no function. *Pseudo-* means "false" or "deceptive."

Homeobox genes As you will learn in Chapter 23, homeobox genes control the development of specific structures. These sequences of genes are found in many organisms, from fruit flies to humans. They also indicate a very distant common ancestor. Evidence of homeobox gene clusters are found in organisms that lived as far back as 600 million years ago.

Protein comparisons Similarities among cell types across organisms can be revealed by comparing their proteins, a technique called molecular fingerprinting. A unique set of proteins are found in specific types of cells, such as liver or muscle cells. Cells from different species that have the same proteins most likely come from a common ancestor. For example, the proteins of light-sensitive cells in the brain of an ancient marine worm, as shown in **FIGURE 10.15**, were found to closely resemble those of cells found in the vertebrate eye. This resemblance shows a shared ancestry between worms and vertebrates. It also shows that the cells of the vertebrate eye originally came from cells in the brain.

FIGURE 10.15 The eye spots of this marine worm have light-sensitive cells with a molecular fingerprint similar to that of a vertebrate eye.

Explain How have protein comparisons helped determine ancestral relationships between organisms?

FIGURE 10.16 Evidence of Whale Evolution

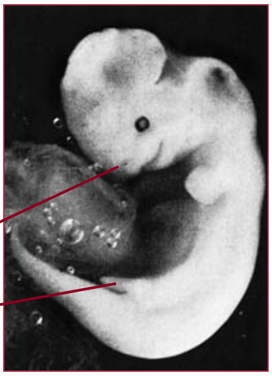
The evidence that whales descended from hoofed mammals is supported by scientific research in several different fields of biology.

Vestigial Evidence

Many modern whale species have vestigial pelvic and leg bones. They also have vestigial nerves for the sense of smell, and small muscles devoted to external ears that no longer exist.

Embryological Evidence

Whale embryos have features such as hind leg buds and nostrils that resemble those of land animals. Nostrils are at the end of the whale's snout early in development but travel to the top of the head to form one or more blowholes before birth.



Molecular Evidence

The DNA sequences of whales and ungulates are very similar, as demonstrated by the DNA fragments below.

Hippopotamus	TCC TGGCA GTCCA GTGGT
Humpback whale	CCC TGGCA GTGCA GTGCT

Fossil Evidence

There are many transitional fossils that have characteristics of both land mammals and whales. These are a few examples.

Dorudon 40 million years ago

Tiny hind legs were useless on land, and a shorter neck and longer tail makes *Dorudon* similar to modern-day whales. Its ankle joints closely resemble those of modern ungulates.

Ambulocetus natans 50 million years ago

With a name that means "the walking whale that swims," *Ambulocetus natans* was an amphibious fish eater the size of a sea lion.

Pakicetus 52 million years ago

Pakicetus had a whale-shaped skull and teeth adapted for hunting fish. However, with ear bones that are in between those of land and aquatic mammals, it could not hear well underwater or make deep dives.

CRITICAL VIEWING **Whales are divided into two groups: tooth whales, such as the orca pictured above, and baleen whales, such as the humpback whale pictured on the next page. Which would you predict is most closely related to *Dorudon*? Explain.**

MAIN IDEA

Evolution unites all fields of biology.

Despite the advances talked about in this section, scientists are still actively studying evolution through natural selection. The theory of natural selection combined with genetics is sometimes called the modern synthesis of evolutionary theory. The 21st century is an exciting time to study evolutionary biology. New tools are providing more data than ever before. When you consider the number of proteins in a single organism, the amount of data that can be gathered through molecular evidence alone is overwhelming. New discoveries are limited only by the time and resources of scientists.

Scientists from many fields of science are shedding new light on the mechanisms and patterns of evolution. In some cases, modern tools add to what has been discovered through fossil evidence. For example, you have read that fossil evidence suggests that early ancestors of whales were hoofed land mammals. As shown in **FIGURE 10.16**, comparisons of milk protein genes confirm this relationship and even provide evidence that the hippopotamus is the closest living land animal related to whales.

The field of evolutionary biology is growing fast. The basic principles of evolution are used in fields such as medicine, geology, geography, chemistry, and ecology. For instance, the idea of common descent helps biologists understand where new diseases come from, as well as how to best manage endangered species. As much as we know about life on Earth, there is so much more waiting to be discovered. As the great geneticist Theodosius Dobzhansky (1900–1975) once noted, "Nothing in biology makes sense except in the light of evolution."

Infer **How can the idea of a common ancestor help us understand new diseases?**

FIGURE 10.17 Baleen whales, such as this humpback whale, have evolved a highly specialized adaptation for catching microscopic food. Molecular techniques have allowed scientists to discover the whale's relationship with hoofed animals.

10.5 ASSESSMENT

ONLINE QUIZ
ClassZone.com

REVIEWING MAIN IDEAS

1. How has our knowledge of the fossil record changed since Darwin proposed his theory of natural selection? **IE.1.k**
2. How has genetics, combined with **paleontology,** added to our understanding of evolution? **IE.1.k**
3. What are some of the fields of science to which evolutionary biology contributes? **IE.1.l**

CRITICAL THINKING

4. **Apply** Describe how similar protein comparisons of cells in two species can suggest a close evolutionary relationship. **8.f***
5. **Synthesize** You have discovered the fossil remains of three organisms. One is mammalian, one is reptilian, and the third has both mammalian and reptilian features. What techniques could you apply to determine the relationship between these organisms? **IE.1.l**

Connecting CONCEPTS

6. **Genetics** Researchers have found that a gene controlling reproduction is linked to the gene for the number of digits an organism has. How does this help explain why many vertebrates have five digits per limb, despite the fact that there is no fitness benefit in having five rather than six or four? **8.f***