10.3 Evidence of Evolution

EXPECTATIONS

- **Evaluate the scientific evidence that supports the theory of evolution.**
- **Analyze how technological development has extended or modified knowledge in the field of evolution.**

Charles Darwin assembled a group of facts that had previously seemed unrelated in *The Origin of Species*. However, before and after publication of this book, biologists, geologists, geographers, paleontologists, and other scientists provided a wealth of information that supported and strengthened the theory of evolution. Evidence in support of evolution has come from the fossil record, the sciences of genetics and molecular biology, the geographic distribution of organisms on Earth, and studies comparing the anatomy of adult and embryonic animals.

The Fossil Record

Fossils are made when organisms become buried in sediment that is eventually converted into rock. Sedimentary rocks with fossils reveal a **fossil record** of the history of life on Earth and show the kind of organisms that were alive in the past. While some fossils look similar to species we see today, most are very different. For example, the animals alive during the Cambrian period that were preserved in the Burgess Shale fossil beds in British Columbia had never been seen in the fossil record before. The animals unearthed in the Burgess Shale lived during the Cambrian Explosion (about 500 million years ago), a time during which a stunning burst of biodiversity occurred, much of which is now preserved as fossils. While some of the animals found in the Burgess Shale are ancestors of animals that are common today, others have long been extinct and are unlike anything in our modern oceans. An artist's representation of how the ocean might have looked when the Burgess Shale animals were alive is shown in Figure 10.9.

Fossils from more recent geological periods are much more similar to species alive today. This also supports the idea that life has evolved over time. Those species that were alive long ago have had a longer time to change, whereas those living only a few million years ago would have had comparatively little time to change. The geological time scale (Figure 10.10 on the following page) shows when organisms first appear in the fossil record.

Figure 10.9 An artist's representation of the habitat and animals now fossilized in the Burgess Shale

Another way in which the fossil record supports the idea of evolution is that fossils appear in chronological order — that is, probable ancestors appear earlier (in older rock strata) in the fossil record. The oldest fossils discovered thus far are of stromatolites that lived over 3.8 billion years ago. Stromatolites are unusual rings formed by cyanobacteria (blue-green algae). The stromatolite formation on the shore of Lake Superior (as shown in Figure 10.11) is approximately 1.9 billion years old. As Figure 10.10 shows, other organisms, from simple invertebrates to mammals, then appear sequentially in the fossil record through time.

The fact that organisms do not all appear in the fossil record simultaneously supports the idea that organisms have slowly evolved from ancestral forms. As an example, the fossil history of vertebrates shows that fossilized fishes are the oldest vertebrate fossils. Next to appear in the vertebrate fossil record are amphibians, followed by reptiles, and then birds and mammals (see Figure 10.10). Biologists and paleontologists have gathered evidence that shows that amphibians evolved from ancestral fish, reptiles from ancestral amphibians, and so on, up through the vertebrate groups.

It is important to keep in mind the vast amounts of time that the history of life covers. Changes are slow and can take millions of years, yet the fossil record gives us a "snapshot" of ancestral forms. Figure 10.12 on page 351 shows the evolution of oyster shells.

Figure 10.11 These stromatolites are among the earliest known organisms preserved in the fossil record.

About 200 million years ago, oyster shells were small and curved. The fossil record shows that the shells of later generations evolved into a larger, flatter shape over a period of about 12 million years. Oysters live on the ocean floor, and the larger, flatter shell shape may have proved a more stable shape to prevent shifting as water moved over the oysters.

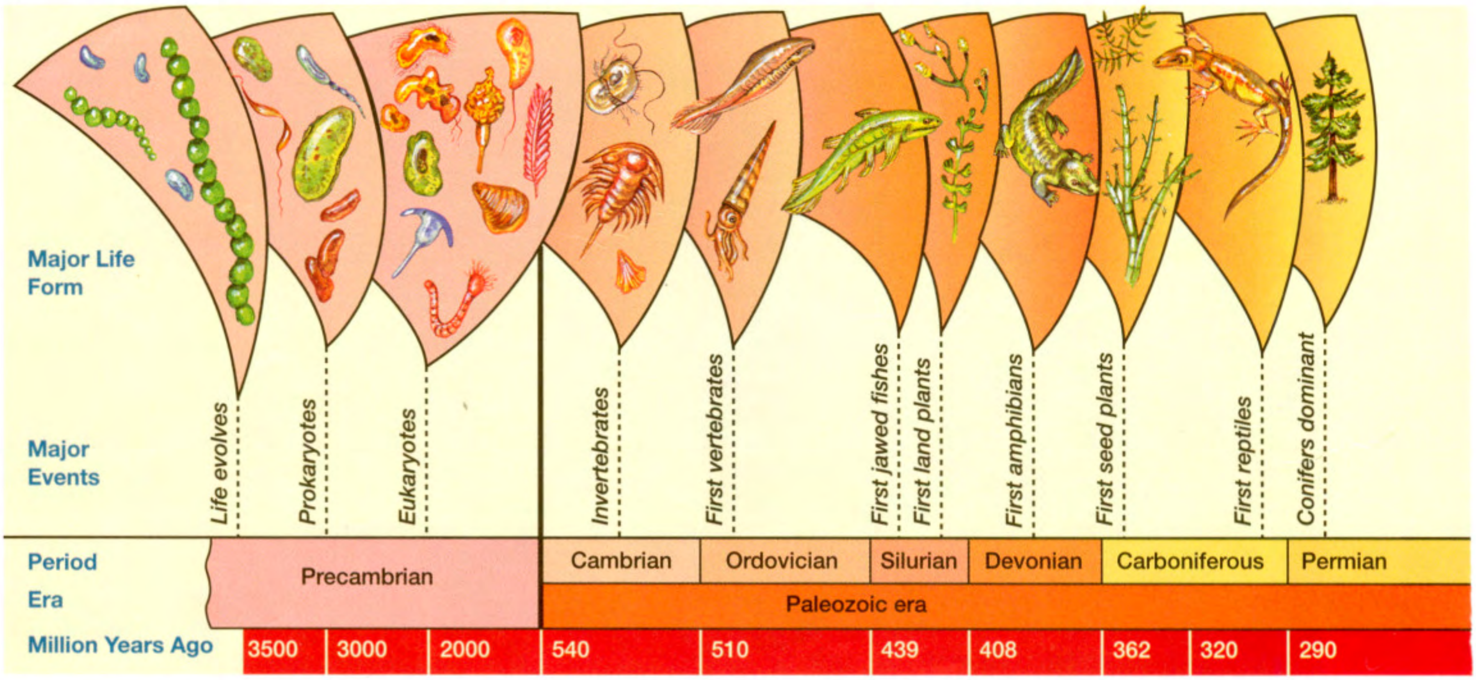


Figure 10.10 The geological time scale shows when organisms first appear in the fossil record.

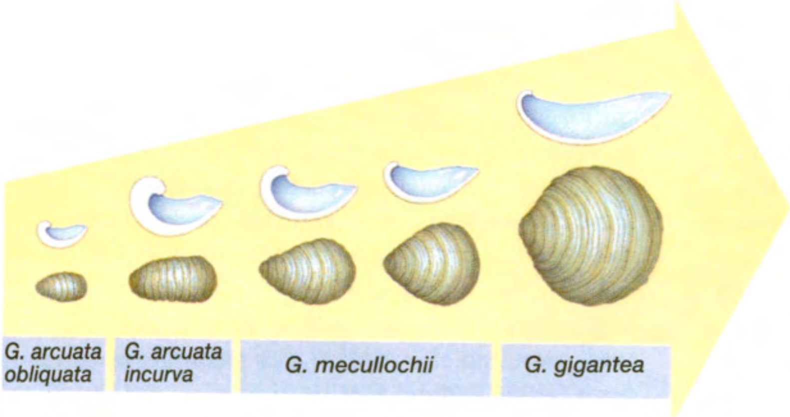
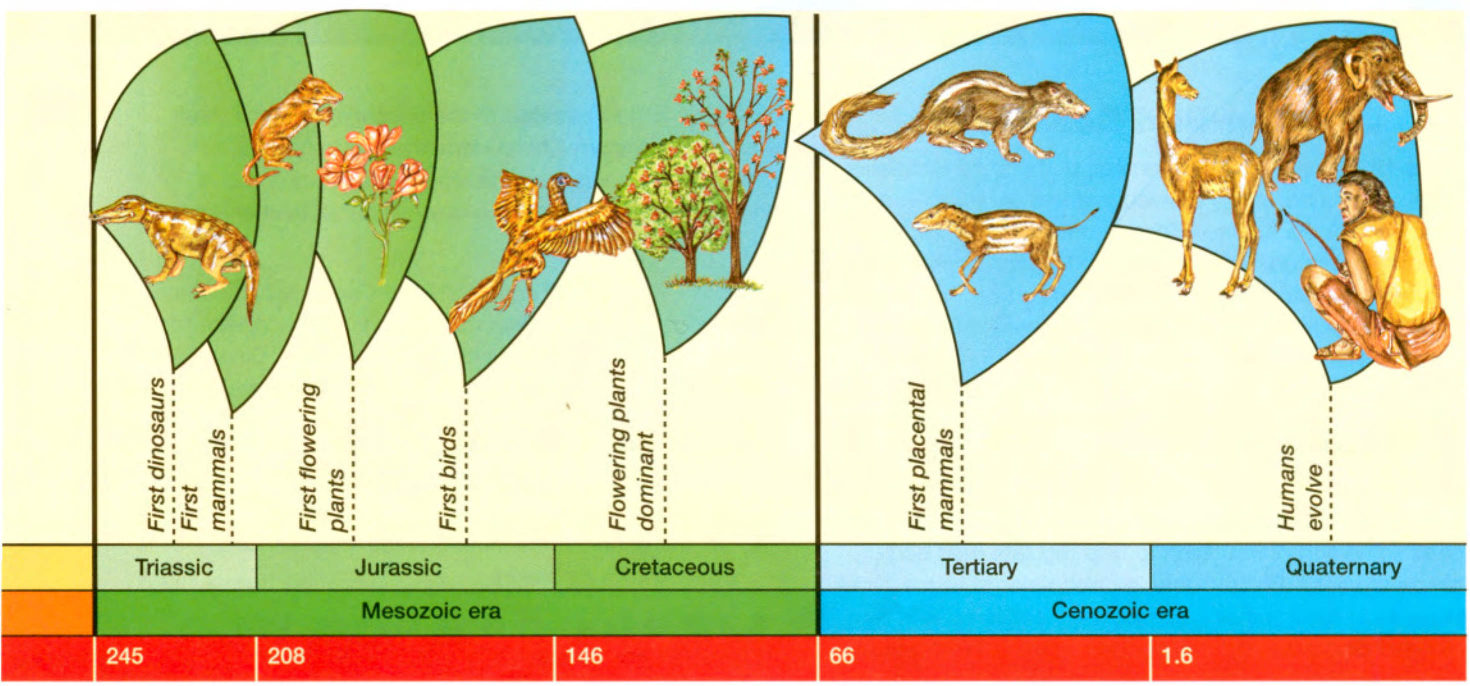


Figure 10.12 Evolution of the oyster shell

How did scientists begin to understand the links between fishes and reptiles or between reptiles and amphibians? What evidence was there to support the main ideas of natural selection — that organisms could slowly adapt and change (even into new species) given vast amounts of time? This idea has been supported by the discovery of hundreds of **transitional fossils**. These fossils show intermediary links between groups of organisms, and share characteristics common to two separate groups.

Archaeopteryx (see Figure 10.13A), for example, lived about 150 million years ago. Fossils of this species reveal characteristics of both reptiles and birds. This creature had feathers, but unlike any modern bird, *Archaeopteryx* had teeth, claws on its wings, and a bony tail. *Archaeopteryx* resembles certain dinosaurs more than any modern bird. This fossil, along with other types of evidence, supports the hypothesis that birds evolved from dinosaurs. (Indeed, if it had not been for the preservation of *Archaeopteryx* feathers, *Archaeopteryx* would have been placed in a group of small, carnivorous, bipedal (two-footed) dinosaurs called theropods.) Several other dinosaurs with feathers have since been unearthed, but *Archaeopteryx* is the first known true-flier and is considered to be the earliest bird.

Figure 10.13A Fossil of *Archaeopteryx*, which shows a link between birds and reptiles



Acanthostega is a fossil that shows the link between fish and amphibians. *Acanthostega* lived about 360 million years ago (see Figure 10.13B). It had gills *and* lungs, stumpy legs, limbs and toes, a long tail almost the length of its body, a crocodile-like snout, and a jaw filled with teeth. Paleontologists do not think *Acanthostega* walked on land. Rather, they believe it used its limbs and toes to grab onto vegetation and pull itself through plant-choked swamps.

Historically, rocks were dated solely by their position relative to one another. Deeper rocks were considered to be older than shallower rocks. Today, new techniques and technologies provide a far more comprehensive understanding of the age of rocks and absolute rather than relative dates. Scientists can now date the rocks in which fossils are found by measuring the degree to which certain radioactive isotopes have decayed since the rock formed. The older the rock, the more its isotopes will have decayed. Radioactive isotopes in rock have been referred to as internal clocks. They measure the time since the rock was formed because they decay at a regular rate.

Figure 10.13B *Acanthostega* **lived in swamps and used limbs and toes to maneuver in swampy waters.**

Paleontologists continue to add to our understanding of evolution. For example, researchers have recently found fossilized whales that link these aquatic mammals to their terrestrial ancestors. The *Basilosaurus* was an ancient whale that had hind limbs but led an entirely aquatic life (see Figure 10.13C on page 353). An earlier transitional form, *Ambolucetus*, had heavier leg bones and was thought to live both on land and in water.

WEB LINK

www.mcgrawhill.ca/links/biology12

Canadian fossil sites, including the Burgess Shale in British Columbia, the rich fossil sites near Drumheller, Alberta, and the Joggins Fossil Cliffs in Nova Scotia, have revealed fascinating information on the evolution of life. To learn more about these sites, go to the web site above, and click on **Web Links**. Choose one fossil site and prepare a short oral presentation or one-page summary on the significance of the site and how it contributed to our understanding of the evolution of life.

MINI LAB

The Dinosaur-Bird Debate

Since 1996, fossils from six families of theropod dinosaurs have been found with preserved feathers or feather-like structures. While *Archaeopteryx* is the first known true-flier, paleontologists do not think that the feathers in the other species were used for flight. Instead, they might have been used for display or to cover eggs in the nests of brooding females. The dinosaur–bird debate actually began in the 1970s, when some paleontologists proposed that dinosaurs might have been warm-blooded and were the direct ancestors of birds. Scientists started to consider the possibility that some dinosaurs might have had feathers, hypothesizing that smaller, warm-blooded dinosaurs would need some sort of insulation to help regulate their body temperature. Dr. Phillip Currie, a paleontologist at the Tyrrell Museum in Alberta, has said that the theories on warm-blooded dinosaurs and the dinosaur origin of birds were "two of the biggest controversies in paleontology at the end of the twentieth century." At first, more people opposed the idea than supported it. However, this trend is now reversing, largely because of the discovery of a rich fossil find in northeastern China. Here, the first feathered dinosaur, *Sinosauropteryx prima*, a small chicken-sized animal that was covered in a downy coat of feather-like structures, was found.

In this activity, you will investigate the dinosaur–bird debate. Using print or Internet resources, gather evidence about the debate and answer the questions posed below. Dinosaurs with feathers include: *Sinosauropteryx*, *Sinornithosaurus*, *Beipiaosaurus*, *Caudipteryx*, *Protarchaeopteryx*, and *Microraptor*.

Analyze

1. List the evidence that supports the idea that birds evolved from dinosaurs.
2. What are the arguments against the idea that birds evolved from dinosaurs?
3. Describe the proposed origin of feathers. Is the use of feathers the same in birds as it is in dinosaurs?

Figure 10.13C Fossilized leg bones of *Basilosaurus,* an ancient whale that provides evidence that whales evolved from terrestrial animals

Geographical Distribution of Species

Biogeography is the study of the geographical distribution of species. Darwin's thinking was influenced by the distribution of animals. Recall that he wondered why the birds in the Galápagos Islands so closely resembled those on the closest continent, South America. This suggests that animals on islands have evolved from mainland migrants, with populations adapting over time to adjust to the environmental conditions of their new home. This idea has since been supported in many studies. Geographically close environments (for example, desert and forest habitats in South America) are more likely to be populated by related species than are locations that are geographically separate but environmentally similar (for example, a desert in Africa and a desert in Australia).

The biogeographical evidence for evolution also points to places such as Australia. Why would so many marsupials but relatively few placental animals live there? (Marsupials such as the kangaroo bear live young, but part of the offspring's development occurs outside the uterus in a pouch. Young develop in the uterus until birth in placental animals.) Australia can clearly support placental mammals; populations of introduced rabbits and mice have certainly increased! The unique marsupials of Australia evolved in isolation from places where the ancestors of placental mammals lived.

Neighbouring New Zealand also has a variety of animals found nowhere else, specifically a variety of flightless birds including the kiwi, the takahe, and the extinct moa, the largest bird to ever live (see Figure 10.14). New Zealand is a country comprised of two large and several small islands. Originally, New Zealand and Australia were part of the supercontinent Gondwana. As these countries drifted away from Gondwana, due to the shifting of the continental plates, they became isolated from other land masses. Once isolated, populations unique, or **endemic**, to these islands evolved.

Islands can have a volcanic origin (such as the Galápagos) or they may have broken off adjacent continental land masses (such as New Zealand). Islands can be colonized by species that swam, flew, or floated from the nearest mainland. Islands with nonvolcanic origins can also be populated by

Figure 10.14 Birds found only in New Zealand include the kiwi (A), the takahe (B), and the moa (C), which is now extinct.

species that remained on the island as it broke away from the mainland. Once isolated on the island, these species begin to evolve in different ways from their ancestors on the mainland. The degree of difference from their ancestors depends on the age of the islands. This can be demonstrated by looking at Madagascar and the Canary Islands, both of which are off the coast of Africa.

Madagascar is an island off the east coast of Africa that was originally connected to the African mainland. Madagascar is thought to have split from the African continent about 150 million years ago, although periodic fluctuations in ocean levels may have reconnected the two on a few occasions up until about 50 million years ago. Today, the channel between Africa and Madagascar is about 400 km wide, so species dispersing to the island during the last 50 million years would have had to cross this channel. Madagascar has 184 species of birds, 125 of which are endemic to Madagascar. Larger birds such as ducks, which can easily cross the water between the two countries, are found in both Africa and Madagascar. However, 90 percent of the land birds in Madagascar are found only there.

Madagascar is also the only place in the world where lemurs are found. However, the fossil record shows that lemurs were once widespread throughout Africa. Lemurs first appear in the fossil record about 65 million years ago; therefore, they were either present on Madagascar when it separated from the African continent or they floated to Madagascar when the channel was narrow. So why are lemurs no longer present in Africa? When Madagascar permanently separated from Africa 50 million years ago, monkeys had not yet evolved. Monkeys do not appear in the fossil record until about 35 million years ago, so they had no way of reaching the island of Madagascar (because the channel between Africa and Madagascar was too wide at that time). However, monkeys eventually took over the niche that lemurs had on the African continent and drove lemurs to extinction there.

The Canary Islands, off the northwest coast of Africa, are about 10 to 15 million years old. They were formed by volcanoes — they were never attached to the African continent. Therefore, unlike Madagascar, the Canary Islands have been colonized only by those animals and plants able to disperse from the adjacent coastline of Africa. Of the 53 bird species known to breed there, only two are endemic. As well, the Canary Islands have no snakes or land mammals (except bats). The eight species of lizards on the islands are thought to have drifted on pieces of wood from the adjacent coastline. They are similar to west African species, yet are sufficiently different to show that natural selection has created some change in the populations. In fact, some of the lizards are now recognized as new species.

Anatomy

When the anatomy of various animals is examined, more evidence for evolution of animals from common ancestors is revealed. Figure 10.15 shows the forelimbs and individual bones of five vertebrates. All of the limbs have the same basic arrangement of bones, yet they are modified into wings, arms, legs, and fins. The present arrangements of bones in the animals shown in Figure 10.15 are variations on a common structural theme. As these animals descended from common ancestors, the same bones were put to different uses. The bones have the same origin yet they now differ in structure and function. Such anatomical signs of evolution are called **homologous structures**. Homologous structures have not only similar numbers of bones but also similar numbers of muscles, ligaments, tendons, and blood vessels. They also have the same developmental origin.

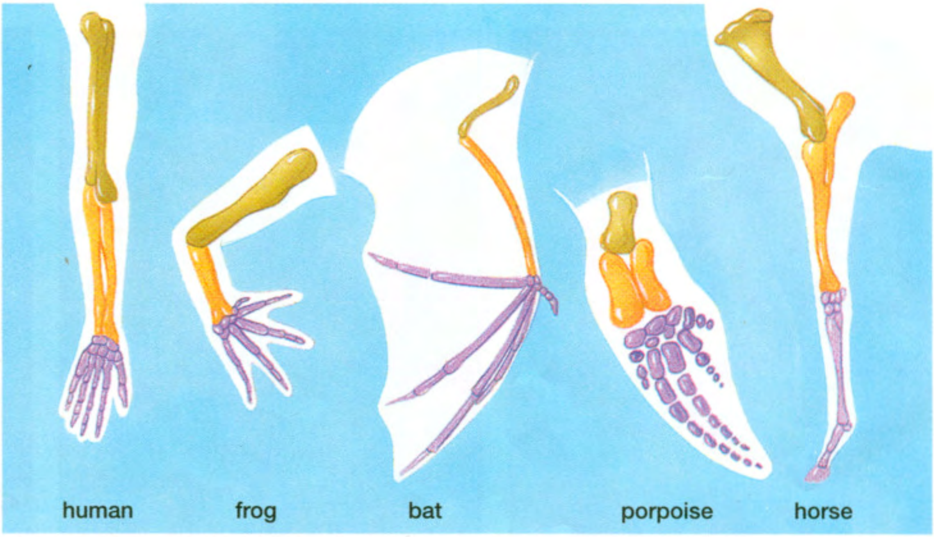


Figure 10.15 These vertebrates have the same basic arrangement of bones, but the bones have been put to different uses.

Homologous structures can be similar in structure, function, or both. For example, the limbs in Figure 10.15 are structurally similar. Also, the limbs of the human, frog, and horse perform the same function: they are designed for walking on land. Functional similarity, however, does not necessarily mean that species are closely related. For example, insect and bird wings are similar in function but not in structure. The wings of these types of animals evolved independently and have very different structures. Bird wings are supported by bones, whereas a tough material called chitin makes up insect wings. Body parts of organisms that do not have a common evolutionary origin but perform similar functions are called **analogous structures**.

Even though analogous structures do not show evolutionary relationships between animals, they do support the idea of natural selection. Bird and insect wings evolved separately when the ancestors of today's species adapted independently to a life that included flight.

Many organisms also possess **vestigial structures**. These are structures that were functional in the organism's ancestors yet have no current function. For example, the baleen whale in Figure 10.16 has vestigial pelvic bones. Pelvic bones perform no function in modern whales since they have no hind limbs. Their presence in modern whales points to the terrestrial origins of ancestral whales. The vestigial pelvic bones are artifacts from the whales' evolutionary history.

The forelimbs of the flightless ostrich are another example of a vestigial structure. The ancestors of modern ostriches were probably able to fly, but they likely foraged and nested on the ground. As a result, over time these animals became quite large and unable to fly, and the forelimbs became unnecessary.

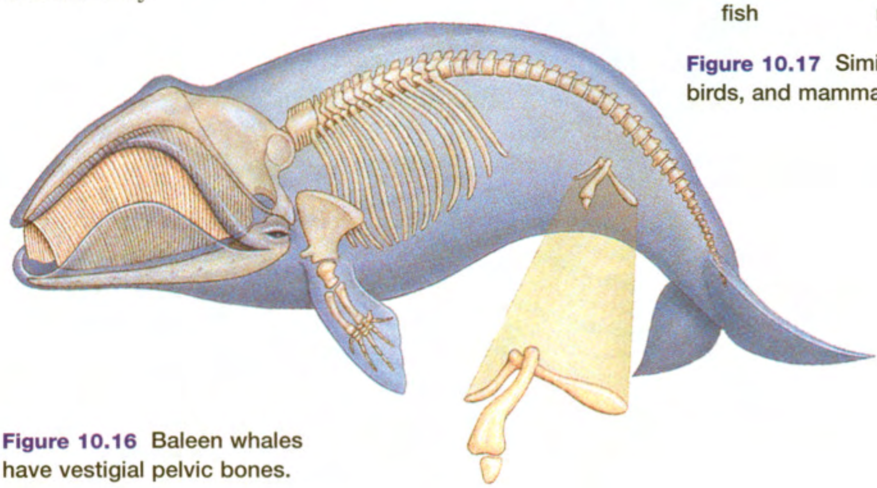


Figure 10.16 Baleen whales have vestigial pelvic bones.

Embryology

Embryology has also been used to determine evolutionary relationships among animals. When the embryos of organisms are examined, similar stages of embryonic development are evident. For example, all vertebrate embryos (including humans) go through a stage in which they have gill pouches (as shown in Figure 10.17). At certain stages in the development of the embryo, the similarities among fish, birds, humans, and all other vertebrates are more apparent than their differences. In Figure 10.17 for example, the early stages of development of fish, reptile, bird, and mammal embryos each have a tail and gill pouches. Gill pouches form gills in fish. In terrestrial vertebrates, the gill pouches are modified for other uses, such as the Eustachian tube in humans. The tail in a human embryo becomes the coccyx at the end of the spine.

These similarities between embryos in related groups (such as vertebrates) point to a common ancestral origin. It follows that related species would share both adult features (such as the number of arm bones, as discussed earlier) and embryonic features (such as the presence of gill pouches).

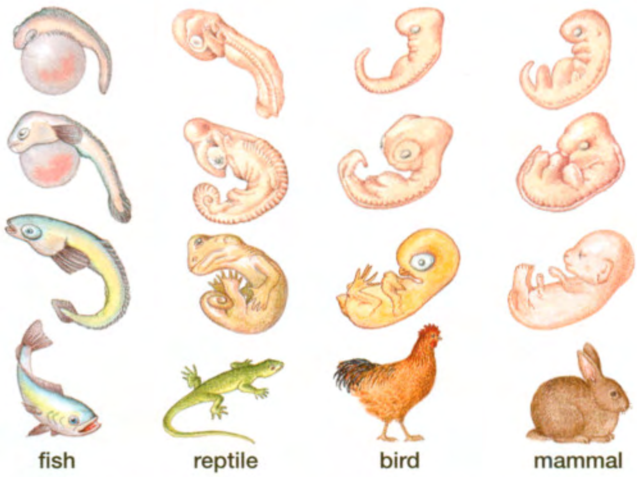


Figure 10.17 Similarities in the embryos of fish, reptiles, birds, and mammals show evidence of evolution.

Heredity

When Darwin published *The Origin of Species*, the science of genetics and an understanding of heredity was not yet established. This meant that Darwin could not completely explain the mechanism that drove natural selection. Today, since the laws of inheritance and the science of genetics are more clearly understood, the variations in organisms required for natural selection to occur can be explained. This will be discussed in further detail in Chapter 11.

Molecular Biology

The evolutionary relationships among species are reflected in their DNA and proteins. Since DNA carries genetic information, how closely related two organisms are can be determined by comparing their DNA. If two species have similar patterns in their DNA, this similarity indicates that these sequences must have been inherited from a common ancestor. For example, by studying gene sequences, scientists have determined that dogs are related to bears and that whales and dolphins are related to ungulates (hoofed animals such as cows and deer).

The degree to which DNA sequences are similar between species determines how closely related those species are. For example, humans and chimpanzees have an approximately 2.5 percent difference between their DNA sequences, while humans and lemurs have a 42 percent difference.

The science of molecular biology has also helped show that all forms of life are related to the earliest

Biology At Work

Paleontologist

In 1985, Wu Xiao-Chun was a student at the Chinese Academy of Sciences. He was studying paleontology. While searching for early crocodiles and dinosaurs, he unearthed a small fossil in southwestern China's Lefung Basin. Thinking it was a fragment of an unimportant lizard-like fossil, he paid little attention to it.

Three years later, Wu Xiao-Chun decided to study the little fossil. As he started chipping away the rock from around the fossil, he began to suspect this was not just a fragment, but rather a complete skull unlike any other reptile fossils found in the same area.

Wu's professor passed the skull on to Dr. Luo Zhe-Xi, a paleontologist at the Carnegie Museum of Natural History in Pittsburgh, Pennsylvania. Dr. Luo and others examined the skull, which was only about the size of a fingernail. Astonishingly, they found that the organism's ear was not encased in its jaw, as is the case with mammal-like reptiles. Instead, the creature's jaw was like that of a modern mammal, even though it had lived in the age of the dinosaurs, some 195 million years ago. The creature also had other modern-mammal features, including a brain cavity that was large in proportion to its skull. Dr. Luo and his colleagues concluded that this was the closest known relative of modern mammals, despite being 45 million years older than any previously discovered mammal. They named it *Hadrocodium wui*. *Hadrocodium* is Latin for "full head," and *wui* refers to its discoverer, Wu Xiao-Chun.

Today Wu Xiao-Chun, now Dr. Wu, is a paleontologist at the Canadian Museum of Nature in Ottawa. He is known for his study of fossils, including feathered dinosaurs, lizard-like animals, and crocodiles in North America, Europe, and Asia. Though Dr. Wu's main interest is in reptiles, he still fondly recalls the day when he unearthed the skull of the world's earliest known mammal.

"I like paleontology because it includes both indoor and outdoor work," he says. "I love hiking." To Dr. Wu, each sediment is "like a mysterious book and the fossils inside like inset pictures or illustrations. Each fossil contains a story."

Career Tips

1. Paleontologists work at universities and at museums such as the Canadian Museum of Nature and the Royal Tyrrell Museum of Paleontology in Drumheller, Alberta. Some also work for private companies.
2. What does this feature tell you about what paleontologists do?

Dr. Wu Xiao-Chun

organisms to some extent. Even organisms that are only remotely related have some proteins in common. One example is **cytochrome c**, a protein involved in cellular respiration that is found in the mitochondria. The amino acid sequence of cytochrome c is so similar among organisms that it can be used to indicate relatedness. The length of the cytochrome c enzyme varies from 103 to 112 amino acids, depending on the organism. The amino acid sequence of the cytochrome c in chimpanzees and rhesus monkeys (both primates) differs by only one amino acid; the sequence in chimpanzees and horses (both mammals) differs by 11 amino acids; and the sequence of the chimpanzee and dogfish (both vertebrates) differs by 24 amino acids.

Scientists have also tracked the evolution of cytochrome c itself. Figure 10.18 shows that the longer the time since an organism evolved from a simple ancestor, the greater the number of differences in nucleotide sequences in the gene for cytochrome c. This also points to the evolutionary idea of organisms having common ancestors. While mutations have substituted amino acids in various places in the protein cytochrome c during the long period of evolution, cytochrome c still has a similar structure and function in all species.

Scientists can also study the evolutionary history of a gene using DNA sequencing. The gene for the protein hemoglobin has been well studied. The pattern of descent, or the **phylogenetic tree**, of the hemoglobin gene is shown in Figure 10.19 on the following page. (A phylogenetic tree shows the pattern of descent. A phylogenetic tree is similar to an evolutionary family tree for an organism.) The progressive changes in the hemoglobin molecule have produced a tree that shows the evolutionary relationships between organisms — the shorter the line in the tree, the more amino acids in common and the closer the evolutionary relationship.

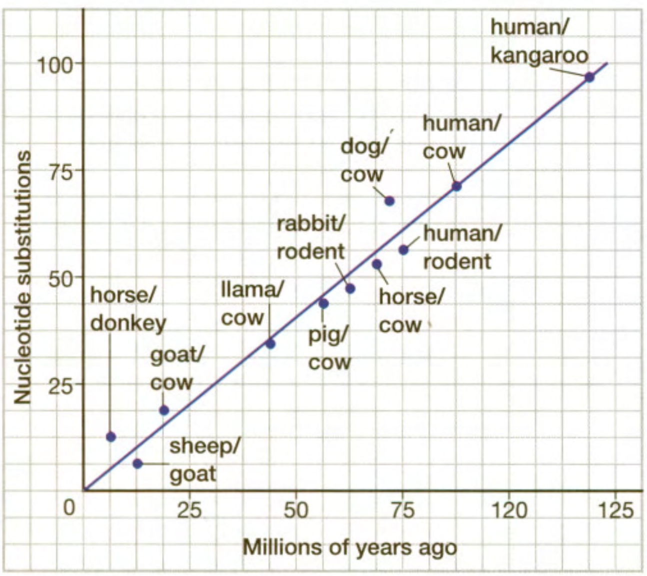


Figure 10.18 Evolution of cytochrome c. The longer an animal diverged from a common ancestor, the greater the difference in genetic sequence.

Defining a Theory

Current understanding of the theory of evolution is dismissed by some as being "just a theory." This implies that somehow a theory is just a guess and therefore is easy to refute. It is important to clarify the use of the words "theory" and "fact" in the realm of science. Scientific facts are the data that have been collected. For example, homologous structures, the fossil record, the DNA sequencing in individual organisms, and the other information presented in this chapter are scientific facts. Scientific theories attempt to explain facts and tie them together in a comprehensive way. For example, the facts gathered by Darwin and people before and after him show that evolution is happening. Darwin's theory of evolution by natural selection is the theory that attempts to tie these facts together.

This chapter has outlined the development of the theory of evolution and the facts from various disciplines, including geography, paleontology, and molecular biology, that all support this theory. The study of evolution continues to spark debate even today. Although there are still lively debates in the scientific community over specific details of exactly *how* life evolved, biologists do not refute the idea of evolution itself.

COURSE CHALLENGE

The evolution of rattlesnake venom or the evolution of sickle cell disease are two potential topics that can be examined in the Course Challenge. Start making notes on the links that evolution (in general) has with metabolic processes, homeostasis, and molecular genetics. In the next unit, think about how the population dynamics might, in turn, be affected by changes in populations.

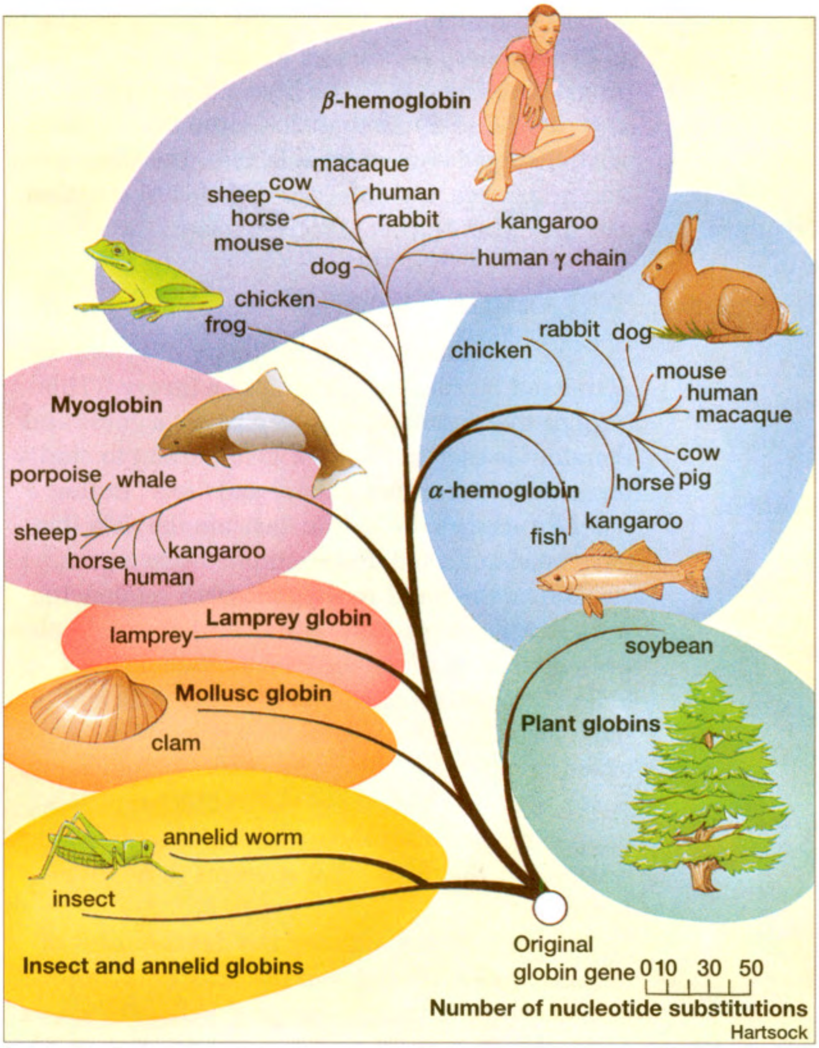


Figure 10.19 Evolution of the globin gene

SECTION REVIEW

1. K/U How does the discovery of so-called missing links in the fossil record help us to understand evolutionary events of the past?

2. C Choose a fossil (either one described in this text or another one you have researched) and describe what information this fossil provides that helps us understand evolution. Give reasons for your opinion.

3. K/U How do the number of endemic species differ between Madagascar and the Canary Islands? Explain why these differences exist.

4. K/U Describe how the anatomy of animals is used to explain evolution.

5. K/U Baleen whales, such as grey and humpback whales, have teeth and body hair while they are embryos, but they lack these features as adults. What does this tell us about the evolutionary history of these animals?

6. K/U When human organs are transplanted, the rate of success is higher in cases where the donor and recipient are close relatives. Why do you think this is so?

7. C Explain how the differences in the sequence of amino acids that make up cytochrome c in different kinds of organisms help us understand evolution.

8. MC Biologist Stephen Jay Gould wrote, "The fact of evolution is as well established as anything in science (as secure as the revolution of the earth around the sun) ... Theories, or statements about the causes of documented evolutionary change, are now in a period of intense debate — a good mark of science in its healthiest state. Facts don't disappear while scientists debate theories." Explain the difference between fact and theory as they relate to science.

9. I Make a hypothesis concerning what species changes and what environmental changes you would expect to see on Madagascar if it were to become reconnected to the mainland of Africa. How might a scientist test your hypothesis?