7.2 The Evolution of an Idea

immutable unable to change

Dating back at least as far as Aristotle (384–322 BCE), most Europeans accepted the idea that Earth and all living things had been created in their present forms and were **immutable**—they could not change and had not changed. The explanations for all natural phenomena were largely based on strongly held religious beliefs, philosophical debate, and thoughtful conjecture. It was not until science began to come of age in the fifteenth to eighteenth centuries that European philosophers recognized the importance of careful observation, experimentation, and deductive reasoning. During this time Copernicus, Galileo, and Newton demonstrated the power of science to explain the laws of motion, both on Earth and in the skies above.

The Seeds of an Idea

Figure 1 Many mammals, including pigs, have toes that do not reach the ground. Buffon puzzled over such useless features and considered them strong evidence that these species had changed over time.

A French scientist, Comte (Count) Georges-Louis Leclerc de Buffon (1707–1788), applied scientific methods to the detailed study of anatomy. He closely examined animal body structures, considered their functions, and tried to account for his findings. Buffon was puzzled by anatomical features that seemed to serve no purpose. For example, he wondered why pigs have extra toes that do not reach the ground (**Figure 1**). Buffon believed the species had been created in a more perfect form but had changed over time.

At about the same time, other prominent scientists, including Carl Linnaeus (1707–1778) and Erasmus Darwin (1731–1802), also proposed that life changed over time. Erasmus Darwin, the grandfather of Charles Darwin, even suggested that all life might have evolved from a single original source.

While the seeds of evolutionary thought had been sown, these scientists could offer no explanation for how living things change. Without a plausible mechanism to explain how a species could change, their ideas remained speculative.

Adaptation and Heredity

Figure 2 Muscles increase in size in response to vigorous exercise. Such an increase in size is considered an acquired characteristic.

A student of Buffon's, Jean-Baptiste Pierre Antoine de Monet, Chevalier de Lamarck (1744–1829), was the first scientist to offer a possible mechanism for the evolution of species. Lamarck proposed that evolutionary change resulted from two distinct principles.

Lamarck's first principle was that of *use and disuse*. He believed that structures an individual used became larger and stronger, while structures that were not used became smaller and weaker. On the surface, this principle seems to be supported by evidence from everyday observations. When athletes train, their muscles respond by getting stronger and increasing in size (**Figure 2**). Conversely, astronauts who return from space have reduced muscle mass resulting from lack of use. It seems reasonable to think that similar responses to use and disuse might occur among all organisms.

Lamarck's second principle was *the inheritance of acquired characteristics*. Lamarck believed that individuals could pass on to their offspring characteristics they had acquired during their lives. He believed, for example, that if an adult giraffe stretched its neck during its lifetime, then its offspring would be born with slightly longer necks.

To Lamarck, these two principles could explain why species were so adapted to their environment and how they could evolve if the environment changed. If the climate gradually cooled, animals might respond by growing a thicker coat of hair and would pass on this acquired characteristic to their offspring. Their offspring would then be born better adapted to the changing environment. The example of the giraffe's neck is often used to illustrate Lamarck's theory (**Figure 3**, next page).

Today we know that Lamarck's theory is flawed. Although organisms can acquire many characteristics during their lives, many features do not change in response to use, and features that do change are not normally heritable. For example, your vision does not improve the more you use your eyes. It is possible to stretch your neck slightly, but this will not alter your DNA, and your children will not be born with longer necks.

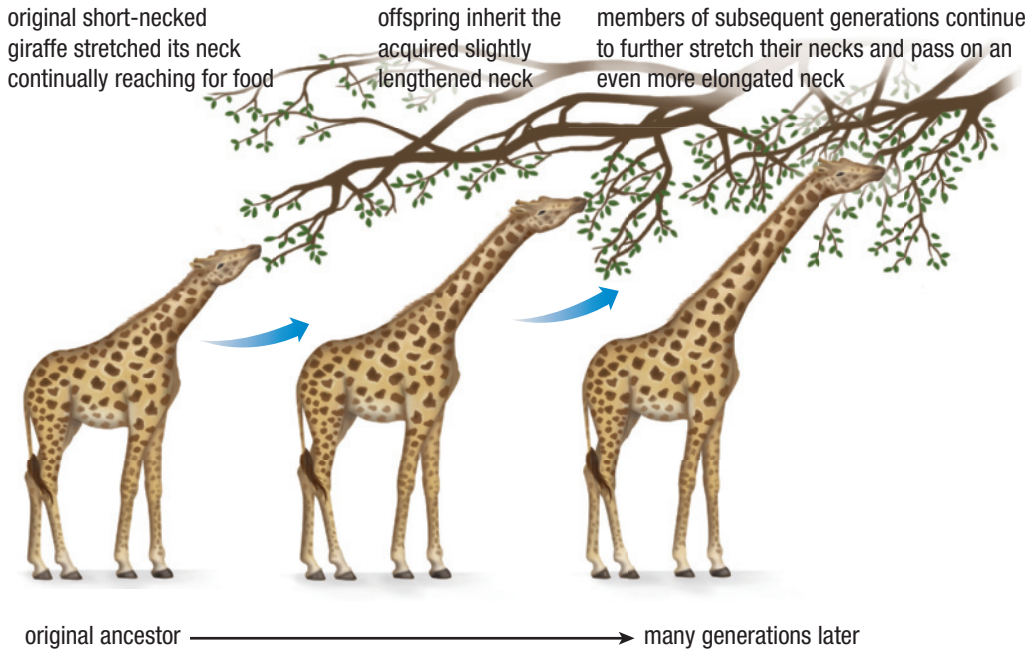


Figure 3 Lamarck's theory of evolution by the inheritance of acquired characteristics

Despite Lamarck's flawed theory, he did make a number of very significant contributions to our understanding of evolution. Lamarck proposed the following:

- All species evolve over time.
- A species evolves in response to its environment and becomes better adapted to that environment.
- Changes are passed on from generation to generation.

Lamarck's theory stimulated a great deal of scientific discussion, and his contributions provided a sound basis for the theory of evolution that would follow.

Patterns of Change

Even scientists who did not accept the idea that species could change were finding evidence that was extremely puzzling. They found some of this evidence in the form of **fossils**, which are preserved ancient remains of dead organisms. A minimum age of 10 000 years is sometimes used as a criterion for designating remains as a fossil.

fossil any ancient remains, impressions, or traces of an organism or traces of its activity that have been preserved in rocks or other mineral deposits in Earth's crust

Fossil Formation

Most fossils are hard impressions in solid rock. Many leave little doubt as to what they represent. No one could mistake a well-preserved fossil of *Knightia* (**Figure 4(a)**) for anything other than a fish or fail to recognize an obvious fossilized leaf (**Figure 4(b)**). It seemed self-evident to most scientists that such fossils had been formed by once-living organisms.

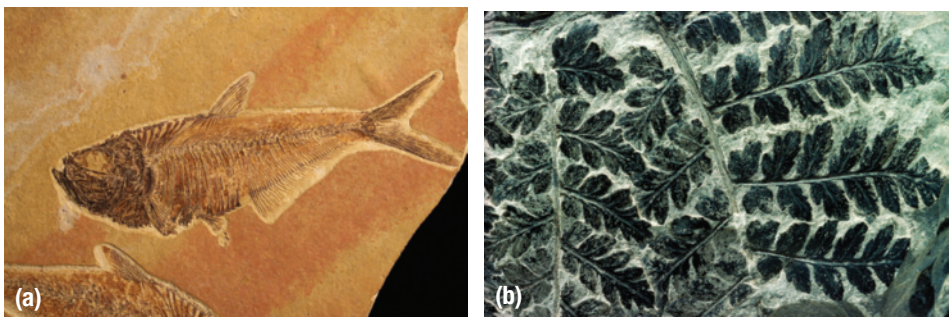
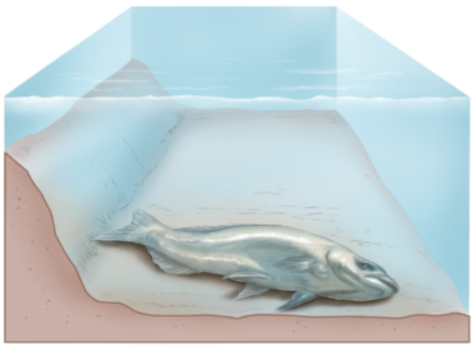
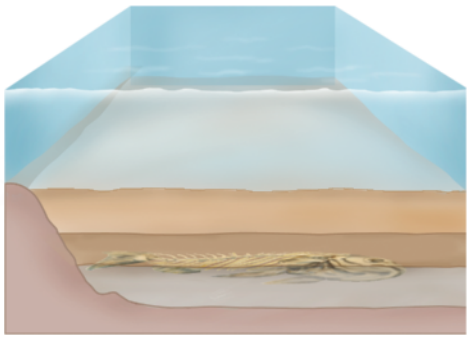


Figure 4 Fossils of both (a) *Knightia* and (b) leaves are extremely abundant in some rock formations.

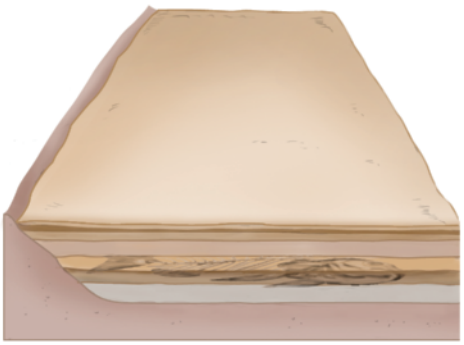
Fossils are formed when the remains of a buried organism are gradually replaced by mineral deposits (**Figure 5**). After an organism dies, the body usually decomposes. However, if it sinks to the bottom of a body of water and is quickly buried by sediments, the resulting lack of oxygen can prevent decomposition. As sediments accumulate over time, the body becomes compressed, and very gradually chemical changes occur that result in the body being mineralized.



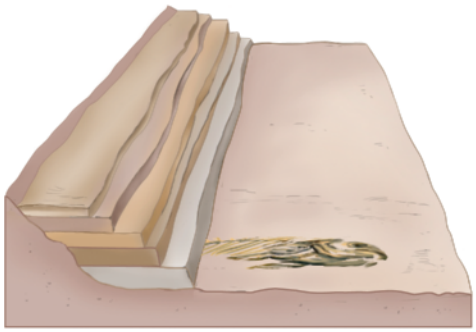
(a) dead organism



(b) organism is buried and compressed under many layers of sediment



(c) under high pressure deposits harden to form sedimentary rock and the fossil remains become mineralized



(d) erosion or excavation of sedimentary rock exposes fossil remains

Figure 5 (a) Most fossils form under water when an organism becomes buried in thick sediments. (b) In the absence of oxygen the organism does not decay. (c) Over time the chemical action and the pressure of the sediments change the organism into a mineralized form. (d) Fossils dating back millions and even billions of years may be found when such deposits are excavated.

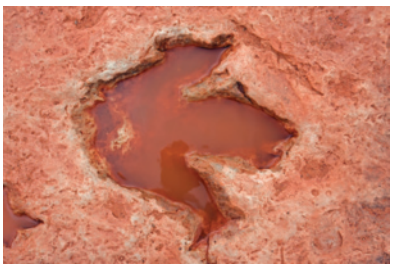


Figure 6 Under the right conditions, footprints can become fossilized.

Figure 7 Organisms can be preserved in amber.

The necessary conditions for fossil formation are rare. When oxygen is present, bodies usually decompose too quickly to fossilize. Therefore, only organisms that die in low-oxygen locations will fossilize. Most often these are aquatic organisms living where sediment is continuously deposited. In addition, organisms with hard body parts such as shells, bones, and teeth are much more likely to be preserved than soft-bodied organisms. As a consequence, fossils of marine organisms with hard body parts, such as clams and snails, are very common, whereas fossils of land animals and plants are much less common. Dinosaur fossils are well known but are very rare in comparison to fossils of marine organisms. Fossils can also be formed from footprints, burrows, and even fecal remains. Sediments may fill in a footprint or burrow and then harden over time to create a fossil (**Figure 6**).

Organisms can also become trapped and preserved in amber—fossilized tree sap (**Figure 7**). Some of the most well-preserved fossils are formed when an entire organism becomes trapped in materials that preserve its chemical remains. Similarly, well-preserved fossils are formed when organisms are trapped in volcanic ash, ice formations such as permafrost, or acidic bogs.

Reading the Fossil Record

At first, scientists may have speculated that fossils were nothing more than recently living organisms that had become trapped in muddy deposits and then hardened over a relatively brief period of time. Perhaps fossils were just preserved plants and animals that were no more than a few hundred or a few thousand years old. This simple explanation was quickly contradicted by a number of observations that this idea could not explain:

- Many fossils appear to be of unusual and unknown organisms. There are fossils of thousands of species that are no longer living (**Figure 8**).
- There are no fossils of most living species.
- Fossils are often buried very deep within rock formations. Some are more than a kilometre below Earth's surface.
- Fossils are often found in unexpected locations. For example, fossils of sea life are found high in mountain formations and in present-day deserts.

Figure 8 Fossils of dinosaurs, like this triceratops, leave little doubt that some fossil species are dramatically different than any species alive today.

Such observations were of great interest to early scientists. They became determined to develop a better understanding of how fossils formed and to understand what fossils could tell us about life in the past. The emerging science that studied fossil organisms to learn about prehistoric life was called **paleontology** (**Figure 9**).

paleontology the scientific investigation of prehistoric life through the study of fossils

Paleontologists used fossils to provide evidence that life had been very different in the past. Also around this time, the field of geology, the study of Earth's physical structure, was beginning to develop. Two prominent scientists, a paleontologist named Georges Cuvier and a geologist named Charles Lyell, began to provide a wealth of new evidence on how species and Earth might have changed over time.

Figure 9 Paleontologists study fossil plants and animals.

Catastrophism and Uniformitarianism

The famous paleontologist Georges Cuvier (1769–1832) conducted the first detailed studies of fossils. Cuvier noted the following:

- Fossils of very simple organisms are found in all depths of fossil deposits.
- Fossils of more complex organisms are found only at shallower depths, in younger rock.
- Fossils in the shallower depths are more likely to resemble living species.
- Rock layers contain fossils of many species that do not occur in layers above or below them (**Figure 10**).

Figure 10 Cuvier noticed that all fossils from deeper layers were simpler than the more complex fossils above them.

Such observations offered strong support for the theory that life had evolved from simple to more complex forms over time. The oldest fossil deposits contain only simple life forms. More recent fossil deposits contain species that are both more complex and more similar to present living species.

Although the fossils Cuvier found showed a clear pattern of change from layer to layer, Cuvier believed that species themselves did not change. Instead, he proposed a theory of catastrophism. According to the theory of **catastrophism**, global catastrophes such as floods caused the widespread extinctions of species. These extinct species, some of which were fossilized, were then replaced by a newly created set of species. Cuvier's theory accounted for the different groups of species in each layer but did not adequately account for why each layer included progressively more complex forms.

catastrophism the theory that the pattern of fossils could be accounted for by a series of global catastrophes that wiped out most species on Earth

At about the same time that Cuvier was postulating catastrophism, Charles Lyell (1797–1875) was studying rocks and fossils and coming to the opposite conclusion. Considered the father of modern geology, Lyell revolutionized geology with his theory of uniformitarianism. In 1830, Lyell put forth the following principles of **uniformitarianism** in his now famous *Principles of Geology*:

uniformitarianism the theory that geological changes are slow and gradual and that natural laws and processes have not changed over time

- Earth has been changed by the same processes in the past that are occurring in the present.
- Geological change is slow and gradual rather than fast and catastrophic.
- Natural laws that influence these changes are constant and eternal, and they operated in the past with the same intensity as they do today.

Figure 11 Millions of years are required for these layers of rock to accumulate and then to be slowly eroded away.

Lyell's ideas were radical. He was proposing that entire mountain ranges might have formed by extremely slow processes, and that deep gorges were the product of slow erosion (**Figure 11**). Lyell's theories directly challenged the belief in a very young Earth. If he was right, Earth was extremely old and life had had a very long time to undergo evolutionary change.

CAREER **LINK**

Paleontologist

Paleontologists are scientists who study ancient fossilized remains. Their work may require expeditions to different parts of the world. To learn more about becoming a paleontologist,

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CAREER **LINK**

Geologist

Geologists study the physical structure of Earth and how it has changed over time. To learn more about becoming a geologist,

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Research This

Paleontology and Geology

Skills: Researching, Evaluating, Communicating

SKILLS HANDBOOK A5.1

The anatomist and paleontologist Baron Georges Cuvier and the geologist Sir Charles Lyell made substantial contributions to our early understanding of the history of life on Earth. In this research activity you and a partner will investigate the contributions of these individuals.

1. With your partner, use the Internet and other sources to research the lives of Cuvier and Lyell. When and where were they born? What were their social status, upbringing, and education? Take note of any unusual aspects of their lives.
2. Document Cuvier's and Lyell's contributions to paleontology and/or geology. Include their association with catastrophism and uniformitarianism.

A. Create a short biographical sketch of these two individuals. You may wish to present your sketch in the form of a personal profile on an Internet social networking or blog page. T/I C

B. In your sketch or profile, include a summary of their contributions to science. In what ways did they break new ground in our scientific understanding of Earth and life on Earth? T/I C

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The Stage Is Set

By the nineteenth century, scientific thought regarding the history of Earth and its life forms was undergoing substantial change. There was growing evidence that Earth was ancient and that species might be evolving. However, the mechanism for such change had yet to be adequately explained. Lamarck's contributions to ideas about evolution were significant, but his explanation for how life evolves was unsatisfactory. Unlike the debate over the age of Earth, however, the search for a mechanism for evolution would not have to wait for very long. It was to become the life's work of a young man named Charles Darwin (**Figure 12**).

Figure 12 Charles Darwin

7.2 Summary

- By the eighteenth century, scientists were beginning to gather evidence supporting the theory that life had changed over time.
- Lamarck was the first scientist to recognize that species evolved in response to their environment, but his hypothesis of how species evolved has proven to be incorrect.
- Fossils provide compelling evidence that species living in the past were different from those living in the present.
- Fossils show that organisms become increasingly complex over time, with the most complex organisms being found in only more recent fossil deposits.
- Cuvier proposed that species did not change but were eliminated by catastrophic events, only to be replaced by newly created forms.
- Lyell proposed that Earth's geologic features can be explained by very slow changes occurring over very long periods of time.

7.2 Questions

1. (a) Why was Buffon puzzled by pig's toes?
   (b) How did he explain them? K/U
2. What explanation did Lamarck propose for how species had changed over time? K/U
3. What role did Lamarck believe the environment played in evolution? K/U
4. Use Lamarck's theory to explain the evolution of running speed in cheetahs. K/U A
5. Based on Lamarck's theory of evolution, what could you do to ensure your children were born with enhanced musical ability? K/U A
6. Illustrate the process of fossil formation using labelled sketches. K/U C
7. What do the following characteristics of fossils reveal about the history of life on Earth? K/U A
   (a) Some fossils of marine organisms are discovered at high elevations in mountains.
   (b) Most fossils are of species that are no longer living.
   (c) Most living organisms are not found in the fossil record.
   (d) Most fossils are of marine organisms.
   (e) The oldest fossil deposits contain only simple organisms. More recent deposits contain both simple and complex fossils.
8. How did the theory of catastrophism account for patterns seen in the fossil record? K/U
9. How did the theory of uniformitarianism account for patterns seen in geology? K/U
10. How might it be possible for fossils to provide evidence about the behaviour of an organism? A
11. There is fossil evidence supporting the hypothesis that some dinosaurs exhibited social behaviour. In what ways do you speculate dinosaurs might have been social? What sort of fossil evidence do you think might support such a hypothesis? Use the Internet and other sources to investigate these questions and report your findings to the class. T/I A C
12. Imagine you were asked to excavate fossils from deposits near the top of the Grand Canyon and near the bottom. Predict any pattern you would expect to find in the fossils. T/I A
13. The most famous fossil deposit in Canada is the Burgess Shale. Use the Internet and other sources to find answers to the following questions: T/I A C
    (a) Where is the Burgess Shale located?
    (b) When and by whom was it discovered?
    (c) What is the age of the fossils in the deposit?
    (d) What makes the deposit of special interest?
14. There are many rock formations containing fossil deposits throughout Ontario. Find out about any such formations in your area and consider seeking appropriate permission and organizing a fossil-collecting trip. T/I

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