Evidence From the Past 11.2

Strong evidence for a changing Earth began with a careful examination of **fossils**. Near the end of the 15th century, Leonardo da Vinci pondered the numerous seashell remains he found high in the Tuscany mountains, hundreds of kilometres from any sea. He became convinced that these very old shell deposits had been formed in an ancient ocean and concluded that Earth's surface had changed dramatically over time.

fossils any preserved remains or traces of an organism or its activity; many fossils are of such hardened body parts as bone

permineralized fossil a fossil formed when dissolved minerals precipitate from a solution in the space occupied by the organism's remains

The Fossil Record

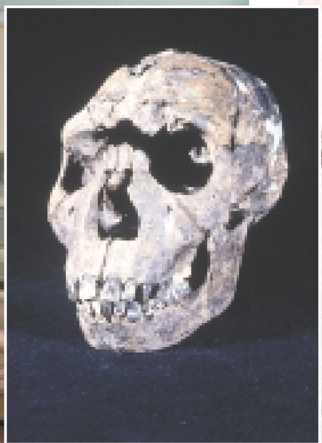
The fossils da Vinci had been examining were traces of organisms from the past. By the late 17th century, geologists had begun to map locations where exposed layers of rock contained distinctive and remarkable fossils that were considered to be evidence of prehistoric life. In 1669, Nicholas Steno's detailed and impressive analyses of fossils clearly demonstrated that they were mineralized remains of living organisms. These ideas were supported by such respected scientists as Robert Hooke, who was among the first scientists to suggest that the surface of Earth had changed over time.

The most common and easily recognized fossils are such hard body parts as shells, bones, and teeth (**Figure 1**). Fossils also include impressions of burrows, footprints, and even chemical remains. Fossils are commonly formed when the bodies of organisms become trapped in sediments, which become compressed into strata, or layers, and eventually harden into sedimentary rock. Many fossils have been unearthed by digging, quarrying, and such natural causes as erosion and Earth movements or slides (**Figure 2**, page 512). An organism may simply leave an impression in hardened material, or, if the rate of decomposition is very slow, the organism's cells may be replaced by minerals, resulting in a **permineralized fossil**. On rare occasions, when conditions

DID YOU KNOW?

Fossils Offer Evidence of Environmental Change

Just as da Vinci found seashell fossils in mountain rock formations, palaeontologists have found 40- to 50–million-year-old whale, clam, snail, and other marine species remains in the deserts of Egypt—clear indications that the environment was considerably different when they were living. Fossilized pollen grains can provide excellent information about the climate that existed when the pollen was deposited.

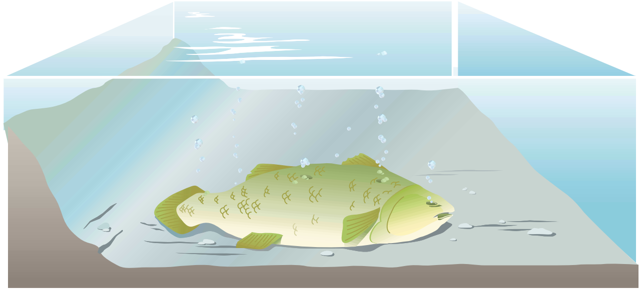


(b) skull of a young male *Homo erectus*

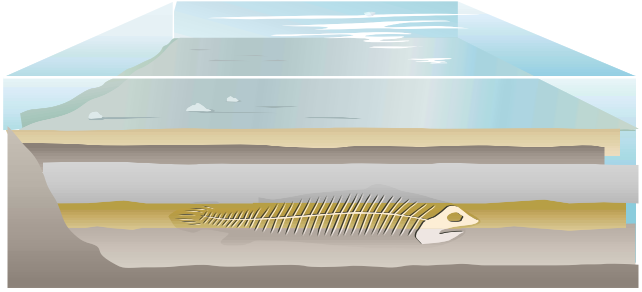
(c) *Pterodactylus kochi* from the Jurassic period

(a) reconstructed mammoth skeleton

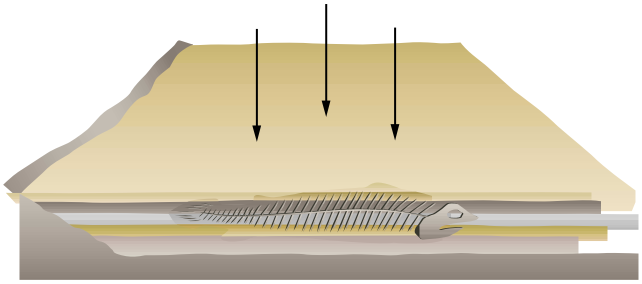
Figure 1
Fossils may be organisms that have been **(a)** preserved intact, **(b)** hard body parts, or **(c)** impressions.



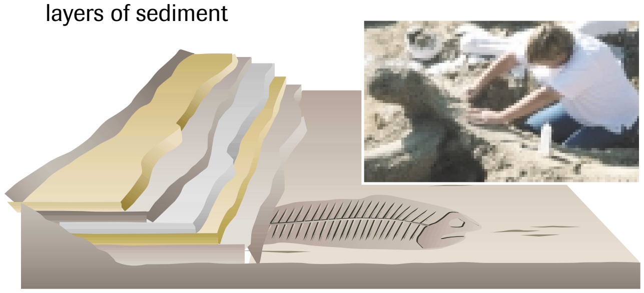
(a) dead organism



(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 on the surface

Figure 2
Long after fossils form in sedimentary rock, mechanisms such as changing sea level, faults, erosion, and human excavation may bring these fossils to the surface (see inset photo).

fossilization the process by which traces of past organisms become part of sedimentary rock layers or, more rarely, hardened tar pits, volcanic ash, peat bogs, or amber

microfossils microscopic remains of tiny organisms or structures that have hard and resistant outer coverings

prevent most decomposition, organisms may be preserved nearly intact; such fossils have been found in tar pits, volcanic ash, peat bogs, permanently frozen ground, and amber (**Figure 3**), or hardened tree sap.

The ideal conditions for **fossilization** are rare. After an organism dies, its soft parts usually are consumed or decompose quickly. Consequently, organisms that have hard shells or bones and that live in or near aquatic environments are much more likely to become fossilized than soft-bodied and land-dwelling species. Although fossils of large land animals such as dinosaurs and sabre-toothed cats are well known, they are rare. Much more common are fossils of hard-bodied marine organisms such as clams and snails. The most abundant are **microfossils**, microscopic remains, such as those of pollen and foraminifera. Regardless of the size of a species, fossils offer unique opportunities to observe evidence of past life directly.

Figure 3
Insect fossilized in amber

TRY THIS *activity* — Visit the Tyrrell on the Web

The Royal Tyrrell Museum in Alberta is one of the world's foremost fossil research centres. At the museum's web site you can

- take the virtual tour of the museum to see what fossils are on display;
- check the "What's Hot" feature and write a short report on the latest fossil discoveries;
- submit a question to "Ask a Palaeontologist;"
- find out the education and training needed to be a palaeontologist.

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The Study of Fossils

The systematic study of fossils—now referred to as **palaeontology**—began in the 18th century, most notably by the respected anatomist, Baron Georges Cuvier. His extensive investigations of fossils revealed that many fossils were of extinct species and that different sedimentary strata contained distinctive fossilized species. His evidence for extinction challenged the widely held view of his time that all fossils were of living species, some of which had yet to be discovered. Today's fossil record comprises more than 250 000 identified species, a number thought to be only a tiny fraction of all species that have lived on Earth. Less than 1% of species in the fossil record are living today.

Cuvier observed that while fossils of simple organisms could be found at all depths, more complex forms were found in the shallower deposits. In addition, fossils contained in shallower deposits were more likely to resemble living species. Each layer seemed to contain many distinct species not found in layers above or below it. He was puzzled by such findings, as he did not believe that species changed over time. Like others of the time, Cuvier believed that all life on Earth had been created. However, rather than believing in a single creation, he suggested that multiple events had occurred at different times. According to his theory of **catastrophism**, local catastrophes such as floods could cause widespread extinctions. These extinct life forms would then be replaced by newly created species. Although this explanation could account for the fossils of new species being found above fossils of extinct species in the same location, it could not account for the progressive complexity of species.

Cuvier determined the **relative age** of fossil deposits by assuming a chronology for rock strata and a corresponding sequence for the location of fossils in the layers. Based on his observations of sediment deposition, he reasoned that deeper deposits were older and, therefore, contained more ancient fossils, while shallower deposits were more recently formed and contained younger fossils. However, Cuvier and others of his time had no precise method for calculating an **absolute age** for the rock or the fossils embedded in them. Not until nearly a century later did scientists have the means to determine such ages.

palaeontology the scientific study of fossil remains

catastrophism Cuvier's theory that numerous global catastrophes in the past had repeatedly caused the extinction of species that were then replaced by newly created forms

relative age an estimate of the age of a rock or fossil specimen in relation to another specimen

absolute age an estimate of the actual age of a rock or fossil specimen

ACTIVITY 11.2.1

Applying Fossil Evidence (p. 534)
How can you apply fossil evidence to test hypotheses about the history of life on Earth? In this activity, you can test your own hypotheses about fossil evidence much as Cuvier did.

The Age of Earth

Physicist Lord William Thomson Kelvin was the first to try to determine the age of Earth through rigorous mathematical and scientific calculations. In 1866, based on the assumption that Earth was gradually cooling down, he assigned it an absolute age of 400 million years; he later revised his estimate to 15 million to 20 million years. As Kelvin's abilities were very highly regarded, few thought to question his estimates. The discovery, by Pierre Curie in 1903, that **radioactive decay** produces heat suggested that radioactive decay within Earth was a major heat source, so Kelvin's model of a once-molten Earth simply cooling off was no longer considered valid. The study of radioactivity also provided geologists with the means to estimate the absolute age of Earth with much greater precision.

Radiometric and other techniques have been used to date meteorites samples (**Figure 4**). Virtually every meteorite that has struck Earth has yielded an age of 4.6 billion years. Moon rocks collected during Apollo missions have all been dated at about 4.53 billion years in age. The oldest rock on Earth—from the Canadian Shield north of Yellowknife—has been dated at about 3.9 billion years. Scientists now believe that this is the age at which the Earth cooled enough that the oldest solidified rock did not undergo further remelting. It is therefore thought that Earth may be about 4.6 billion years old.

radioactive decay the release of subatomic particles from the nucleus of an atom, which results in the change of a radioactive parent isotope into a daughter isotope; when the number of protons is altered, a different element is formed

Figure 4
Meteorites provide evidence about the age of other bodies in the solar system and universe.

radioisotopes atoms with an unstable nuclear arrangement that undergo radioactive decay

parent isotope changes into a daughter isotope as radioactive decay occurs

daughter isotope what a parent isotope changes into during radioactive decay; may be stable or may be radioactive and capable of further decay

half-life the time required for half a radioactive material to undergo decay; for any given isotope the half-life is constant

radiometric dating calculation of the age of rock—and of embedded fossils or other objects—through the measurement of the decay of radioisotopes in the rock

Radiometric Dating

Radioisotopes are atoms that undergo radioactive decay, and radioactive decay rates can be measured very accurately. The decay of radioactive materials changes a **parent isotope** into a **daughter isotope** of the same element or of a different element. For example, radioactive potassium 40 (^{40}K), can undergo two forms of decay: it can change into either argon 40 (^{40}Ar), or calcium 40 (^{40}Ca). Each radioisotope decays at its own constant rate, measured in a unit called a **half-life**. A half-life is the time it takes 50% of a sample of a parent isotope to decay into a daughter isotope (**Figure 5**). Physicists have determined the half-lives of many radioactive materials (**Table 1**), which are considered accurate to within a few percentages. The rate of half-life decay for different isotopes varies considerably

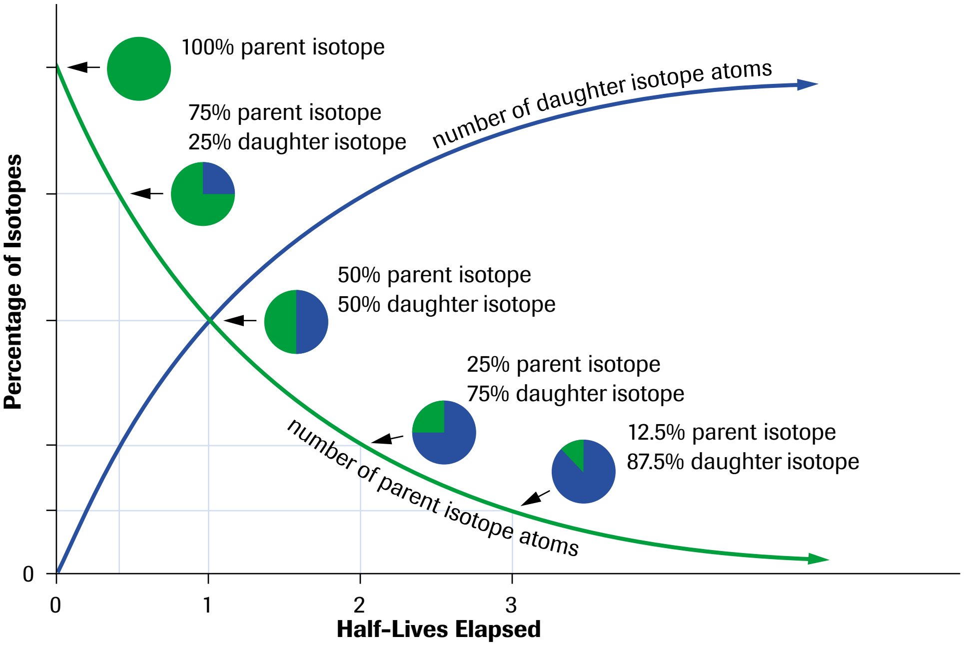

Figure 5
During each half-life of radioactive decay, 50% of a parent isotope decays into a daughter isotope. The result is a quantitative, predictable relationship between the ratio of parent-to-daughter isotopes and elapsed time.

Table 1 Radioisotopes Used in Radiometric Dating

Parent isotope	Daughter isotopes	Half-life (years)	Effective dating range (years)
^{14}C (carbon 14)	^{14}N (nitrogen 14)	5730	100 to 100 000
^{235}U (uranium 235)	^{207}Pb (lead 207)	713 million	10 million to 4.6 billion
^{40}K (potassium 40)	^{40}Ar (argon 40) and ^{40}Ca (calcium 40)	1.3 billion	100 000 to 4.6 billion

but is unaffected by temperature, moisture, or other environmental conditions. As the half-life for a given isotope is constant over time, it can be used as a naturally occurring radiometric clock. Since modern palaeontologists are able to measure the age of rock through **radiometric dating**, they can estimate much more accurate ages for fossils found between layers of rock that contain radioactive materials. Because carbon is found in all living things, carbon-14 dating can be used to determine the age of organic materials directly. The relatively short half-life of carbon 14—at 5730 years—makes it unreliable for testing objects more than 100 000 years old; it is, however, ideally suited for testing such archaeological finds as human remains.

Potassium–Argon Dating

SAMPLE problem

When a volcano erupts, gases in the lava escape. As a result, when the lava cools to form igneous rock, it may contain radioactive potassium, ^{40}K, but it will not contain argon gas, ^{40}Ar. As radioactive decay occurs, some argon daughter isotopes will accumulate within the solid rock. Thus, the ratio of the amount of ^{40}K to the amount of ^{40}Ar present when samples are taken can be used to determine how long ago the rock in the sample formed.

Example

A sample of igneous rock contains small amounts of radioactive potassium and argon. Using the ratio of ^{40}Ar to ^{40}K , it is determined that only 25% of the original parent potassium isotope remains. How old is this rock sample?

Solution

Figure 5 shows that it requires two half-lives for the ratio of parent-to-daughter isotopes to change from 100%:0% to 25%:75%. Given a half-life for ^{40}K of 1.3 billion years (**Table 1**), this igneous rock formed 2.6 billion years ago.

Practice

Understanding Concepts

1. A sample of igneous rock is found to contain the radioactive parent and daughter isotopes uranium, ^{235}U, and lead, ^{207}Pb, in the ratio of 12.5%:87.5%. Assuming that no ^{207}Pb was present when the rock first formed, estimate the age of this sample.
2. A fossil skull of *Homo neanderthalensis*, is discovered in northern Europe and is tested using carbon-14 dating. Palaeontologists are curious about whether the Neanderthal was living at the same time as members of *H. sapiens*, thought to have been living in the same area of northern Europe 45 000 years ago. Measurements suggest that, of the original amount of carbon-14 isotope present in the skull when the Neanderthal died, only 1.56% remains in the fossil fragment.
   (a) How old is the fossil?
   (b) Could this Neanderthal have been a contemporary of *H. sapiens* in this area?

Answers

1. 2.14 billion years old
2. (a) 34 380 years old

EXPLORE an issue

Take a Stand: The Economics of Fossil Study

Decision-Making Skills

- ● Define the Issue
- ○ Defend the Position
- ● Analyze the Issue
- ● Identify Alternatives
- ● Research
- ● Evaluate

Fossil-hunting expeditions are costly and the rarest fossils are very valuable. In October 1997, Sotheby's auctioned an almost perfect 65-million-year-old *Tyrannosaurus rex* fossil for U.S.$8.4 million (**Figure 6**). Sotheby's described the fossil as a world treasure. The buyer, the Field Museum of Natural History in Chicago, received donations from Ronald McDonald House, Walt Disney, and others to buy the fossil. The sale ended a legal, scientific, and ethical controversy revolving around the rightful ownership of the fossil, which was found by a commercial fossil hunter.

Statement: Fossils should be donated to research institutions because their investigations benefit everyone.

- In a group, research issues for this statement using print and electronic resources.
- Develop a list of points and counterpoints on these issues.
- Write recommendations on the economics of fossil research.

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Figure 6
Museums must bear the costs of equipment, research staff, facilities, and the procurement of fossils through purchases or field expeditions.

SUMMARY The Fossil Record

- Early scientific thinking about the origins of life on Earth focused on the study of fossils embedded in rock. Fossils were readily identified as mineralized remains or traces of organisms that are now extinct. Fossils contained within older (usually deeper) rock formations were observed to be simpler in structure and less similar to modern species than those found in younger (usually shallower) rock deposits.
- By the 19th century, scientists began to gather evidence that Earth could be extremely old. As fossils were part of rock that might be of great antiquity, the possibility was raised that life on Earth might also have an ancient past.
- The ability to measure relative amounts of radioactive parent and daughter isotopes in rock provided an accurate and reliable method of determining the age of both rock and fossil remains.

Section 11.2 Questions

Understanding Concepts

1. Outline the processes of fossil formation in rock.
2. In what materials might fossil remains be found besides sediments? Explain why such finds are rare.
3. On what evidence did Cuvier base his theory of catastrophism? Cuvier compared fossil remains with species living at his time. Explain his reasoning.
4. What property of radioactive material invalidated Kelvin's assumptions? How?
5. How are scientists able to assume that igneous rock contains no ^{40}Ar when it first forms?
6. How old is Earth now thought to be, and how was this estimate derived? How much greater is this age than the calculations of Lord Kelvin and Archbishop Ussher?
7. The Moon and most other solid bodies in the solar system, such as meteors, do not exhibit volcanic activity. How does this factor affect reasoning about the age of Earth?

Applying Inquiry Skills

8. Outline the steps you might use to determine the age of a fossil embedded between two layers of igneous rock.
9. Explain how carbon-14 might be used to date relatively recent organic remains or archaeological finds.
10. Before the discovery of radioactivity, what doubts might scientists of Kelvin's day have raised about his estimates? Research Kelvin's investigations into evidence that Earth was cooling and prepare an assessment of his reasoning from his experiments. How might his approach have given credibility to his theories?
11. Examine **Figure 7**, which shows one of the world's most famous fossil species. The first *Archaeopteryx* was discovered in 1861 in a quarry in Solnhofen, Germany. What features are visible on this fossil that might have interested palaeontologists studying the evolution of reptiles and birds?

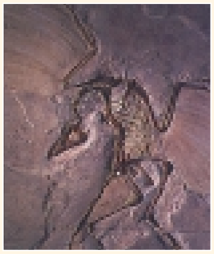

Figure 7
A 140-million-year-old fossil of *Archaeopteryx*

Making Connections

12. Cuvier and da Vinci both approached their interpretations about Earth's past from acute observations. Find out more about their scientific studies that supported their interpretations. Compare their theories and beliefs, including ways in which they were influenced by nonscientific thinking.
13. Fossils have been unearthed by many people who are not scientists. Find articles in print and online about such finds and compare them with scientific fieldwork. Prepare a class presentation of your comparison. Be sure to take into account societal and technological differences.

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14. Microfossils of the foraminifera, *Neogloboquadrina pachyderma* are excellent recorders of relative ocean temperatures. As they grow, these marine microorganisms build an outer shell that generally coils to the right under warm water conditions and to the left under cooler conditions.
    (a) How might such differences in coiling be of value to scientists studying past climate changes or to oil companies in search of new fuel deposits?
    (b) Search electronic sources for further examples of applications of fossil study to significant present-day issues.

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