# A FOSSIL PRIMER

## Early Fossil Studies

The word *fossil* comes from the Latin verb "to dig." Back in the middle of the 16th century when the word *fossil* was first used, it meant anything weird or curious that was dug out of the earth. Earlier there were some philosophers and priests in ancient Greece, Rome, and Egypt who thought that fossils were probably remnants of once-living plants and animals. Leonardo da Vinci also concluded that the shells he found while supervising the digging of some canals in northern Italy had once contained living animals.

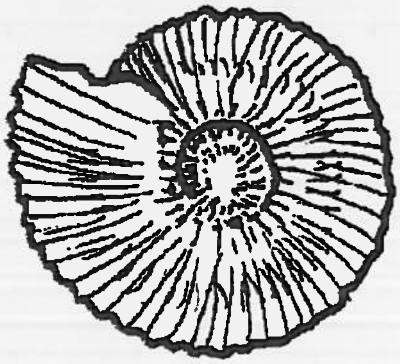
This idea was difficult for people to accept in the early 18th century. How could plants and animals find their way into rocks at the time the rocks formed? This idea contradicted much of what people at that time believed about the story of Creation. Most people believed that all rock formed at one time and that animals did not exist until later.

A French naturalist named Jean-Baptiste-Pierre-Antoine de Monet, Chevalier de Lamarck (Lamarck for short), was a professor of zoology in the late 18th century. He was the first person to define the word *fossil* to mean only the remains of prehistoric (living before human beings) creatures or the results of their activities, such as footprints. His studies focused on the invertebrates—animals without backbones. At the same time, a French baron named Georges Cuvier was studying vertebrate fossils found in rocks near Paris.

It was James Hutton who came up with the principle of uniformitarianism, "the present is the key to the past." This principle is used in the study of geology to help explain what Earth was like millions of years ago. Lamarck used this principle, and others devised by Hutton, to explain what fossils are and how they form. He observed that, when present-day shellfish die, they are buried in mud and other sediments. He reasoned that mud and shells accumulated over vast periods of time. The mud turned to rock, and the shells became fossilized. It is a logical inference to conclude that the locations where shellfish fossils are found today were once part of the ocean bottom in the past.

Lamarck was a careful observer. He compared fossilized organisms with similar organisms living today. For example, he noticed that fossils of palm trees and corals found in a shale deposit near London were similar to some of the palms and corals that live in tropical environments today. He also observed that the corals forming reefs today thrive in waters less than 150 feet deep that are free of mud and maintain a temperature between 24° and 30°C. Using Hutton's idea that "the present is the key to the past," he concluded that fossil corals lived in a prehistoric environment similar to the environment where corals live today. That must have posed a problem for Lamarck, because the conditions around London where the fossils were found is a far cry from a tropical environment.

Lamarck contributed so much to the understanding of fossils that he is called the father of *paleontology*, the branch of science devoted to the study of fossils.



## INDEX FOSSILS

About the time Lamarck and Cuvier were beginning their studies in paleontology near Paris, 25-year-old William Smith began his study of fossils in England. After 3 years as a surveyor's assistant and 4 more years planning coal-mine operations, he became a surveyor and engineer for a canal being dug to carry coal from western England to cities in eastern England.

Smith went into the field and studied the rocks through which they planned to dig the canal. He was puzzled by the different layers of rocks. He observed several outcrops of limestone in different places that did not appear to be part of the same layer. He also observed that many of the layers were not flat, but were tilted and folded. He tried to figure out a way to match up rock layers from one site to another. He knew it would be a great advantage if he could infer what the rocks were like below the surface along the route of the canal.

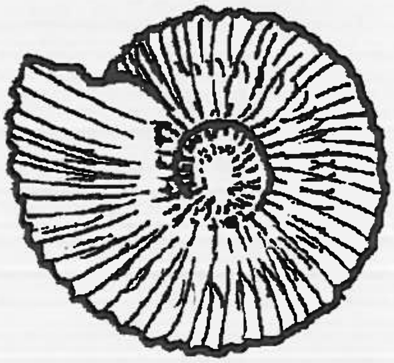
When Smith was a young boy he had been a fossil collector. Many people thought he was silly, considering fossils mere curiosities. Smith didn't know exactly what his fossils were, but he learned to tell them apart by their shapes and markings. Later, as he roamed the countryside planning the course of the canal, Smith collected fossils from the different rock layers, added them to his collection, and recorded where he found them.

Smith began to notice one difference between the limestone layers. Each kind of limestone contained its own particular set of fossils. He could determine if two samples of limestone were from the same layer by studying the fossils embedded in them. His best discovery, however, came after much more study. Smith observed that some fossils were found in several different layers, but other fossils were found in *only one layer.* These fossils found in only one layer could be used as the *index*, or indicator, for identifying a layer. Furthermore, all layers that had a particular index fossil would be the same age, that is, they would have formed at the same time in history.

By paying attention to the fossils in the rock layers, Smith could predict the sequence (order) of rocks in an outcrop. He could even predict what rock layers were below the surface. Because some rock layers are harder to dig through than others, the ability to predict what type of rock was below the surface was very helpful in planning a route for the canal.

Smith used these *index fossils* to correlate the rocks and determine their *relative ages* (ages in relation to each other). He was able to draw a column of all the rocks in an area, showing their relative ages, even though there was no one site where all of the rocks were exposed together.

Smith's work on index fossils was a great contribution to geology. He determined that fossils provided important evidence for the relative age of rock layers. To some he was known as William "Strata" Smith, the father of *stratigraphy* (the study of the order and correlation of Earth's rocks). To others he was the father of *historical geology*, the study of Earth's history. By comparing fossils, geologists can relate rocks on one continent to those on another. Geologists continue to use index fossils to help write a connected history for the entire Earth.



## FOSSIL SUCCESSION

If we begin at the present and examine older and older rock layers, such as at the Grand Canyon, we will soon come to a level where no fossils of humans are present. If we continue backward in time, we will come to levels where no fossils of flowering plants are present. And then no birds, no mammals, no reptiles, no four-footed vertebrates, no insects, no land plants, no fishes, no shells, and no animals of any kind.

Three concepts are important in the study and use of fossils.

- Fossils represent the remains of once-living organisms.
- Most fossils are the remains of extinct organisms; that is, they belong to species that are no longer living on Earth.
- The kinds of fossils found in rocks of different ages are different because life on Earth has changed through time.

The three concepts are summarized in the principle called the *law of fossil succession.*

- The kinds of animals and plants found as fossils change through time.
- When we find the same kinds of fossils in rocks from different places, we know that the rocks are the same age.

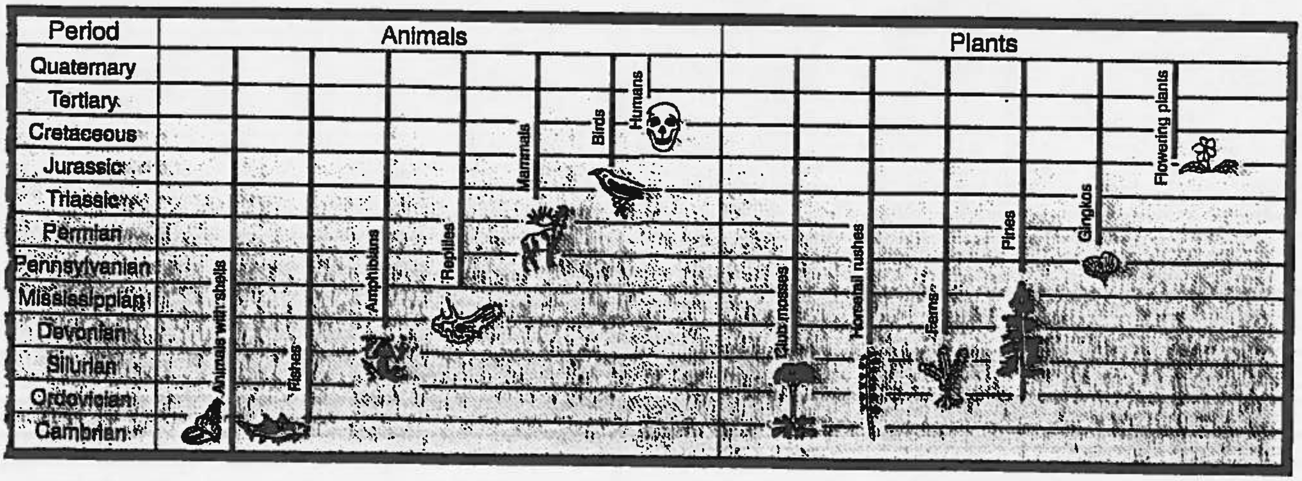
How do scientists explain these changes in life-forms that are obvious in the record of fossils in rocks? Early explanations suggested successive natural disasters that destroyed life every so often. After each catastrophe, life began again.

In the mid-19th century, both Charles Darwin and Alfred Wallace came up with another idea. They proposed that older forms of life produced new forms of life. According to Darwin, this change or evolution is driven by four processes.

- Variation
- Overreproduction
- Competition
- Survival of those best adapted to survive in their environment

Darwin's theory accounted for all of the diversity of life, both living and fossil. His explanation gave scientific meaning to the observed succession of once-living species seen as fossils in the record of Earth's history preserved in the rocks.

Scientific theories are continually being corrected and improved, based on new observations and discoveries. Darwin's theory of evolution has been refined and modified as new information has been added. All of the new information has supported Darwin's basic concept—that living beings have changed through time and older species are ancestors of younger ones.



The law of fossil succession is important to geologists who need to know the ages of the rocks they are studying. The fossils present in a rock outcrop or in a core sample can be used to determine rock ages very precisely. Detailed study of many rocks from many places has produced a collection of index fossils. To qualify as an index fossil, it must have a relatively short, well-known time of existence on Earth.

Index fossils allow geologists to "pinpoint" the age of a rock layer (within a few million years). The best index fossils are ones that

- Had a wide geographic range during their brief period of existence.
- Are abundant.
- Are easy to identify.

Many fossils are too small to be studied without a microscope.

One interesting index fossil is *Tetragraptus*, which lived during the early Ordovician period. (*Tetragraptus* is found in early Ordovician rocks of the Colorado Plateau.) It was a marine organism recognized by its four branches suspended from a thin fiberlike support. Because it floated all over the early Ordovician seas, it had a wide distribution. This makes it an important index fossil for rocks of this age.

Today the animals and plants that live in the ocean are very different from those that live on land, and the animals and plants that live in one part of the ocean or on one part of the land are very different from those in other parts. Fossil animals and plants from different environments are also different. It is a challenge to recognize rocks of the same age when one rock was deposited on land and another was deposited in the deep ocean. Scientists must study the fossils from a variety of environments. This gives them information to build a complete picture of the animals and plants that were living at a particular time in the past.

The study of fossils and the rocks that contain them occurs both out of doors and in the laboratory. The fieldwork can take place anywhere in the world. Rock saws, dental drills, pneumatic chisels, acids, and other mechanical and chemical procedures may be used to prepare samples for study in the laboratory. Preparation may take days, weeks, or months. Large dinosaurs may take years to prepare. Once the fossils are removed from the rock, they can be studied and interpreted. The rock itself also provides useful information about the environment in which it and the fossils were formed.

## THE NUMERIC (OR ABSOLUTE) TIME SCALE

How did geologists determine that

- Earth is about 4.6 billion years old?
- The oldest known fossils are from rocks that were deposited about 3.5 billion years ago?
- The first abundant fossils with shells occur in rocks that are about 570 million years old?
- The last ice age ended 10,000 years ago?

Nineteenth-century geologists and paleontologists believed that Earth was quite old, but they had only crude ways of estimating just how old. In 1896 a discovery brought geologists a tool for measuring Earth's age. Henri Becquerel, a French physicist, found that the element uranium changed into lead through a process called natural radioactive decay. His discovery was the first step in calculating a numeric age for rocks.

Not all elements go through the process of radioactive decay, only the ones that have radioactive isotopes, such as uranium. To use uranium as a tool for dating rocks, scientists had to determine how fast the uranium turned to lead. Most radioactive isotopes decay in a matter of years and even days. But the isotopes that take a long time to decay are useful to geologists. It takes 700 million years for half of a uranium sample to turn into lead. Scientists call this the isotope's half-life. By measuring the ratio of uranium to lead in a rock sample, geologists can calculate how many years ago the rock formed. Finally, early in the 20th century rocks could be dated absolutely!

Professor B. B. Boltwood, a radiochemist from Yale University, figured out a way to do this. In 1907 he published the first list of absolute ages for geological eras, based on radioactivity.

The theory of absolute dating is fairly straightforward. But the process of dating rocks involves complex procedures in well-equipped laboratories. Scientists need to determine the numbers of parent (starting) and daughter (changed) isotopes in rock samples, using various kinds of analysis. Since the quantities of isotopes are usually very small, precise measurement is the biggest challenge.

Nowadays the two most commonly used methods of radiometric dating are potassium-argon dating and carbon-14 dating. Each method is used for particular kinds of samples. Potassium is an element found in many rock-forming minerals, such as feldspar. Geologists have found that quantities of argon 40 can be identified in minerals of nearly all ages and can be measured accurately, even in small quantities. Potassium-argon dating can be used on rocks as young as a few thousand years as well as on rocks over 2 billion years old.

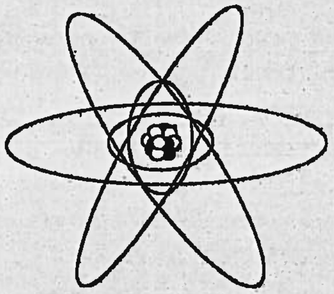
Carbon 14 has a half-life of 5730 years. Carbon 14 is constantly being produced in Earth's upper atmosphere and eventually finds its way into all living things. After an animal or plant dies, carbon 14 decays, creating nitrogen 14. By measuring the amount of carbon 14 remaining, scientists can calculate the time of death. If a piece of old wood is found to have only half as much carbon 14 as in wood from a living tree, the age of the old wood is estimated as 5730 years. Because carbon 14 has a relatively short half-life, it is very useful in dating materials that were alive during the past 50,000 years.

One more factor complicates the picture. Not all rocks can be dated absolutely. Only rocks that have crystallized directly from molten rock or magma, like granite or basalt, provide the samples needed for accurate dating. Geologists can measure the potassium and argon in the minerals found in these igneous rocks and calculate when these rocks became solid. Sedimentary rocks, such as sandstone and shale, may contain potassium, but the date determined by the potassium content is when the minerals originally crystallized, not when the sedimentary rock itself was formed. When an igneous rock is found in contact with sedimentary layers, the age of the igneous rock can be determined absolutely. This information can then be used with relative-age dating techniques to come up with an age for the surrounding rocks.

In the example below, a dike of melted rock or magma broke through the sedimentary layers and spilled out at Earth's surface. Geologists could use potassium-argon methods to determine the age of the igneous rock. Let's say it's 23 million years old. Since the sedimentary rocks had to be there first in order for the dike to pass through them, we can infer that the sedimentary rocks were formed before 23 million years ago.

To understand radioactive decay, we need to review a little about the atomic structure of matter. Matter is the material out of which everything we know is made. It comes in different forms called elements. Oxygen, hydrogen, gold, and uranium are all examples of elements.

Elements are made up of particles called atoms. Atoms are made up of even smaller particles called protons, neutrons, and electrons. Each element consists of atoms with a specific number of protons in their nuclei, or central core. Neutrons also exist in an atom's nucleus, but the number of neutrons may vary. The number of neutrons determines an element's atomic weight. Atoms of the same element with different atomic weights (different numbers of neutrons) are called isotopes.



**NOTE: This outdated representation of atomic structure is included for basic reference only.**

Radioactive decay is a process during which an original isotope, or parent, loses atomic particles spontaneously from its nucleus. When it loses the particles, it forms a new isotope, or daughter. Scientists have discovered that this process of losing isotopes, or decay, takes place at different rates for different elements. They call this rate the isotope's half-life. Half-life is the time it takes for one-half of a particular isotope in a sample to decay.