FOSSILS IN THE ROCKS

FOSSIL HISTORY

What are **fossils**?

Fossils—the word comes from the Latin word *fossilis,* or “something dug up”—are any preserved remains or imprints of living organisms (usually ancient animals and plants), such as bones, shells, footprints, or leaf impressions. Most fossils are found in sedimentary rock; others can be found imbedded in igneous rock, or changed by heat and pressure in metamorphic rock. Some fossils resemble the original organism’s shape; but those buried deep under sediment layers may be folded, crushed, or twisted from the great pressures. Usually, the hard parts of an animal or plant, such as bones, teeth, shells, seeds, or wood, can all become fossils, but in rare instances soft tissue can be preserved as well.

The word fossil was first used in 1546 by the German scientist Georgius Agricola (Georg Bauer, 1494–1555). During this time, the word fossil was used to describe all minerals and metals dug up from the ground. The word is now used to describe objects obviously formed in the past by living organisms. In general, fossils are usually considered to be objects older than 10,000 years; younger objects are often classified as subfossils.

What are the **three types of fossils**?

The following lists the three major types of fossils:

Body fossils—Body fossils are the preserved skeletal or structural forms of an organism, and in some rare instances, the preserved soft tissues. They are the most common type of ancient preservation we think of when someone mentions the word “fossil.”

Trace fossils—Trace fossils are evidence of biological and behavioral activities of organisms while they were alive, including tracks, trails, burrows, leaf imprints, and skin imprints.

Why are fossils important?

Fossils are not important because they are old, pretty, or collectible. The real reason lies in the information they provide. Without fossils, the history of life on our planet—spanning over hundreds of millions of years—would remain unknown to us. We would have no idea how life began and what shapes it took. There would be no record of the numerous catastrophes and extinctions that have befallen life on our planet. We would have no clues that large and diverse reptiles called dinosaurs once roamed the Earth, or that the continents have been (and are) continuously moving, changing the face of our planet, the climate, and the flora and fauna. Without the fossil record of how life has changed over millions of years, there would be no concept of evolution, the fundamental principle that governs the growth and change of all living things. And we would have no knowledge how our species, *Homo sapiens*, came to exist on this planet.

Chemofossils—Chemofossils are chemical signatures of life in rock. They may be organic chemical compounds (also called biomarkers) indicative of certain organisms, or trace elements that are the result of biological processes.

How did **trace fossils** form?

Trace fossil are evidence that animals ran, walked, crawled, burrowed, or hopped across land, usually in soft sediment such as sand or mud. For example, dinosaurs walking along a river left their footprints in soft sand; small animals dug branching tunnels in the mud of a lake bed in search of food. These traces then filled with sediment and were buried under layer upon layer of sediment over millions of years, eventually solidifying into rock. When the rock is exposed and collected, the trace evidence of the organisms can be seen. Some of the most famous examples of trace fossils are footprints in hardened sediment, such as the humanlike ones found in East Africa and the numerous dinosaur tracks in the Connecticut River Valley.

What are some of the **oldest fossils** found to date?

The oldest fossils—bacteria found in western Australia—are thought to be single-cell organisms about 3.5 billion years old. In 2002, scientists also discovered one-billion-year-old marks in Australian sandstone that may have been made by wormlike life. They might be the tracks of the oldest multicelled, mobile organisms, but to date, associated fossils have been found. So far, the oldest fossil hard parts (for example, shells) of organisms are from close to 600 million years ago, when organisms first began to develop skeletons, shells, and other hard body structures.

What is **paleontology**?

Paleontology is the study of ancient life (mostly through fossils). The word comes from the Greek word for "ancient life." Paleontologists study all types of fossils—marine and terrestrial, plant and animal. This close look at fossils allows us to understand what ancient life was like over a billion years ago.

There are many divisions of paleontology. A paleobotanist studies fossil flora (plants). A paleozoologist studies ancient fauna (animals), a study that can also be broken down into invertebrate paleontology, or the study of invertebrates (animals with no backbone), and vertebrate paleontology, or the study of vertebrates (animals with a backbone). Paleopalynology is the study of ancient pollen and spores (and in marine environments, single-celled algae); paleoichnology is the study of footprints, tracks, and traces left by ancient organisms (animals and plants).

Fossils also aid other scientific studies. For example, in geology fossils help scientists determine the relative age of rocks. Paleobiologists also use fossils for information about how life has evolved, or what lifeforms have descended from other lifeforms.

What were some **early theories** about the origin of **fossils**?

One of the first reports we have of fossils came from the Greek philosophers Xenophanes (570–475 B.C.E.) and Pythagoras (582–500 B.C.E.), recorded before 500 B.C.E. The two philosophers independently concluded that fossils were the remains of once-living animals and plants, but the organisms were no longer present in the known world, which for them meant mostly ancient Greece.

Herodotus (485–425 B.C.E.), a Greek philosopher and historian who lived about a century after Xenophanes and Pythagoras, studied tiny fossils embedded in the sandstones of the Egyptian pyramids. He concluded that an ocean once covered what is now the Libyan desert. A century after Herodotus, the Greek philosopher Aristotle (384–322 B.C.E.) drew his own conclusion concerning fossils: He proposed that fossils were the failures left behind when life spontaneously generated from mud.

What did the **Chinese** believe **dinosaur fossils** were?

The Chinese have been collecting dinosaur fossils for over 2,000 years, but they mistakenly identified the pieces as the remains of dragons, a prominent cultural symbol for the Chinese. Although modern scientific evidence has dispelled this notion, many still believe that ground up "dragon's teeth" have medicinal healing properties.

Who was the **founder of modern paleontology**?

French naturalist and anatomist Baron Georges Leopold Chretien Frederic Dagobert Cuvier (1769–1832) is considered the founder of modern paleontology. As a scientist at the French National Museum of Natural History, he was the first (in 1812) to propose that certain animal fossils were representative of forms that had completely died

Who discovered the origin of fossils in the Alps?

One of the greatest scientists, inventors, and artists of all time, Leonardo da Vinci (1452–1519) was the first to uncover the true reason behind fossils in the Alps. The Italian Renaissance scientist discovered marine fossils in the Apennines in the late 1400s. He correctly speculated that the fossils were once-living organisms that were buried at a time before the mountains were raised. "It must be presumed," he said, "that in those places there were sea coasts, where all the shells were thrown up, broken, and divided." In other words, he believed that where there was land, there was once ocean; the regions subsequently uplifted, exposing the remains of sea creatures.

Although da Vinci probably could have been called the father of modern paleontology because of his observations, it was not to be. As with many of his ideas, da Vinci hid his notes, keeping them from those who would accuse him of heresy. After all, the main belief at the time—that the fossils were carried to the mountaintops by the Great Flood—was based on the Bible. Still others thought the fossils grew on their own within rock layers.

out or became extinct. Cuvier also tried to reconcile his finding with the Bible by proposing a "catastrophe theory" to account for the extinctions.

What is the connection between **continental drift and fossils**?

There is a definite connection between continental drift—or how the continents move around the planet—and fossils. In particular, the theory of continental movement is based on the idea that identical rock types and associated fossils are found on continents now widely separated by oceans. For example, the Lystrosaurus was a mammal-like reptile that lived during the Triassic Period and behaved much like the modern hippopotamus. Fossils of this reptile are found in modern Africa, Antarctica, and India. This is seen as direct evidence that these landmasses were once linked together. (For more information about plate tectonics and continental drift, see "The Earth's Layers.")

FORMING FOSSILS

What is **taphomony**?

Taphomony is the study of the processes that lead to the formation of a fossil. In other words, it is the study of the conditions under which plants, animals, and other organisms become altered after death to be preserved as fossils.

A visitor looks at a Ceresiosauraus, displayed on a wall of the Fossils Museum in Meride, at the foot of Monte San Giorgio. The Swiss region on the southern shore of Lake Lugano is famous for its abundance of well-preserved reptile and fish fossils dating from the mid-Triassic Period, around 240 million years ago. *AP/Wide World Photos.*

What **conditions** are necessary to **form a fossil**?

In general, the process of fossilization starts when sediment, such as mud or sand, covers a dead organism. Overall, it is believed that fossilization takes well over 10,000 years because most younger bones show little or no mineralization (for more information about mineralization, see below).

It is difficult for something to become a fossil. Most remains are scavenged by other animals before becoming weathered by wind, water, and sunlight. The soft tissues not eaten—such as skin, eyes, muscles, and internal organs—rot away at various rates, depending on the climate, leaving only the bones and teeth to become fossilized, which is why these parts are most often fossilized.

Burial by sediment (sand or mud) is the next and most crucial step in the process of becoming a fossil. It reduces the amount of oxygen that would otherwise decay the bones. If sediment does not bury remains, the pieces are often broken and scattered by such events as flash floods. As more sediment accumulates over millions of years, it buries the remains deep within the ground. Eventually, due to pressure from the overlying layers, much of the water is forced out of the sediment. Minerals in the groundwater (such as carbonate, silica, and iron oxides) help to slowly cement the grains together, turning the sediment into rock in a process called lithification.

How do **bones and other hard parts** undergo **mineralization** to become fossils?

Entrapped animal parts—mainly bones and teeth—must undergo some form of mineralization to become fossils. Bones are composed of inorganic minerals and organic molecules (especially proteins and fat). Most of the organic components are eventually consumed by bacteria. What remains are brittle, microscopically porous bones. Water percolating down through the soil above dissolves mineral salts, some of which are precipitated out into the porous areas of the bones. These minerals are usually calcium carbonate (limestone), silica, or iron compounds. Over time, the parts then become a form of rock themselves.

The actual rate and type of bone mineralization depends on the type and chemistry of the sedimentary environment surrounding the buried bones. The following lists several ways in which this occurs:

Recrystallization—In this process, the bone or other hard biomatter converts to a new mineral or to coarser crystals of the original mineral. For example, a mineral found naturally in bones called apatite (calcium phosphate) may recrystallize.

Permineralization—Many bones, shells, and plant stems have porous internal structures that become filled with mineral deposits. In the process of permineralization, the actual chemical composition of the original biomatter might not change. But the bones themselves fossilize, as minerals such as calcite (calcium carbonate) fill the spaces in the bone structures.

Dissolution/replacement—In dissolution and replacement, groundwater (especially acidic water) dissolves the part of the organism that is trapped in sediments; it might simultaneously deposit a mineral such as silica, calcite, or iron in its place.

Carbonization—Carbonization leaves traces in the rock when the temperatures and pressures of burial cause the liquid or gaseous (volatile) components to be squeezed out, leaving a film of carbon.

How does **wood** become **petrified**?

Wood becomes petrified through the process of dissolution and replacement. This occurs when water that contains dissolved minerals such as calcium carbonate ($CaCO_3$) and silicate permeates it. Over thousands of years, the original plant is replaced or enclosed by these minerals—mainly silica—seemingly turning it to stone. Often, the plants' original form is retained, allowing scientists to study the structure of extinct organisms.

What are some examples of **carbonization and carbon films**?

The process of carbonization often produces films that preserve the outlines of animals' bodies, such as those found in the famous Burgess Shale layer of British Columbia. And animals are not the only organisms that can leave carbon films behind: The leaves of some plants have been preserved as carbon layers, revealing an outline and hint of a vein pattern and often allowing the original plant to be identified.

A section of the rock-lined shore edge in Jamestown, Rhode Island, illustrates how the curvature seen in the rocks shows years of ripple sand and how it was compressed over time. Geologists examine the tissued layers of the rocks and hunt for ancient fossils in its petrified folds. *AP/Wide World Photos.*

How are **fossils found** at the surface?

The only way to find fossils—short of digging a huge hole—is for the ancient remains to be exposed on the surface. Most fossils found in sedimentary rock have been uplifted by the movement of the Earth's crust (tectonic activity). Another way fossils are exposed is by the action of erosion, especially by wind, water, and ice that carve out the soft sedimentary rocks in which fossils reside. But if the fossils are not discovered in time, the same agents that expose the pieces will eventually destroy them. One prime example of this occurred in the northern regions of the United States, where huge glacial ice sheets that receded about 10,000 years ago after the ice ages wore away millions of years worth of rock along with countless numbers of fossils.

Are there **gaps** in the fossil **records**?

Unfortunately, there are many gaps in the fossil records, with whole eras or evolutionary stages missing. The loss of these precious fossils is most often the result of erosion. The action of water, ice, wind, and other erosional agents wears away layers of rock and the embedded fossils. Gaps can also be caused by mountain uplift that physi-

Why do scientists say there is a bias in the fossil record?

It is hard to estimate how many organisms became fossils over time. In fact, the late United States paleontologist Stephen J. Gould (1941–2002) estimated that 99 percent of all plant and animal species that ever lived are already extinct—and most of these have left no fossil evidence of their existence. The fossils we do find are therefore representative of only a small fraction of the animals and plants that have ever lived on our planet. This seemingly sparse fossil record leaves a considerable gap—and bias—in our knowledge about the history of life on our planet.

There are good reasons for this bias. One is because not all organisms' hard parts survive equally well. Light-weight bones with relatively large surface areas deteriorate more quickly, and thus are less often fossilized. Small, delicate bones, such as those of birds, are more likely to be crushed, eroded, or carried away from the rest of a skeleton by running water, storms, or even winds. Thicker, heavier bones survive much better, giving the fossil record a bias toward organisms that have this type of bone.

Another reason is the rate of fossilization. The best chance for fossilization comes when sediment covers an organism just after it dies. This protects the decaying organism from scavengers and predators, and from possible chemical erosion (such as from acidic water). The soft parts quickly decay, leaving behind the hard bones and teeth, the pieces with the best chance of surviving as fossils.

One other bias in the fossil record results from the paleontologists themselves. All areas of the globe have not been equally searched. Because of the inaccessibility of some regions, such as central Asia and Africa, these fossil records are poorly represented (and understood) compared to those from Europe and North America.

cally destroys the fossils. Hot magma from volcanic activity can also bury and change the rock and associated fossils.

Why is it difficult to **categorize** newly discovered **fossils**?

There are many reasons why it is difficult to categorize newly discovered fossils. In particular, many times there are few fossils—sometimes only one—to determine the species or even family of a new discovery. In other words, there is a poor representation of how the species truly looked. Other fossils might only be partially preserved, thus making it difficult to determine the true identity of the organism.

In addition, there are two different, opposing approaches to identifying the species represented by a fossil (even new species found in modern times). Scientists who use the

What's the largest coprolite found to date?

It is called the pride of Saskatchewan, Canada: "Scotty" the Tyrannosaur, a *Tyrannosaurus rex* fossil excavated near the town of Eastend in 1994. More excitement followed only four years later, when a large, whitish-gray lump about 1.5 feet (0.5 meters) long was discovered a few miles away from Scotty's bones. Although Upper Cretaceous Period crocodiles and small theropod fossils have been discovered in the area, only a Tyrannosaur could have produced a coprolite that large. It is considered to be the largest single feces ever recorded from any carnivore—fossil or living—and the first *T-rex* coprolite ever found. The shattered bone and other material within the coprolite suggest to many scientists that tyrannosaurs pulverized large quantities of bone, along with flesh, skin, and organs, and did not just "gulp and swallow" their prey.

typological approach believe that if two fossils look even slightly different, they must be from two distinct species. This reveals an emphasis on minor differences. In contrast, those who use the populationist approach accept that individuals in all populations of organisms normally have at least minor differences. When they encounter fossils that are similar, but not identical, they tend to lump them into the same species. Currently, the populationist approach to defining species has become the dominant one today.

What are **coprolites**?

Coprolites are the petrified feces of ancient animals. Scientists study the scat (droppings) of ancient animals as it can sometimes give definitive knowledge about the animal's diet and how its digestive systems worked. Coprolite—Greek for "dung rock"—is the scientific name coined by Dr. William Buckland in 1829. A good environment that allowed for the preservation of coprolites was along flat banks (floodplains) of rivers, areas in which the deposited feces could dry slightly before rapidly being buried by sediment from a river flood. Although coprolites are fairly common fossil objects, dinosaur coprolites are rare.

What are **gastroliths**?

Gastroliths, also called stomach or gizzard stones, are smooth, polished stones often found in the abdominal cavities of the skeletons of dinosaurs, such as the Apatosaurus and Seismosaurus (both plant-eaters). Scientists believe the stones tumbled around in the stomachs of the giant animals, helping to grind tough vegetable matter such as twigs, leaves, and pine needles. This is similar to how some animals, especially birds, use small stones today. For example, emus eat tough, fibrous food and need the stones in their digestive tracts because they have no teeth.

Volunteers carefully excavate around the skulls of two sabertooth cats and a dire wolf in the sticky asphalt of Los Angeles's Page Museum at the La Brea tar pits. Oozing in a pit thirteen feet below the heart of the city lies a treasure trove of Ice Age animals, including mammoths, mastodons, and land sloths, which literally sank into history. *AP/Wide World Photos.*

Have any **soft parts** of organisms been found as **fossils**?

Yes, there have been some "soft parts" found as fossils, but very few. The main reason is simple: Soft parts easily decay within a short period of time.

But there have been some interesting discoveries. One recent finding gave scientists a good idea about ancient reptiles' hearts: A plant-eating, 66 million-year-old (late Cretaceous Period) *Thescelosaurus* fossil known as Willo had a fossilized heart. This dinosaur was about 13 feet (4 meters) long and about 665 pounds (300 kg) when alive. It was found in South Dakota and is currently exhibited at the North Carolina Museum of Natural Sciences in Raleigh. Scientists realized after years of painstaking research that this fossil might be the most important dinosaur in the world. Finding the heart attached to the dinosaur's skeleton—and fossilized in iron and sulfur—was an amazing discovery.

The finding also changed scientists' theories about dinosaurs because the heart showed that Willo was warm-blooded like a mammal, rather than a cold-blooded reptile as expected. Of course, not everyone agrees. Some people claim the heart is actually a concretion—a hard, stone-like mass found in sedimentary rock. But the apparent heart in Willo's chest contains complex structures, whereas lumps of mud like concretions do not.

What are the La Brea tar pits?

The Rancho La Brea tar pits are some of the most famous in the world. Located in southern California, the tar pits are excellent sites for fossilization, filled with pools and deposits of asphalt. Tar pits form as crude oil seeps to the surface; the small amount of oil associated with the seep evaporates, leaving behind a heavy tar (asphalt) in pools that easily trap unsuspecting animals.

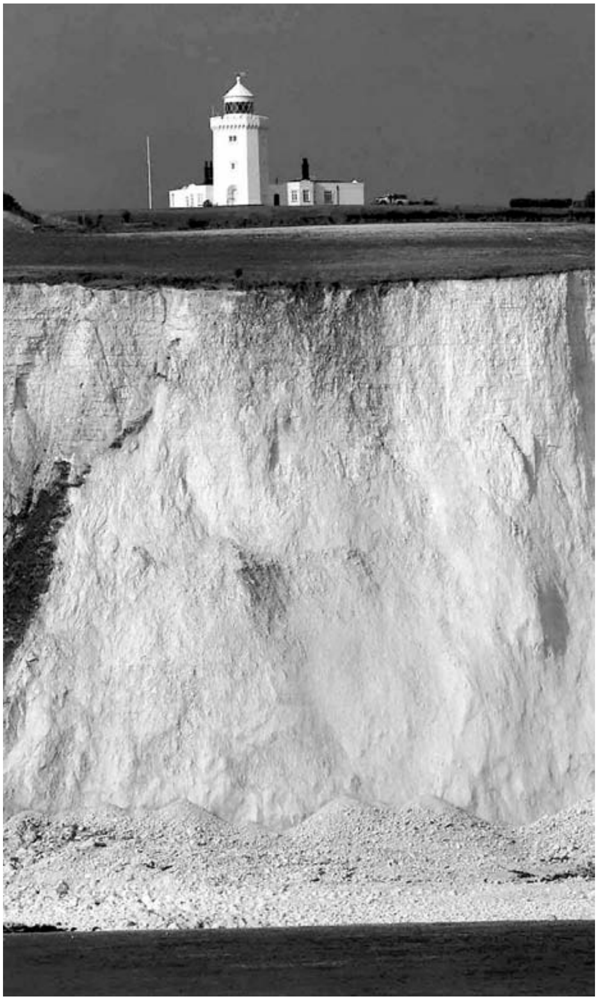
La Brea in particular has yielded rich collections of fossil vertebrate bones, wood, insects (even insect larvae), plants, mollusks, and sundry other organisms from a time span between 40,000 to 8,000 years ago. Since 1906, more than one million bones have been recovered, representing over 660 species of organisms, including 159 kinds of plants. Of the Pleistocene (Ice Age) vertebrates, 59 species of mammals and 135 species of birds have been identified. Based on the number of animal fossils discovered in the muck, scientists estimate that, on the average, this represents about 10 animals caught every 30 years.

The fossil bones first pulled from the La Brea pits were thought to be from some unlucky cattle that became entrapped in the tar. By 1901, the first scientific excavation of the pits took place, revealing a treasure of ancient animals and plants. The most common large mammal fossils pulled from the pits are the dire wolves. The second most common are fossils of the *Smilodon,* the most famous of the saber-toothed cats. Besides these cats, a number of the larger animal species found at La Brea no longer exist in North America, including native horses, camels, mammoths, mastodons, and longhorned bison. Even today, about 8 to 12 gallons (32 to 48 liters) of tar bubble to the surface, occasionally trapping all types of organisms—from birds and reptiles to small and large mammals—especially on warm days from late spring to early fall, when the asphalt is soft and sticky.

Are remains always **preserved in rock**?

No, not all remains are preserved in layers of rock. While the majority are, there are also other materials that hold fossils, including tar, peat, ice, and the resin of ancient trees (amber). A few fossils have been found pickled in swamps, dried in desert caves, or desiccated and wind-buried in deserts. In any of these conditions, even soft body parts can be well-preserved indefinitely.

Human body remains are also often found preserved as “fossils” in places other than rock. For example, the mummies of ancient Egypt could be considered fossils and contain both soft and hard body parts preserved by extreme, continuous dehydration. Bodies found in cold, stagnant swamps or bogs—and submerged for thousands of years—have also been found in remarkably good condition. The lack of oxygen (anaerobic conditions) preserved their soft tissues, literally halting most decay.



A large segment of chalk lies at the foot of the famed white cliffs of Dover beneath the South Foreland lighthouse in England. *AP/Wide World Photos.*

What are **molds and casts**?

Molds and casts are types of fossils. When a dead organism is buried, it often decays completely, leaving behind only an impression in the rock in the form of a hollow mold. The hard parts are most likely to leave an impression, although sometimes so can soft parts. If the mold then fills with sediment, this can also harden, forming a corresponding cast.

What are **pseudofossils**?

Pseudofossils are patterns in rocks that may be mistaken for fossils. For example, some branching or dendritic patterns (called dendrites) found in layers of sandstones and other sedimentary rocks often look like plants. In actuality, they are caused by the percolation of chemicals in rock fissures; the stain from the chemical (often iron or manganese oxide) forms the plant-like pattern. Another example are stromatolites, which are concentric rings formed by ancient blue-green algae. Sometimes rocks are not stromatolites but layers of calcite and serpentine minerals that are probably of volcanic origin.

What are the most **common fossils** found on Earth?

The most common fossils on Earth are pollen grains (the male reproductive bodies of advanced plants) and shells. Pollen grains are usually seen under a microscope; most shells are larger and more obvious.

Fossil pollen is found in many rock layers around the world. Produced during the reproduction of plants, these small and mobile cells enable plants to disperse and interact over long distances. Because of this, they have a thick, external wall (of sporopollenin, a durable organic polymer) and resistance to drying out, thus enabling the pollen to be preserved in the fossil record. Scientists have used the pollen record to determine what the ancient climate and environment were like. For example, scientists know that Mongolia had plains 36 million years ago, thanks to studying fossil plant pollen within the region's rocks. Plants have changed little over the past 40 million years, and plant families found today in arid regions are similar to those found in 36-million-year-old Mongolian rocks. This suggests that it was dry in Asia at that time, too.

Shells can be as large as a giant clam shell or as small as plankton. In fact, the chalk and beaches of the White Cliffs of Dover were created from the lime shells of billions of Cretaceous microscopic, single-celled marine animal and plant plankton (coccoliths). The chalk cliffs began to form as the plankton died, the layer becoming ever thicker as their shells fell to the ocean floor between 80 and 65 million years ago.

How did **ancient insects** become trapped in **amber**?

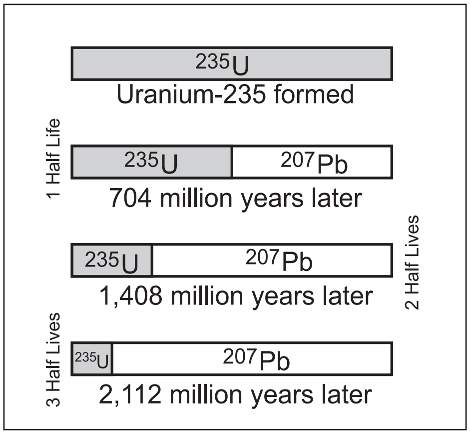
Ancient insects have been found in amber, a resin produced from certain cone-bearing trees, such as pine, fir, and spruce. When a tree was damaged, it produced the resin, a sticky, viscous fluid. If an insect was traveling up the tree bark and encountered the resin, it could become entangled in the blob. (Fossilized feathers, pieces of bark, and at least one small frog have also been found.) If the resin was buried (before or after the tree fell), it eventually produced fossil amber.

Insects preserved in amber have been discovered in certain Baltic Sea coast regions and various islands in the West Indies. But in reality, fossilized insects, in amber or rock, are rare. The chance that amber would form in conjunction with the meeting of the damaged tree and insect was not high. In addition, although more than half of the millions of species alive today are insects, of the 250,000 species known from fossils only 8,000 are insects. Fewer insects meant there was less of a chance of catching one in the ancient resin.

DATING FOSSILS

How is a **fossil's relative age** determined?

The relative age of a fossil is based on its position within the surrounding rock layer. The most common way of looking at relative age is called superposition, which is based on the fossil's position in a stacked sequence of sedimentary rock layers. The ages are relative: Fossils in the lowest layers are older than the fossils in the upper layers. This method has been used for centuries to determine the approximate age of rocks and fossils. (For more information about ages of rocks, see "Measuring the Earth.")



The radioactive decay of Uranium-235 into lead (Pb-207). The half-life of Uranium-235 is 704 million years.

What are **index fossils**?

Index fossils are those that form a "pattern" throughout geologic history. These are organisms that existed during limited periods of geologic time, making them perfect to use as guides to date the rocks in which they are found. For example, ammonites were common during the Mesozoic Era (245 to 65 million years ago), but became extinct at the end of the Cretaceous Period (during the Cretaceous-Tertiary [K-T] extinction event that killed off the dinosaurs). Other index fossils include brachiopods (during the Cambrian Period, 540 to 500 million years ago), with some still surviving; graptolites from the Cambrian Period to the early to mid-Carboniferous Period (360 to 320 million years ago); conodonts from the Paleozoic (540 to 245 million years ago) and the Mesozoic (245 to 65 million years ago) eras; and trilobites from the beginning of the Paleozoic (about half the Paleozoic fossils are trilobites) to the late Permian Period (248 million years ago).

How do you find a **fossil's absolute age**?

The absolute age (or direct dating) of a fossil is determined by knowing the age of the surrounding rock. The most common way is by radiometric dating, a method that relies on the natural radioactivity of certain elemental isotopes. Different isotopic elements—such as uranium, rubidium, argon, and carbon—have varying (but constant) rates of radioactive decay. This constancy provides a "radiometric clock," allowing scientists to analyze rock samples and measure the relative ratios between the "parent" and "daughter" isotopes. The ratios reveal the age of the rock layer, and thus, the age of the associated fossil. As with many scientific measurements, although the method is called "absolute," the dates are not exact and there is room for potential errors.

What are some **absolute dating methods**?

The following lists a few of the radiometric and other dating methods used to determine the absolute age of rocks and fossils:

Thermoluminescence and electron spin resonance—The atoms in minerals are continuously being bombarded by radioactivity present within the ground. This excites electrons that subsequently become trapped in the minerals' crystal structures. Geologists use thermoluminescence and electron spin resonance to determine the number of excited electrons present in the

Professor Jacques Millot, left, and assistants, are shown with a preserved coelacanth in Paris, France, in 1956. The lobe-finned fish, previously thought to be extinct, was caught off the coast of East Africa at a depth of more than 1200 feet. *AP/Wide World Photos.*

minerals of a rock. Thermoluminescence uses heat to free the trapped electrons, while electron spin resonance measures the amount of energy trapped in a crystal. This data is compared to the actual rate of increase of similar excited electrons. Geologists can then calculate how long it took for the excited electrons to accumulate within the minerals, determining the age of the rock and, thus, the age of the fossils.

Uranium-series dating—Another radiometric method used to determine the age of a fossil is called uranium-series dating. This measures the amount of thorium-230 present in limestone deposits. Uranium is present when these deposits form, but almost no thorium. The rate of decay of uranium into thorium-230 is known, so once the amount of thorium-230 in a limestone rock has been determined, the age can be calculated.

Tree rings and varves—Tree rings (the growth rings found in fossilized and living trees that indicate years) and varves (seasonal sedimentary deposits) are consistent in their growth. Thus, some scientists also use these patterns to determine the absolute age of rocks and fossils.

What are **carbon dating techniques**?

Carbon dating techniques measure the age of organisms that are relatively young in terms of geologic time. This method is based on the fact that there are two stable iso-

What is the most famous "living fossil"?

The most famous living fossil is the coelacanth, a fish with a three-lobed tail and fins with armlike bases. It was first discovered as a fossil in Devonian Period rock and was thought to have gone extinct at the beginning of the Cenozoic Era, approximately 60 million years ago. However, in 1938 Captain Hendrik Goosen caught a live coelacanth in the Indian Ocean off the coast of South Africa. It wasn't until 1952 that another was caught, and today many of these "living fossils" have been photographed in deep water off the coast of the Cormoro Islands near Madagascar.

topes of carbon, ^{12}C and ^{13}C, with the former being slightly lighter than the latter. Living organisms will preferentially absorb the ^{12}C, as it takes less energy. A larger than normal ratio of ^{12}C to ^{13}C in a sedimentary rock indicates that these amounts have been altered by living organisms, and therefore life was once present.

Since the decay of carbon isotopes does not occur over a very long period, carbon dating can be used to determine the age of more recent fossils, especially those younger than 45,000 years. When nitrogen-14 (^{14}N) in the atmosphere is bombarded by cosmic rays, carbon-14 (^{14}C) is produced, drifting down towards the surface, where plants absorb it from the air. Animals take the ^{14}C into their bodies by either eating the plants directly or eating other plant-eating animals. The death of an organism stops the intake of ^{14}C, which begins to decay to ^{14}N. The half life of ^{14}C is 5,730 years, meaning that in this time period one half of the ^{14}C will change into ^{14}N. In another 5,730 years, half of the remaining amount of ^{14}C will change into ^{14}N, and so on. By measuring how much C-14 is left in the fossil—and how much has decayed—geologists can determine the approximate age of the fossil.

What are **"living fossils"**?

Living fossils are modern animal and plant species that are almost identical to their ancestors that lived millions of years ago. In fact, many of these species were discovered and identified as actual fossils long before they were found as modern living organisms. For example, one species of modern ginko tree survives intact from the Triassic Period (approximately 220 million years ago). One of the earliest true flowering plants, the magnolia, existed some 125 million years ago during the Cretaceous Period; the horsetail was present during the Devonian Period almost 380 million years ago.

And it is not just plants that are found today as living fossils, but animals as well. The modern brachiopod *Lingula* is almost identical to its ancestor that lived during the Devonian Period. Other animals include the tuatara, a reptile species from the Triassic, and the didelphids, marsupials, including the modern opossum, that lived at the end of the Cretaceous Period. Insects such as cockroaches and dragonflies are also living fossils that evolved during the early Carboniferous Period (approximately 350 million years ago).

DINOSAUR, HUMAN, AND OTHER FAMOUS FOSSILS

What did some **ancient cultures believe** about **dinosaur fossils**?

People have been finding and digging for fossils for hundreds—perhaps thousands—of years. The "dragon" bones found in Wucheng, Sichuan, China, over 2,000 years ago were probably dinosaur fossils. And the Greek and Roman ogre and griffin legends might have originated with dinosaur fossil discoveries.

When was the **first dinosaur fossil** collected and described?

In 1676, a huge thigh bone was found in Oxfordshire, England, by Reverend Robert Plot. Although Plot scientifically recorded the bone, he also claimed it was from a humanlike "giant," not anything like a dinosaur. By 1763, British naturalist R. Brookes studied the fossil, also concluding it was from a giant and giving it the name *Scrotum humanum*.

The first dinosaur to be truly scientifically described (and the first theropod dinosaur discovered) was a Megalosaurus, which was also found in Oxfordshire, England. (It is interesting to note that the first dinosaur found was an Iguanodon, but it was named and scientifically described after the Megalodon.) The fossil's genus was named in 1824 by British fossil hunter and clergyman William Buckland (1784–1856), who studied the creature's lower jaw and teeth; Gideon Mantell (1790–1852) gave the scientific type species name, *Megalosaurus bucklandii*. No one knew it was a "dinosaur" yet, the word having not yet been invented.

What are some **famous dinosaur fossil discoveries**?

There are numerous famous dinosaur fossil discoveries. The following lists some of the more interesting ones:

- The first dinosaur fossil discovered in the United States was a thigh bone found by Dr. Caspar Wistar in Gloucester County, New Jersey, in 1787. The bone has since been lost, but more fossils were later found in the area.
- In 1877, the first dinosaur bones were pulled out of a rock formation that would prove to be one of the most prolific in the United States. Named after a nearby Colorado town where the first dinosaur bones were discovered, the world-famous Morrison Formation is where most of the fossils were found in the middle green siltstone beds and in the lower sandstones.

A Neanderthal skeleton reconstructed from casts of more than 200 Neanderthal fossil bones stands in the foreground with a modern version of a *Homo sapiens* skeleton behind. *AP/Wide World Photos.*

- Perhaps the most famous fossils are of dinosaurs preserved in the act of nesting on their eggs. Located in the Gobi Desert, Ukhaa Tolgod proved to be an incredibly rich area for dinosaur, mammals, and other animal skeletons. The fossils discovered here are mostly uncrushed, often complete, and preserved in exquisite detail.
- In an extremely rare discovery in 2001, a 77-million-year-old, nearly complete duck-billed dinosaur fossil was found in Montana with much of its skin and muscle tissues preserved by the mineralization process.

Is there a **connection** between **dinosaurs and birds**?

Most likely, yes. Many scientists now believe there is a connection between birds and dinosaurs. One of the first birdlike fossils to be found was the *Archaeopteryx lithographica,* which literally means "ancient wing from lithographic limestone."

Thought by many paleonologists to represent the oldest bird yet discovered, the first fossil was found in 1855 in the Solnhofen quarry in southern Germany. This fossil laid in sedimentary rock from the upper Jurassic Period, but it was not recognized as a bird until 1970. Over the years, six more fossil skeletons have been uncovered and are dated between 125 to 147 million years old. The fossils of these birdlike creatures—about the size of a present-day crow—were used by some early paleontologists to help substantiate the theory of evolution.

What happened to the Homo neandertalensis?

More fossil bones of the *Homo neandertalensis* have been found in relatively good condition compared to earlier humanlike species—mainly because they are younger and the Neandertals (also seen as Neanderthals—both spellings are correct and in common usage, even among paleoanthropologists) buried their dead. On the average, they were 5.5 feet (just under 2 meters) in height, had short limbs, and were well-adapted to living in a cold climate. Attached to their thick and heavy bones were powerful muscles. The Neandertal's brain was larger than that of living humans, with its shape longer from front to back and not as rounded in the front.

The anatomy of Neandertals and modern humans (*Homo sapiens*) seem so similar that in 1964 it was proposed that Neandertals were not a separate species from modern humans, but the two were actually subspecies: *Homo sapiens neandertalensis* and *Homo sapiens sapiens*. Popular throughout the 1970s and 1980s, this naming convention has since been dropped in favor of the two-species classification. Either way, Neandertals represent an extremely close evolutionary relative of modern humans.

What happened to the *Homo neanderthalensis*? No one has yet figured out this mystery. It is interesting to note that the Cro-Magnons arrived about 40,000 years ago in Europe, a region already populated with Neandertals. The two populations coexisted for as much as 10,000 years, then the Neandertals were either wiped out or assimilated into the Cro-Magnon groups.

In modern times, many scientists see the *Archaeopteryx* as marking the transition between dinosaurs and birds, providing proof that birds descended from dinosaurs. But other scientists are not ready to jump on the bird-as-dinosaur bandwagon, especially because there have been so few such fossils found around the world.

What were some of the first **hominid fossils discovered**?

One of the first hominid (humanlike) fossils was discovered in 1856 and belonged to the *Homo neandertalensis*. The discovery of a skullcap and partial skeleton in a cave in the Neander valley near Dusseldorf, Germany, signaled the first recognized fossil human form. *Homo neandertalensis* lived about 200,000 to 30,000 years ago. In 1893, the first fossil of *Homo erectus* (known as "Java Man") was uncovered in Indonesia. Similar fossil remains were subsequently found throughout Africa and Asia, making it the first wide-ranging hominid with a skeleton very similar to that of modern humans, although it was thicker and heavier. *Homo erectus* was probably the first hominid to use fire and lived from about 1.6 million to 200,000 years ago.

What are thought to be some of the **evolutionary steps** leading to **Homo sapiens**?

Although the road to discovering how *Homo sapiens* evolved is a long and fiercely debated one, there are still some fossil hominid bone discoveries that do give some evidence. Based on these fossil finds, scientists have determined some of the previous human-like species that existed for the past approximately 4 million years. The following lists some of the names given to these fossils and their approximate ages (note: this listing of names and dates continues to be highly debated):

Species	Years Ago
Ardipithecus ramidus	4.4 million
Australopithecus anamensis	4.2–3.9 million
Australopithecus afarensis	3.9–3.0 million
Australopithecus africanus	2.8–2.4 million
Australopithecus garhi	2.5 million
Paranthropus aethiopicus	2.7–1.9 million
Paranthropus boisei	2.3–1.4 million
Paranthropus robustus	1.9–1 million
Homo rudolfensis	2.4–1.9 million
Homo habilis	1.9–1.6 million
Homo ergaster	1.8–1.5 million
Homo erectus	1.6 million to 200,000
Homo heidelbergensis	600,000 to 200,000
Homo neandertalensis	200,000 to 30,000
Homo sapiens (and *Homo sapiens sapiens*)	100,000 to present

What are some of the more **famous human fossils**?

There are numerous human fossils that have captured the public's attention. For example, "Lucy"—from the species *Australopithecus afarensis*—is one of the most famous and dates to about 3.2 million years ago. Her remains were found in Hadar, Ethiopia—and she is considered one of the oldest human fossils ever found. Another famous human fossil is the "Taung child," an *Australopithecus africanus* that lived at least 2.4 million years ago. These fossil remains were found in Taung, South Africa. Still another human fossil is the "Peking Man," a member of the *Homo erectus* that lived about 500,000 years ago. His remains were found in Zhoukoudian, China.

What are some **other famous fossils**?

There have been many famous fossils around the world. Here are just a few of the old and new discoveries:

Have there been any fossils from Mars?

A 4.5 billion-year-old rock, labeled meteorite ALH84001, is believed to have once been a part of Mars and to contain fossil evidence that primitive life might have existed on the red planet more than 3.6 billion years ago. The rock is a portion of a meteorite dislodged from Mars by a huge impact about 16 million years ago. It subsequently fell to Earth in Antarctica 13,000 years ago. The meteorite was found in 1984 in Allan Hills ice field, Antarctica, by an annual expedition of the National Science Foundation's Antarctic Meteorite Program. It is currently preserved for study at the Johnson Space Center's Meteorite Processing Laboratory in Houston. (For more information about this special meteorite, see "The Earth in Space.")

Trilobites—One of the most famous fossils, trilobites date back 550 million years ago and were the first animals to develop eyes. The largest fossils of this "armored" animal can measure over 2 feet (almost a meter) in length.

Burgess Shale—Discovered in 1909, the Burgess Shale animal fossils comprise more than 140 species in 119 genera, with the majority of species being bottom-dwelling (benthic) organisms. In addition to specimens with the usual hard skeletal material fossilized, the excellent preservation of the rock layer has resulted in a large number of soft-bodied organisms being discovered.

Chengjiang mud beds—Many Burgess Shale-type fossils have also been found in lower Cambrian Period deposits near the town of Chengjiang in the Yunnan Province of China; they are about 15 million years older than the Burgess Shale deposits. To date, more than 10,000 specimens have been discovered.

Wormlike fossils—In 1998, researchers discovered what appeared to be worm-like animals in rock over 1 billion years old—almost twice as old as any other multicellular life yet discovered. This finding has lead many scientists to look once again at the origins of multicellular organisms, which are typically thought to have originated around the Cambrian Period around 600 million years ago.

Are there any **fossil parks in the United States**?

Yes, there are many National Parks known for their fossils. The following lists the major ones administered by the National Parks Service:

- Agate Fossil Beds National Monument, Nebraska
- Badlands National Park, South Dakota
- Channel Islands National Park, California

- Death Valley National Park, California and Nevada
- Delaware Water Gap National Recreation Area, Pennsylvania and New Jersey
- Dinosaur National Monument, Colorado and Utah
- Florissant Fossil Beds National Monument, Colorado
- Fossil Butte National Monument, Wyoming
- Grand Canyon National Recreation Area, Arizona and Utah
- Grand Canyon National Park, Arizona
- Guadeloupe Mountains National Park, New Mexico and Texas
- Hagerman Fossil Beds National Monument, Idaho
- John Day Fossil Beds National Monument, Oregon
- Petrified Forest National Park, Arizona
- Theodore Roosevelt National Park, North Dakota
- Yellowstone National Park, Montana, Idaho and Wyoming