Fossils

A fossil is any evidence of past life. Scientists can use these fossils to understand past environments.

Figure 1. A Trilobite fossil. The exoskeleton of the trilobite has been replaced with minerals over time, leaving evidence of its burial in sediment. Credit: M. Collier.

How do fossils form?

Living things are made up of chemical compounds, many of which are organic compounds. Organic compounds consist mainly of carbon, oxygen, and hydrogen. After an organism dies, it decomposes and their organic compounds change into simpler compounds like carbon dioxide and water. Decomposition is fastest when the organisms are in water that contains dissolved oxygen. Organisms can also decompose even without oxygen. Some kinds of bacteria feed on plant and animal tissues even though there is no oxygen. These are called anaerobic ("no air") bacteria. Sooner or later, almost all organic matter within organisms decays. Decay slows down only when the organic matter is buried in very fine mud. That seals the organic matter off from water with oxygen.

The soft parts of an organism decompose the fastest. You know how little time it takes for food to spoil and rot in warm weather when it is not in the refrigerator. Bones and shells decompose much more slowly. Over long times, their mineral materials dissolve. That can happen rapidly when the shells and bones lie on the ground surface or on the sea bottom. If the shell or bone is buried in sediment, it dissolves more slowly. Shells are preserved without being dissolved only when they are buried in sediments that consist of calcium carbonate minerals, like limestones. The woody parts of plants that consist mostly of cellulose and lignin decompose much more slowly than the softer parts.

Most animals become fossilized by being buried in sediment. For them to be fossilized, they have to be buried and leave an imprint before they decompose. Sometimes the actual shell or bone is preserved. Usually, however, you see only its imprint. If it resists being dissolved for a long enough time, the sediment around an organism's remains turns into rock. Then, even though the shell or bone dissolves, the imprint is preserved. When a hammer splits the rock open, the fracture might pass through the imprint, and you see a fossil.

Animals without skeletons are seldom fossilized, because they decompose so quickly. Animals with hard skeletons are much easier to fossilize. The most common fossils are shells of marine animals like clams, snails, or corals. Insects, with thin outside skeletons of chitin, are not as easy to fossilize. Sometimes an insect is trapped in sticky material, resin, which comes out of some kinds of trees. The resin then hardens to a material called amber. The insect fossil is preserved in the amber, often perfectly.

In what types of rocks do fossils form?

In certain conditions, and over a very long period of time, sediment becomes compacted and cemented into sedimentary rock. Fossils are more common in some kinds of sedimentary rocks than others. There are many factors that can contribute to the likelihood of an organism being preserved as a fossil. Fossils are most common in limestones. That is because most limestones consist partly or mostly of the shells of organisms. Sometimes, however, the shells are worn so much that they look like sediment grains rather than "real" fossils.

Figure 2. Sedimentary rocks are the mostly likely rock type in which fossils can be preserved. Credit: James St. John via Flickr.

Fossils are also common in shales, which form from muds. Excellent imprint fossils can be formed in fine-grained sediments like muds. Only some shales contain fossils, however, because many areas of muddy ocean floor had conditions that were not suitable for animal life. In this case, only swimming or drifting organisms that die and fall into the mud have a chance to become fossilized. Although this does happen, it is a very rare occurrence. Some sandstones contain fossils as well. Most sandstones do not contain fossils, for various reasons. Water currents in the environment might have been too strong for animals to survive. Also, sands are very porous, so water seeping through the sand might have dissolved the shells away long before the sand was buried and changed into sandstone.

What effect does sediment size have on fossils?

Sediment ranges in size from large boulders to very fine mud. Sediments coarser than two millimeters are called gravel. Sand is defined as sediment with sizes between one-sixteenth of a millimeter and two millimeters. All sediment finer than sand is called mud. The coarser part of the mud is called silt, and the finer part is called clay.

Sediments are formed when rocks on the land surface are broken down by rain, wind, and sun. Sediments consist of particles of minerals, and also loose pieces of rock. Streams and rivers move the sediments downstream toward the ocean. Some of the sediment is stored in large river valleys, but most of it reaches the ocean. Some is deposited in shallow water near the shore, and some is carried far out into the deep ocean. Most of the sediment deposited near the shore is coarse, and it gets finer farther away from the shore. Most of the sediment in the deep ocean is very fine mud.

Sediments are also formed when calcium carbonate minerals are separated from warm, shallow waters in the ocean. Much of this is used by marine animals to make their skeletons. After the animals die, their skeletons become sediment. Where currents are weak, this sediment stays where the animals lived. Where currents are strong, the shells are moved along the bottom and are worn into rounded particles.

What kinds of fossils are there?

Sediments are home for many kinds of marine animals. Some animals live on the surface of the sediment, and some burrow into it. Some fossil shells are found mixed with the mud they lived in. Other fossil shells were moved by strong currents and deposited along with sand or even gravel. If the shells are buried by more sediment before they are worn away or dissolved, they become fossilized.

Fossils formed from animals' bodies or their imprints are called body fossils. Sometimes a fossil consists of original shell material. This is common in very young sediments that have not yet been turned into rock. Older sediments usually have been buried deeply by later sediments and turned into rock. Then it is more likely that the original shell has been dissolved away by water seeping through the pore spaces in the sediment. The fossil is left as an imprint of the original shell. An imprint like that is called a mold. Sometimes the space that was occupied by the shell is now empty. In other cases that space has been filled with later minerals that were precipitated by the flowing pore water. That material, which has the shape of the original shell, is called a cast.

Trace fossils are another kind of fossil. A trace fossil is any evidence of the life activity of an animal that lived in the past. Burrows, tracks, trails, feeding marks, and resting marks are all examples of trace fossils. It is usually hard to figure out exactly which kind of animal made a particular trace fossil. Trace fossils are useful to paleontologists (scientists who study past geologic time based on fossils), however, because they tell something about the environment where the animal lived and the animal's behavior.

Figure 3. Human footprints that date to the Permian Period (~250-299 million years ago) are examples of trace fossils. Credit: Mo. Collier.

Under what conditions do fossils form?

For a fossil to form, several conditions have to be met. First of all, the animal had to live in the given area! Animals live in many environments on Earth, but not everywhere. The water above many lake bottoms and many areas of the deep ocean bottom are stagnant. The bottom water is never exchanged with surface waters, so the water contains no dissolved oxygen. Animals cannot live without oxygen, so no animals live there. In these situations, the only possibility of fossilization is if a fish or other swimming animal dies in oxygen-rich waters above, sinks down into the stagnant muddy bottom, and is buried by sediments.

Most environments on the land surface are populated with animals. Fossilization on land is very uncommon, however, because most areas of the land are being eroded. Unless there is deposition, fossils cannot be preserved. Deposition on land is common only in river valleys. Fossils are fairly common in sediments deposited on river floodplains. Some ocean environments that support animal life are exposed to very strong currents and waves. After a shelled animal dies, the strong water motions cause the hard body parts to be broken and worn. Often the shells end up just as rounded grains of sand or gravel, which no longer look like fossils.

For animals without skeletons, like worms or jellyfish, fossilization is a very rare event. When paleontologists find a well-preserved fossil of a soft-bodied animal, it's an occasion for celebration. For a soft-bodied animal to be fossilized, its body must be protected from decomposition. The body is usually exposed to air and water with a lot of oxygen, so it decomposes rapidly. The animal is likely to be fossilized only if it is buried soon after it dies (or when it is buried alive!). Even then, it is likely to decompose, because water that seeps through the sediment around it usually is rich in oxygen. Sometimes, however, the body is buried rapidly by fine mud. Water seeps through mud much more slowly than through sand, so the body does not decompose as fast. Mud often contains a lot of other organic matter as well, and that uses up oxygen faster. Some animal bodies then escape decomposition. Under just the right conditions, a delicate impression of the animal might be preserved.

Figure 4. A paleontologist taking GPS coordinates of a trackway fossil so they can be carefully documented. Credit: NPS Photo by Caitlin Olejniczak.

Paleontologists are sure that the fossil record is biased. That means that some kinds of organisms are much scarcer as fossils than they were when they were alive. Other kinds of organisms are much better represented by fossils. Animals with hard shells and skeletons are represented well in the fossil record. On the other hand, soft-bodied animals are probably represented very poorly. It's likely that most soft-bodied species that ever existed are gone forever without a trace. Land animals are probably very poorly represented as well. For example, most animals that are now alive, or ever have lived, are insects, but the fossil record of insects is poor.

How do species change over geologic time?

Every plant or animal belongs to a species. A species is a population of plants or animals that can breed to produce offspring that can then produce offspring themselves. Biologists believe that new species evolve from existing species by a process called natural selection. Here's how it works. Genes are chemical structures in the cells of the organism. The nature of the organism is determined by its genes. The organism inherits the genes from its parents. Occasionally a gene changes accidentally. That's called a mutation. The changed gene is passed on to the next generation. Most mutations are bad, but some of them make the organism more successful in its life. Organisms that inherit that favorable new gene are likely to become more abundant than others of the species.

Sometimes the population of a species becomes separated into two areas, by geography or by climate. Then the two groups no longer breed with each other. The two groups then slowly change by natural selection. Each group changes in different ways. Eventually, the two groups are so different that they can't breed to produce offspring anymore. They have become two different species. Species eventually become extinct. That means that the population gets smaller and smaller, until no more organisms of that species are left alive. Species become extinct for various reasons. If the environment changes too fast, the species might not be able to adapt fast enough. Also, a new species might evolve to compete with an existing species. Biologists are sure that once a species becomes extinct it never appears again.

In the modern world, biologists can identify species by seeing whether the organisms can breed with one another. Paleontologists have much more trouble with fossil species, because the organisms are no longer around to breed! All that can be done is to match up shells or imprints that look almost identical and then assume that they represent a species.

What can we tell from the fossil record?

Paleontologists want to know the history of evolution and extinction of fossil species through geologic time. To do that, they try to study all of the fossils that have been preserved in sedimentary rocks. That's called the fossil record. Paleontologists have been collecting fossils from sedimentary rock layers around the world for over two hundred years. Their goal is to figure out the succession of species through all of geologic time. Once that succession is known, it

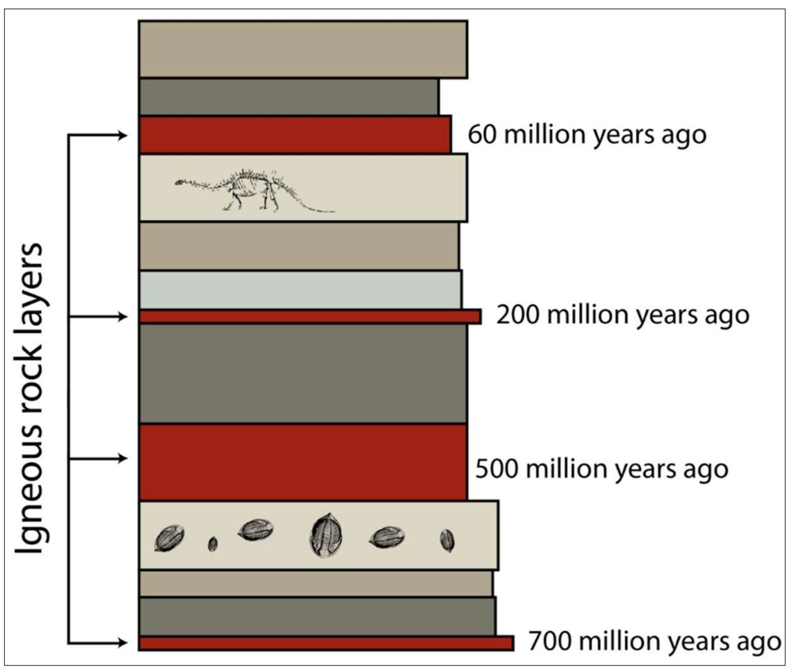

Figure 5. The fossil record can help scientists determine the relative and exact ages of rock layers. Credit: Jill Curie, Creative Commons Attribution-Share Alike 3.0 Unported.

serves as a scale of geologic time. Then, if you find a particular fossil in a rock, you know where that rock fits into the geologic time scale.

There's a big problem in figuring out the succession of species through geologic time. You don't know beforehand what the succession of species is! All you have are many stacks of sedimentary rocks (called stratigraphic sections) around the world to look at. No single stack spans all of geologic time, and no single stack has nearly all of the species that ever lived. You have to compare all of the stacks against one another to get the best approximation to the real succession. Paleontologists are still refining their ideas about the succession, as new fossils are found.

Matching up stratigraphic sections from around the world can be very difficult. If there were no fossils and you could only use the characteristics of the rock layers, it would be even harder! This is because at any given time, very different types of sediments can be deposited in different places. It is these sediments that will eventually become the sedimentary rock layers making up the stratigraphic sections. At any given time, mud may be slowly collecting in some places while in other places sand is piling up rapidly. In other places, maybe there is nothing collecting at all! So, you see, very different looking rock layers may mark the same time interval in different stratigraphic sections! The process of matching up equivalent "time layers" of rocks in different places is called stratigraphic correlation. One of the best (and oldest) tools for correlating strata around the world is the use of special fossils called index fossils.

Index fossils of organisms have two important characteristics. First, they must have been widely distributed around the world. Second, they must have only existed for relatively short periods of geologic time before becoming extinct. Consider a fossil of an organism that only lived in one place, or that existed for very long periods of geologic time. It would be of little use in matching up layers of rock that were deposited far from one another over the same limited span of time.

How can we tell how old rocks are?

Knowing the fossil record lets a geoscientist place a particular fossiliferous rock layer into the scale of geologic time. But the time scale given by fossils is only a relative scale, because it does not give the age of the rock in years, only its age relative to other layers. Long after the relative time scale was worked out from fossils, geologists developed methods for finding the absolute ages of rocks, in years before the present. These methods involve radioactivity. Here's how one of the important ones works.

Some minerals contain atoms of the radioactive chemical element uranium. Now and then, an atom of uranium self-destructs to form an atom of lead. Scientists know the rate of self-destruction. They grind up a rock to collect tiny grains of minerals that started out containing some uranium but no lead. Then they use a very sensitive instrument, called a mass spectrometer, to measure how much of the uranium has been changed to lead. Using some simple mathematics, they can figure out how long ago the mineral first formed. It is possible to date rocks as old as four billion years this way.

Absolute dating of rocks has provided many "tie points" for the relative time scale developed from fossils. The result is an absolute time scale. When you collect a fossil from a rock, you can place it in the relative time scale. Then you also know about how old it is in years (or usually millions, or tens of millions, or hundreds of millions of years). Even though modern technology makes it possible to date some rocks, the relative time scale is still very important. This is because it takes a lot of time and money to obtain an absolute date, and not all rocks can be dated using radioactivity.

How do paleontologists identify fossils?

A paleontologist collects as many fossils as possible from rocks or sediment. Once the fossils are prepared by scraping and cleaning, they are sorted by geometry. Fossils with very similar geometry are assumed to belong to a single species. Fossils with somewhat different geometry are assumed to belong to a different species. Usually, the fossil species has already been studied and named. Sometimes, however, the species is a new one. Then the paleontologist writes a detailed description of the new species, gives the new species a name, and publishes the description for others to read and use in their own work. Not much excites a paleontologist more than discovering a new species!

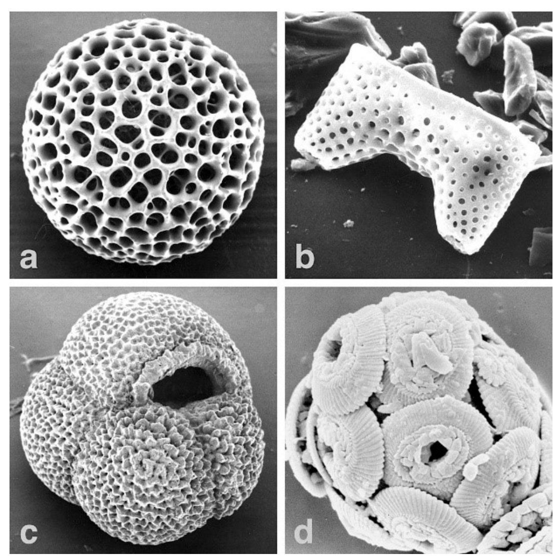

Figure 6. Microfossils can be particularly difficult to identify, so their shape is studied very carefully to help in naming them. Credit: Hannes Grobe/AWI, CC 3.0.

Sorting fossils can be difficult, for several reasons. Some organisms died when they were young and still developing, and some died when they were old. Some were male and some were female. Also, most species show a lot of natural variability. You know that from looking at other members of your own species! It's often impossible for paleontologists to decide whether they are looking at a single species with a lot of variability, or two similar species.

The oldest fossils are more than three and a half billion years old. They are simple unicellular (single-celled) algae, very similar to algae that still exist today. Evolution was very slow until about seven hundred million years ago, when unicellular organisms with larger and more complex cells evolved. Not long after that, a little more than half a billion years ago, multicellular (many-celled) organisms appeared. Instead of consisting of just a single cell, multicellular organisms have an enormous number of cells, grouped according to their function. Several kinds of multicellular organisms evolved in a very short time, geologically. Paleontologists still do not understand very well how this happened. Many of these early kinds of multicellular organisms, like clams, snails, and corals, are still abundant today. More complex kinds of animals, like reptiles, birds, and mammals, evolved even more recently in geologic time.