Science B-16: The History of Life

Lab 2: The Fossil Record

Objectives

Last week you became familiar with the major types of organisms that make up the fossil record. This week, you will learn what happened to these poor creatures after they died to turn them into fossils. In addition to learning about the process of fossilization, and the various ways in which organisms can become fossilized, you will also learn about the ways that marine sediments get turned into rock. As you will see, the rock in which a fossil is found can often yield just as much interesting information as the fossil itself. Once again, we will be attacking a great deal of information this week, so it is imperative that you ***read this entire lab handout before coming to section***.

Sediments and Rocks

Fossils are found in sedimentary rocks, so we should first get an idea of what comprises these rocks and how they are formed. **Sediments** are simply loose bits of broken up rock or other mineralized material, like shell or bone. Mud, sand, and gravel are all examples of sediments. A **sedimentary rock** is formed by cementing together sediments (e.g., loose sand into sandstone), or by chemically precipitating minerals out of water (e.g., rock salt, some limestones). Sediments are usually derived from rocks exposed on land and are ultimately transported to the oceans; thus the great bulk of sedimentary rocks are marine in origin. Sediments are usually transported and deposited by moving water or wind, such as in rivers, on the beach, or in desert sand dunes. As sediments accumulate, the underlying material is buried and compacted, squeezing the sedimentary particles closer together. This compaction, usually combined with the chemical precipitation of a cementing mineral, sticks the sediments together and forms a sedimentary rock.

Fossilization

If the remains of an organism (or the traces left by one) are somehow incorporated into sediments and then into the subsequent sedimentary rock, that organism has been **fossilized**. The chances of this occurring are very small for most organisms in most environments, but certain organisms in certain environments have a better chance of being preserved than others do. The organisms most often preserved as fossils are those that possess hard body parts, such as bone, shell, or wood. This includes marine animals like clams, coral, and snails, as well as land organisms such as vertebrates, insects, and trees. We know little or nothing about the history of many groups of animals, however, because they have few or no hard body parts and so have left behind very sparse fossil records (e.g., jellyfish and worms).

No matter how hard and preservable organic remains may be, they will not become fossilized if they are not protected from destruction by abrasive forces such as running water, shifting sediments, animal scavengers, and chemical dissolution. This is best achieved by rapid burial in sediments. Thus, the great majority of fossils found are of marine organisms, since sediments are continuously being delivered to the ocean and once deposited they are unlikely to be disturbed. By contrast, there are abundant organisms on land that could be preserved, but erosion (the removal of sediments) normally predominates over sedimentation here so few organisms are able to be buried long enough to be fossilized. Paleontologists refer to this under-representation of terrestrial organisms in the fossil record as the **marine bias**. This is the reason that much of this class will be based on the fossil records of marine organisms, and not so much on those of terrestrial plants and animals.

Modes of Preservation

Once incorporated into sediments, many processes may act on organic remains to either preserve or destroy them. **Soft parts** almost always decay and disappear rapidly, although they are sometimes preserved in very fine-grained muds where there is insufficient oxygen to support decay-causing bacteria. Sedimentary rocks formed under these conditions are often black due to the large amount of organic matter preserved within them (e.g., coal, black shales). Soft parts can also be preserved inside **amber** -- fossilized tree resin. Insects and other small organisms (even frogs!) are often spectacularly preserved in this way.

Hard parts may be preserved relatively **unaltered** in sediments, even to the point of preserving original color patterns in shells. This is a mode of preservation common in Cenozoic molluscs. More often, however, the composition of the hard parts is altered by infiltration of mineral-bearing ground waters. This process may take place in two related ways. The simpler method, usually called **permineralization** or **petrifaction**, occurs when the softer, more easily decomposed, organic constituents of the organism decay away, and ground waters carry dissolved minerals into the cavities left behind in the remaining, more resistant organic material. The minerals are deposited there, producing stony fossils that still contain a good deal of their original, organically produced, hard parts. For example, a tree is buried by ash from a volcanic eruption. The soft, pulpy parts of the wood decay rapidly, leaving pore spaces behind where each cell used to be. The resistant cellulose matrix separating those cells remains intact because it is difficult to decompose. Ground water then infiltrates the wood, and minerals (often silica) precipitate out into the cavities. The result is the petrified wood you can find in rock shops and gift stores. The bones and teeth of marine and terrestrial vertebrates are often preserved in the same way: cavities that contained blood vessels or cells are filled with mineral precipitates, but the original bone material is still present, imbedded in it. One can therefore easily tell fossil bone from modern bone by its weight, because the fossil bone has had all its pore spaces filled in with minerals.

The other way to preserve hard parts is by **replacement**. Replacement occurs when the original hard parts are completely dissolved and replaced with new mineral material. This may happen very slowly, so that the replacing mineral duplicates even the microstructural details of the original, or it may take place all at once so that virtually no detail remains. The shells of marine invertebrates are usually preserved in this manner, often with the replacing mineral being calcite, the same as the original shell only **recrystallized** in place. Silica (quartz) and pyrite (fool's gold) can also be the "replacement" minerals (the fossils are then referred to as **silicified** or **pyritized**) -- this can result in extraordinarily beautiful specimens.

There are other modes of preservation where the original hard parts are not preserved, but an impression or reproduction of them is. For example, a shell may remain in sediments for a substantial period of time -- until the sediments become firm and retain the form impressed on them by the shell. The original shell then decays or dissolves away, leaving a cavity called an **external mold** that preserves the surface texture and shape of the shell. Molds are abundant in many fossil assemblages, but just as frequently sediment has filled in the mold to form a **cast**. Casts look like the original but have no internal structure at all, like a plaster cast of a dinosaur bone. **Internal molds** form when sediment fills the inside of hollow objects like bivalve shells. The sediment hardens then the actual shell dissolves away, leaving a solidified replica of the internal cavity. **Imprints**, or **impressions**, are basically molds of very thin objects, such as leaves.

Some of the finest examples of fossilization are results of the process of **carbonization**. This is another process of incomplete decay in which the volatile elements in the tissue (those that easily go to a gaseous state when heated or compressed, like hydrogen, oxygen, and nitrogen) are driven off during the rock-forming process. The remaining material (predominantly carbon) is pressed flat by the weight of the overlying sediment. At its extreme, carbonization may reduce plant and animal remains to shiny black or brown films as thin as tissue paper. This method is capable of preserving the details of soft part anatomy, like the fleshy parts of plants, fish, aquatic reptiles, and even the internal organs of some marine invertebrates. Such instances of exceptional preservation of soft tissues are rare and extremely valuable in the study of life's history.

Some modes of preservation will leave behind no trace of the organism itself, but evidence of the organism's activity. These fossils are called **trace fossils**. Trace fossils can be obvious evidence of activity, such as **tracks**, **burrows**, or **coprolites** (fossilized feces), or they can be subtler such as chemical alteration of the sediment caused by microscopic organisms. In fact, the evidence for the earliest life on Earth comes from chemical traces presumably left by bacteria.

Depositional Environments

The term **environment** simply refers to the physical surroundings of an organism. If we are to paint a picture of an ancient environment and the organisms that lived in it, we must first be able to determine the type of environment we are attempting to reconstruct. Was it on land or in the sea? Deep water or shallow? A wave-swept beach or a stagnant marsh? Questions such as these can be answered in large part by looking at the sedimentary rock that encloses the fossils. More information is available in the rock record than the casual observer will realize. Several easily-observed properties of sedimentary rocks can help you to determine the **depositional environment**, or setting, in which the material originally accumulated.

As was mentioned previously, sedimentary rocks are formed by the deposition and subsequent burial of sediments. Such rocks can be initially divided into two groups:

Chemical sedimentary rocks are those made of chemical precipitates that crystallized out of a solution in which they were dissolved. The most important of these is **limestone**, made of calcium carbonate. Conditions necessary for the formation of limestone are two-fold. There must be an absence of other clastic materials (e.g., mud; see below) in the environment, and there must be a source for the carbonate. The most common source of carbonate is the seawater from which calcareous marine organisms secrete their skeletons. Most limestones are therefore actually created by the growth of these organisms and accumulation of their skeletons.

Clastic sedimentary rocks are those made from sediments (sand, pebbles, shells, mud, etc.) that have been transported by a fluid. We will concentrate here on sediments deposited by water, as opposed to those deposited by wind, because they typically contain more fossils. Clastic sedimentary rocks can provide a wealth of information about the environment in which they were deposited. The most important property of clastic rocks is the **grain size** -- the average size of the particles composing the rock. The grain size gives information about the **current energy** (how fast the water was moving) where the material was deposited. High energy environments include rapidly flowing rivers and exposed shorelines where waves continually pound on the coast. Low energy regimes include lakes, protected bays or inlets, and deep-water sea bottoms where water is not moving very fast, if at all. Current energy is related to grain size because the faster the water is flowing, the larger the particle it can transport. A very coarse-grained sedimentary rock, therefore, was deposited in a high-energy setting, because the water was moving fast enough to bring in the pebbles that compose it and keep transporting everything smaller. Conversely, a very fine-grained rock made out of mud was deposited in a place where water was moving very slowly, and so could only bring the smallest of particles to the site of accumulation. A classification scheme for some common sedimentary rocks based on grain size is as follows:

GRAIN SIZE	SEDIMENT	ROCK NAME
2 mm to 65 mm	pebbles	Conglomerate
0.065 mm to 2 mm	sand	Sandstone
less than 0.065 mm	mud	Mudstone or shale (if layered)

The **composition** of the rock also tells much about the environment of deposition. If, for example, the rock has a reddish color (due to oxidized iron, like rust), chances are good that it was deposited on land and often quite rapidly. If the rock has a black color, it was probably deposited in a setting where oxygen was scarce and decomposition of organic matter (mostly carbon) was not complete (e.g., coal). If a rock is made of calcium carbonate, it is called limestone, and was almost surely deposited in a marine (as opposed to freshwater) environment.

One final, useful characteristic of sedimentary rocks concerns the nature of the **bedding**, or layering, of the rock. Sedimentary rocks are deposited horizontally as layer upon layer of material. If these initial layers are not disturbed before the sediments are **lithified** (turned to rock), the resulting sedimentary rock will retain them and appear thinly and evenly laminated. If, however, something churns up the sediment while it is still soft, the initial layering in the rock will be homogenized and beds will be thicker and less well defined. The main reason for this churning is **bioturbation** - the action of burrowing organisms (worms, bivalves, crustaceans, etc.) that effectively mixes the sediment so that little evidence of layering is preserved. A thoroughly bioturbated rock indicates that oxygen was abundant below the sediment surface and burrowing animals were common, while a thinly laminated one suggests that burrowers were excluded or absent.