Fossils and physical markers indicate the relative ages of rocks

Remnants of ancient life, called **fossils**, are useful for comparing the ages of bodies of sedimentary rock throughout the world. The term *fossil* is usually restricted to tangible remains or signs of ancient organisms that died thousands or millions of years ago. Because few fossils can survive the high temperatures at which igneous and metamorphic rocks form, almost all fossils are found in sediments and sedimentary rocks. Fossils range in size from cells of tiny bacteria to massive dinosaur bones. They include such things as shells of invertebrate animals and teeth and bones of vertebrate animals, as well as leaves of plants and impressions of soft-bodied animals.

Fossils provide one valuable means of establishing the relative ages of rocks that lie far apart. William "Strata" Smith, a British surveyor, noted late in the eighteenth century that fossils are not randomly distributed in rocks. When Smith studied large areas of England and Wales, he found that fossils in sedimentary rocks throughout those areas occurred in a particular vertical order ("vertical" in terms of the succession of one layer above another). To the surprise of less experienced observers, Smith could predict the vertical ordering of fossils in areas he had never visited. We now recognize that this ordering, known as **fossil succession**, reflects organic evolution and extinction—the natural appearance and disappearance of species through time. Figure 1-10 illustrates fossil

In the course of geologic time, many of the organisms that have inhabited Earth have left a partial record in rock of their presence and their activities. This record reveals that life has changed dramatically since it first arose. At times of sudden environmental change, many forms of life have died out. After each such crisis, evolution has produced many new forms of life. This chapter introduces the major groups of organisms that have evolved on Earth, some extinct and others still alive.

It is not easy to define life precisely, but two attributes that are generally regarded as essential to life are the capacity for self-replication and the capacity for self-regulation (criteria that viruses do not meet). On Earth today, all entities that are self-replicating and self-regulating are also cellular: they consist of one or more discrete units called cells. A living **cell** is a membrane-bounded module with a variety of distinct features, including structures in which certain chemical reactions take place. The chemical "blueprint" for a cell's operation is encoded in the chemical structure of its genes. Essential to this blueprint is the cell's built-in ability to duplicate its genes so that a replica of the blueprint can be passed on to another cell or to an entirely new organism. The fossil record reveals that life existed 3.8 billion years ago, and it may have originated hundreds of millions of years earlier.

Fossils and Chemical Remains of Ancient Life

Most of our knowledge about the life of past intervals of geologic time is derived from **fossils**, the tangible remains or signs of ancient organisms that died thousands or millions of years ago. Few fossils consist of materials that can survive the high temperatures at which igneous and metamorphic rocks form. Consequently, almost all fossils are found in sediments or sedimentary rocks. Fossils are especially abundant in sedimentary rocks that were formed in the ocean, where animals with skeletons abound.

Hard parts are the most commonly preserved features of animals

The most readily preserved features of animals are "hard parts": teeth and bones of vertebrate animals and comparable solid, mineralized skeletal structures of invertebrate animals. Many groups of invertebrates lack skeletons and have therefore left poor fossil records, or none at all. Some, however, have internal skeletons embedded in soft tissue; among them are some relatives of sea stars, called crinoids (Figure 3-1A). External skeletons protect other invertebrates, among them bivalve and gastropod mollusks, whose tissues are housed inside skeletons popularly known as seashells. Hard parts are often preserved with only a modest amount of chemical alteration, but at times they are completely replaced by minerals that are unrelated to the original skeletal material (Figure 3-1B).

Soft parts of animals are rarely preserved

Fleshy parts of animals, or "soft parts," are occasionally found in the fossil record, but only in an altered state and only in sediments that date back a few millions or tens of millions of years. In older rocks, nothing but chemical residues of organisms remain.

One deposit that is famous for preservation of soft parts is the Messel Shale of Germany, which is about 47 million years old. In organic-rich portions of these sediments, which are nearly impermeable to air and water because they are rich in oily plant debris, an array of

A B

FIGURE 3-1 Fossil crinoids of Paleozoic age. A. In life, each of these animals was attached to the seafloor by a flexible stalk. B. The calcium carbonate skeleton of this specimen has been altered chemically to pyrite, a mineral that consists of iron sulfide and is known as "fool's gold." The stalks of these animals are several millimeters in diameter. (A and B, © 2013 National Museum of Natural History, Smithsonian Institution.)

A

B

FIGURE 3-2 **Remarkable preservation of soft parts.** A. This Eocene mammal, *Darwinius masillae*, is one of the most complete ancient primate fossils known from the fossil record. It became buried at the bottom of a lake, preserving a nearly intact skeleton, along with outlines of skin and fur and even the preserved contents of the animal's stomach. This fossil, from the Messel Shale in Germany, is about 47 million years old and is 58 centimeters (24 inches) long. B. Preserved skin of a Sauropod dinosaur embryo discovered at a dinosaur nesting site in Argentina. The width of the photo is about 8.8 millimeters (1/3 inch.) (A, Mike Segar/Reuters/Corbis; B, epa/Corbis.)

delicately preserved fossils can be found that include plants, mammals, birds, fish, and insects, some of which retain parts of their original color. Some animals are preserved here with their last meals remaining only partly decomposed in their stomachs, and some have fur still intact (Figure 3-2A). In other, older rocks, impressions of skin and other soft tissues of dinosaurs have also been found (Figure 3-2B). Protection from oxygen is the secret for fossilization of soft tissue: it is most likely to be preserved when organisms are buried in fine-grained, relatively impermeable sediment, especially if oily, water-repellent organic matter is also present.

Some sedimentary deposits that contain exceptionally well-preserved fossils, often with delicate soft parts preserved, are known as *lagerstätten* (plural of *lagerstätte*, which means "resting place" in German). These deposits form under a variety of unusual conditions, but require either low oxygen, rapid burial, or both. Dozens of famous lagerstätten have been found, including the Burgess Shale, the Ediacara Hills, the Green River Formation, and the La Brea Tar Pits. Despite their rare occurrence in the geologic record, lagerstätten provide us with a critical understanding of many important fossils.

Permineralization produces petrified wood

Terrestrial plants do not generally have mineralized skeletal structures, but the cellulose walls of their cells are so rigid that woody tissue, and even leaves, are much more commonly preserved in the fossil record than is the flesh of animals. After plants are buried in sediment, the spaces left inside the cell walls of woody tissue may be filled with inorganic materials—most commonly chert (finely crystalline quartz). This process, known as **permineralization**, produces what is informally called petrified wood, and it also fills the pores in bones with minerals.

Molds and impressions are imprints

Sometimes solutions percolating through rock or sediment dissolve fossil skeletons, leaving a space within the rock that is a three-dimensional negative imprint of the organic structure, called a **mold** (Figure 3-3). If it has not been filled secondarily with minerals, a paleontologist can fill the mold with wax, clay, or liquid rubber to produce a replica of the original object.

Fossils called **impressions** might be viewed as squashed molds. Impressions usually preserve, in flattened form,

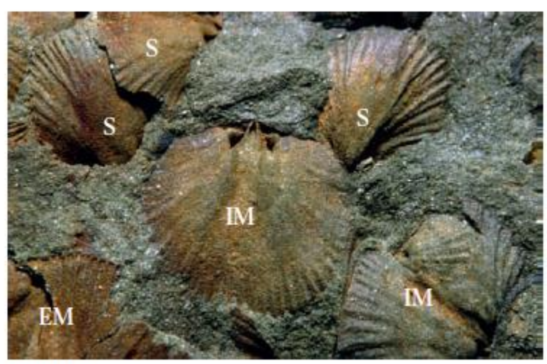

FIGURE 3-3 **Preservation of brachiopods.** The two shell halves of brachiopods meet along a hinge. This Paleozoic rock surface contains fossil brachiopod shells (S) as well as molds of the interiors (IM) and exteriors (EM) of other shells of the same species. The largest of these speciments is about 3 centimeters (1.2 inches) across. (Sinclair Stammers/Science Source.)

FIGURE 3-4 **Carbonized fossil leaf impression from the Jurassic Period.** This leaf, which is about 5 centimeters (2 inches) wide, belongs to the group of plants known as cycads. (Martin Land/Science Photo Library/Science Source.)

the outlines and some of the surface features of soft or semihard organisms such as insects or leaves (Figure 3-4). A residue of carbon remains on the surface of some impressions after other compounds have been lost through the escape of liquids and gases. This process of carbon concentration is known as **carbonization**.

Trace fossils are records of movement

Tracks, trails, burrows, temporary resting marks, and other structures left by animal activity are known as **trace fossils**. Trace fossils can reveal aspects of the behavior of extinct animals, even though the animal that made a particular trace cannot always be identified. Trackways of dinosaurs, for example (Figure 3-5A), show that these animals were very active. Unlike modern reptiles, they customarily moved about at a fast pace. Farther back in the geologic record, preserved tracks and burrows reveal how the earliest animals colonized the floors of ancient seas at a time when very few kinds of animals left fossils that revealed the shapes of their bodies. Once burrowers were well established, however, they were able to obliterate traces of bedding in many marine sediments (see Figure 2-27). Many burrows become filled with sediment that differs enough from the surrounding sediment that they stand out on bedding planes or weathered rock surfaces (Figure 3-5B).

The quality of the fossil record is highly variable

Although fossils are common in many sedimentary rocks, many kinds of animals and plants that have existed in Earth's history have never been discovered as fossils. Rare species and those that lack skeletons are especially unlikely to be found in fossilized form. Even most forms with skeletons have left no permanent fossil record. Several processes destroy skeletons. Animals that scavenge carcasses, for example, may splinter bones in the process. Many bones, teeth, and shells are abraded beyond recognition when they are transported by moving water before finally becoming buried. Even after burial, many fossils fail to survive metamorphism or erosion of the sedimentary rocks in which they are embedded. Finally, many kinds of fossils remain entombed in rocks that have never been exposed at Earth's surface or sampled by drilling operations.

Biomarkers are useful chemical indicators of life

A dead organism that decays within sediment may leave a chemical residue behind. Some residues of this kind, known as **biomarkers**, provide key information about the presence of ancient life. Certain biomarkers show, for example, that organisms more complex than bacteria existed more than 1.7 billion years ago.

Dead organisms decay to form fossil fuels

Organisms usually lose their identity in contributing to *fossil fuels*. Coal is formed by alteration of plant debris that accumulates in water as peat (see Figure 2-24). Petroleum

A

B

FIGURE 3-5 **Two kinds of trace fossils.** A. Dinosaur tracks in Spain that have been artificially darkened for clarity. One or more dinosaurs formed these tracks by walking across wet mud that later hardened into rock. B. Finger-sized burrows in the Bright Angel Shale from the Grand Canyon that were formed by worm-shaped organisms in a marine setting. (A, age footstock/Superstock; B, NPS/Alamy.)