Sedimentary rocks

Surface Processes of the Rock Cycle

Sediments, and the sedimentary rocks formed from them, are produced by the surface processes of the rock cycle. These processes act on rocks after they have been moved from Earth's interior to its surface and uplifted by mountain building and before they are returned to Earth's interior by subduction. They move materials from a *source area*, where sediment particles are created, to a *sink area*, where they are deposited in layers. The path that sediment particles follow from source to sink may be a very long one—one that involves several important processes resulting from interactions between the plate tectonic and climate systems.

Let's look at the role of the Mississippi River in a typical sedimentary process. Plate movement lifts up rocks in the Rocky Mountains. Rainfall in those mountains—a source area—causes weathering of the rocks there. If precipitation increases in the mountains, weathering also increases. Faster weathering produces more sediment to be released into the river and transported downhill and downstream. At the same time, if the flow in the river also increases because of the higher rainfall, transportation of sediment down the length of the river increases, and the volume of sediment delivered to sink areas—sites of deposition, also known as *sedimentary basins*—in the Mississippi delta and the Gulf of Mexico increases as well. In these sedimentary basins, the sediments pile up on top of one another—layer after layer—and are eventually buried deep in Earth's crust, to depths where they may become filled with valuable oil and natural gas.

The surface processes of the rock cycle that are important in the formation of sedimentary rocks are reviewed in **Figure 5.1** and summarized here:

- *Weathering* is the general process by which rocks are broken down at Earth's surface to produce sediment particles. There are two types of weathering. **Physical weathering** takes place when solid rock is fragmented by mechanical processes, such as freezing and thawing or wedging by tree roots (**Figure 5.2**), that do not change its chemical composition. The rubble of broken stone often seen at the tops of mountains and hills is primarily the result of physical weathering. **Chemical weathering** refers to processes by which the minerals in a rock are chemically altered or dissolved. The blurring or disappearance of lettering on old gravestones and monuments is caused mainly by chemical weathering.
- *Erosion* refers to processes that dislodge particles of rock produced by weathering and move them away from the source area. Erosion occurs most commonly when rainwater runs downhill.
- *Transportation* refers to processes by which sediment particles are moved to sink areas. Transportation occurs when water, wind, or the moving ice of glaciers transport particles to new locations downhill or downstream.
- *Deposition* (also called *sedimentation*) refers to processes by which sediment particles settle out as water currents slow, winds die down, or glacier edges melt to form layers of sediment in sink areas. In aquatic environments, particles settle out, chemical precipitates form and are deposited, and the bodies and shells of dead organisms are broken up and deposited.

Sedimentary Rocks

Sediments, the precursors of sedimentary rocks, are found at Earth's surface as layers of loose particles, such as sand, silt, and the shells of organisms. These particles originate in the processes of weathering and erosion. **Weathering** refers to all of the chemical and physical processes that break up and decay rocks into fragments and dissolved substances of various sizes. These particles are then transported by **erosion,** the set of processes that loosen soil and rock and move them downhill or downstream to the spot where they are deposited as layers of sediment (Figure 3.26).

Sediments are deposited in two ways:

- **Siliciclastic sediments** are made up of physically deposited particles, such as grains of quartz and feldspar derived from weathered granite. (*Clastic* is derived from the Greek word *klastos,* meaning "broken.") These sediments are laid down by running water, wind, and ice.
- **Chemical sediments** and **biological sediments** are new chemical substances that form by precipitation. Weathering dissolves some of a rock's components, which are carried in stream waters to the ocean. Halite is a chemical sediment that precipitates directly from evaporating seawater. Calcite is precipitated by marine organisms to form shells or skeletons, which form biological sediments when the organisms die.

FROM SEDIMENT TO SOLID ROCK **Lithification** is the process that converts sediments into solid rock. It occurs in two ways:

- In *compaction,* particles are squeezed together by the weight of overlying sediments into a mass denser than the original.
- In *cementation,* minerals precipitate around deposited particles and bind them together.

Sediments are compacted and cemented after they are buried under additional layers of sediments. Sandstone forms by the lithification of sand particles, and limestone forms by the lithification of shells and other particles of calcite.

LAYERS OF SEDIMENT Sediments and sedimentary rocks are characterized by **bedding,** the formation of parallel layers of sediment as particles are deposited. Because

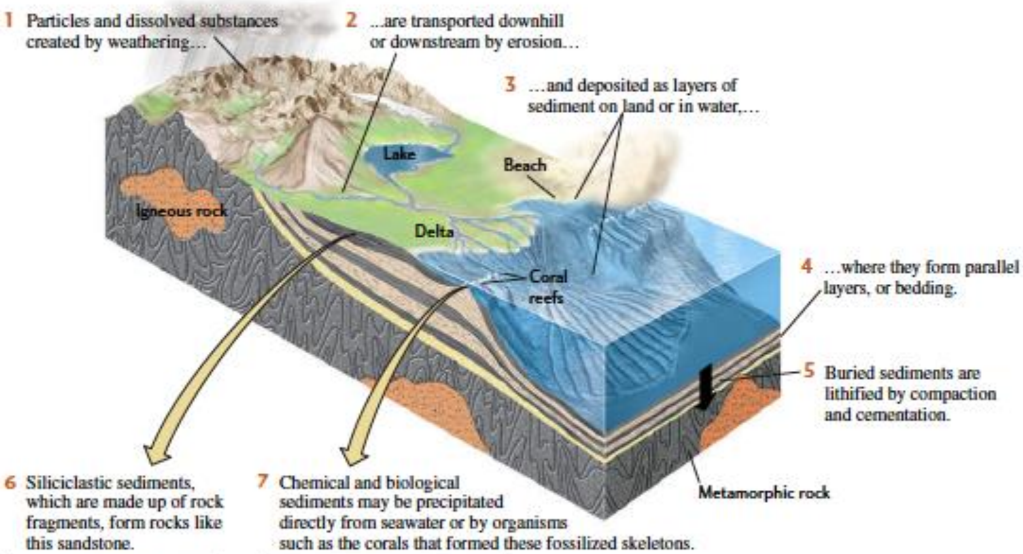

FIGURE 3.26 ■ Sedimentary rocks are formed from particles of other rocks. [Photos by John Grotzinger/Ramón Rivera-Moret/MIT.]

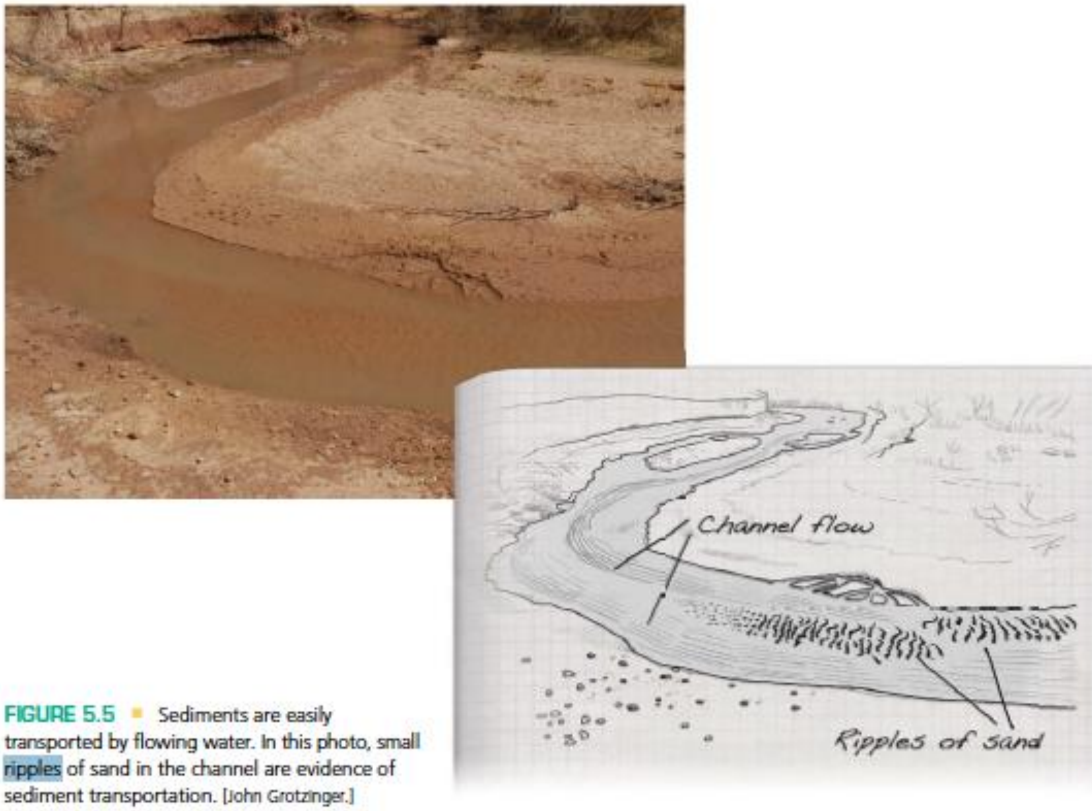

FIGURE 5.5 ▪ Sediments are easily transported by flowing water. In this photo, small ripples of sand in the channel are evidence of sediment transportation. [John Grotzinger.]

Because all clastic particles have roughly the same density, we use particle size as the best indicator of how quickly a particle will settle. (We will take a more specific look at particle size categories later in this chapter.) In water, large particles settle faster than small ones. This is also true in air, but the difference is much smaller.

Current strength, which is directly related to current velocity, determines the size of the particles deposited in a particular place. As a wind or water current begins to slow, it can no longer keep the largest particles suspended, and those particles settle. As the current slows even more, smaller particles settle. When the current stops completely, even the smallest particles settle. Currents segregate particles in the following ways:

- *Strong currents* (faster than 50 cm/s) carry gravel (which includes boulders, cobbles, and pebbles), along with an abundant supply of smaller particles. Such currents are common in swiftly flowing streams in mountainous terrain, where erosion is rapid. Beach gravels are deposited where ocean waves erode rocky shores.
- *Moderately strong currents* (20–50 cm/s) lay down sand beds. Currents of moderate strength are common in most rivers, which carry and deposit sand in their channels. Rapidly flowing floodwaters may spread sand over the width of a river valley. Waves and currents deposit sand on beaches and in the ocean. Winds also blow and deposit sand, especially in deserts. However, because air is much less dense than water, much higher current velocities are required for it to move sediments of the same size and density.
- *Weak currents* (slower than 20 cm/s) carry muds composed of the finest clastic particles (silt and clay). Weak currents are found on the floor of a river valley when floodwaters recede slowly or stop flowing entirely. In the ocean, muds are generally deposited some distance from shore, where currents are too slow to keep even fine particles in suspension. Much of the floor of the open ocean is covered with mud particles originally transported by surface waves and currents or by wind. These particles slowly settle to depths where currents and waves are stilled and, ultimately, all the way to the bottom of the ocean.

As you can see, currents may begin by carrying particles of widely varying sizes, which then become separated as the strength of the current changes. A strong, fast current may lay down a bed of gravel while keeping sand and mud in suspension. If the current weakens and slows, it will lay

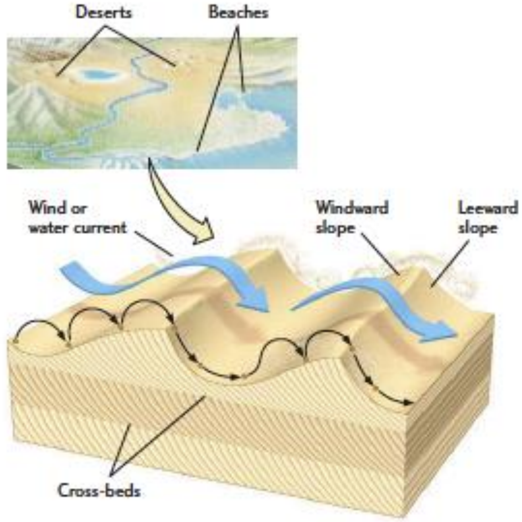

FIGURE 5.11 ▪ Sediment particles transported down the steeper, downcurrent slope of a sand dune, sandbar, or ripple form cross-bedding.

particles. The grading indicates a weakening of the current that deposited the particles. A graded bed comprises one set of sediment particles, normally ranging from a few centimeters to several meters thick, that formed a horizontal or nearly horizontal layer at the time of deposition. Accumulations of many individual graded beds can reach a total thickness of hundreds of meters. A graded bed formed as a result of deposition by a turbidity current is called a *turbidite*.

Ripples

Ripples are very small ridges of sand or silt whose long dimension is at right angles to the current. They form low, narrow ridges, usually only a centimeter or two high, separated by wider troughs. These sedimentary structures are common in both modern sands and ancient sandstones (**Figure 5.12**). Ripples can be seen on the surfaces of windswept dunes, on underwater sandbars in shallow streams, and under the waves at beaches. Geologists can distinguish the symmetrical ripples made by waves moving back and forth on a beach from the asymmetrical ripples formed by currents moving in a single direction over river sandbars or windswept dunes (**Figure 5.13**).

Bioturbation Structures

In many sedimentary rocks, the bedding is broken or disrupted by roughly cylindrical tubes a few centimeters in diameter that extend vertically through several beds. These sedimentary structures are remnants of burrows and tunnels excavated by clams, worms, and other marine organisms that live on the ocean bottom. These organisms churn and burrow through muds and sands—a process called **bioturbation.** They ingest the sediment, digest the bits of organic matter it contains, and leave behind the reworked sediment, which fills the burrow (**Figure 5.14**). From bioturbation structures, geologists can determine the behavior of the organisms that burrowed in the sediment. Since the behavior of burrowing organisms is controlled partly by environmental factors, such as the strength of currents or the availability of nutrients, bioturbation structures can help us reconstruct past sedimentary environments.

(a)

(b)

FIGURE 5.12 ▪ Ripples. (a) Ripples in modern sand on a beach [Courtesy of John Grotzinger.] (b) Ancient ripple-marked sandstone. [John Grotzinger/Ramón Rivera-Moret/MIT.]