CHAPTER 6

Sedimentary and Metamorphic Rocks

BIG Idea **Most rocks are formed from preexisting rocks through external and internal geologic processes.**

6.1 Formation of Sedimentary Rocks
MAIN Idea Sediments produced by weathering and erosion form sedimentary rocks through the process of lithification.

6.2 Types of Sedimentary Rocks
MAIN Idea Sedimentary rocks are classified by their mode of formation.

6.3 Metamorphic Rocks
MAIN Idea Metamorphic rocks form when preexisting rocks are exposed to increases in temperature and pressure and to hydrothermal solutions.

GeoFacts

- The exterior of the Empire State Building is made of limestone, marble, granite, and metal.
- 5663 m^3 of Indiana limestone and granite, 929 m^2 of Rose Famosa and Estrallante marble, and 27,870 m^2 of Hauteville and Rocheron marble were used in the building's construction.
- Overall, the Empire State Building weighs 331,122.43 metric tons.

Start-Up Activities

LAUNCH Lab

What happened here?

Fossils are the remains of once-living plants and animals. In this activity, you will interpret animal activity from the pattern of fossil footprints.

Procedure

1. Read and complete the lab safety form.
2. Study the **photograph of a set of footprints that have been preserved in sedimentary rock.**
3. Write a description of how these tracks might have been made.
4. Draw your own diagram of a set of fossilized footprints that records the interactions of organisms in the environment.
5. Give your diagram to another student and have him or her interpret what happened.

Analysis

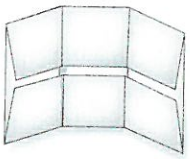
1. **Determine** the number of animals that made these tracks.
2. **Infer** types of information that can be obtained by studying fossil footprints.
3. **Interpret** another group's diagram. Is your answer the same as theirs? What might have caused any differences?

FOLDABLES™ Study Organizer

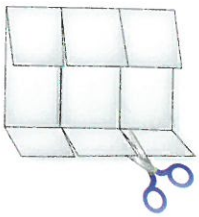
The Rock Cycle Make the following Foldable to show possible paths of rock formation.

STEP 1 Mark the middle of a vertical sheet of paper. Fold the top and bottom to the middle to form two flaps.

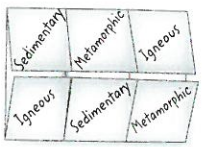
STEP 2 Fold into thirds.



STEP 3 Unfold the paper and cut the flaps along the fold lines as shown.



STEP 4 Label the tabs as shown in the diagram to the right.



FOLDABLES **Use this Foldable throughout the chapter.** Record under each tab the processes rocks might undergo as they change into the type of rock on an adjoining tab of the Foldable.

Earth Science Online

Visit glencoe.com to

- **study entire chapters online;**
- **explore Concepts in Motion animations:**
  - **Interactive Time Lines**
  - **Interactive Figures**
  - **Interactive Tables**
- **access Web Links for more information, projects, and activities;**
- **review content with the Interactive Tutor and take Self-Check Quizzes.**

Section 6.1

Objectives

- **Sequence** the formation of sedimentary rocks.
- **Explain** the process of lithification.
- **Describe** features of sedimentary rocks.

Review Vocabulary

texture: the physical appearance or feel of a rock

New Vocabulary

sediment
lithification
cementation
bedding
graded bedding
cross-bedding

Formation of Sedimentary Rocks

MAIN Idea **Sediments produced by weathering and erosion form sedimentary rocks through the process of lithification.**

Real-World Reading Link Whenever you are outside, you might see pieces of broken rock, sand, and soil on the ground. What happens to this material? With one heavy rain, these pieces of broken rock, sand, and soil could be on their way to becoming part of a sedimentary rock.

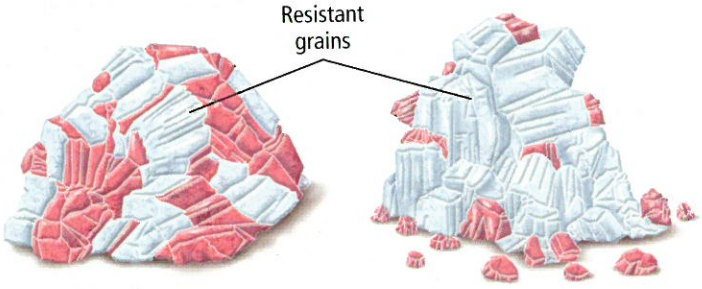
Weathering and Erosion

Wherever rock is exposed at Earth's surface, it is continuously being broken down by weathering—a set of physical and chemical processes that breaks rock into smaller pieces. **Sediments** are small pieces of rock that are moved and deposited by water, wind, glaciers, and gravity. When sediments become glued together, they form sedimentary rocks. The formation of sedimentary rocks begins when weathering and erosion produce sediments.

Weathering Weathering produces rock and mineral fragments known as sediments. These sediments range in size from huge boulders to microscopic particles. Chemical weathering occurs when the minerals in a rock are dissolved or otherwise chemically changed. What happens to more-resistant minerals during weathering? While the less-stable minerals are chemically broken down, the more-resistant grains are broken off of the rock as smaller grains. During physical weathering, however, minerals remain chemically unchanged. Rock fragments break off of the solid rock along fractures or grain boundaries. The rock in **Figure 6.1** has been chemically and physically weathered.

Figure 6.1 When exposed to both chemical and physical weathering, granite eventually breaks apart and might look like the decomposed granite shown here.

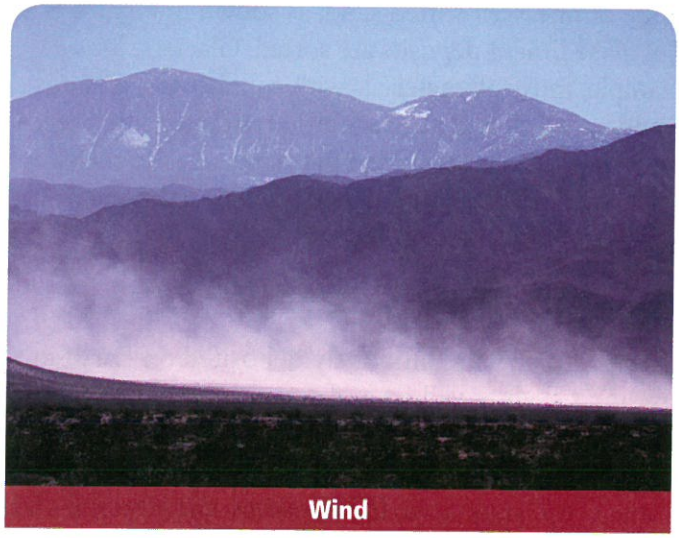
Explain *which of the three common minerals —quartz, feldspar and mica—will be most resistant to weathering.*

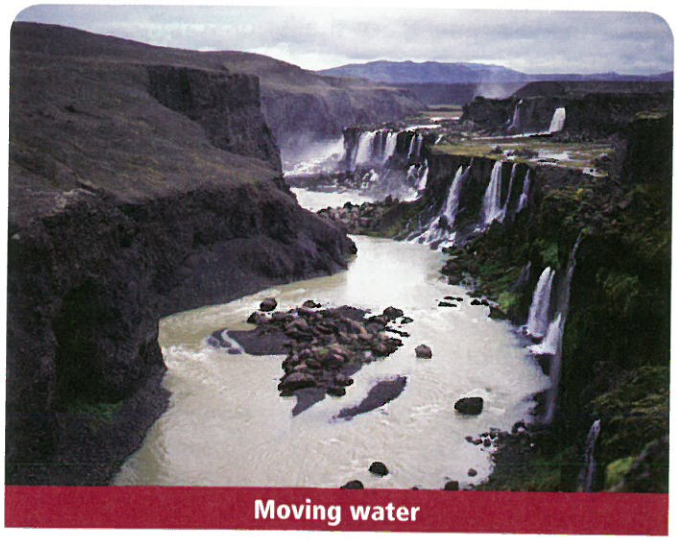


Erosion The removal and transport of sediment is called erosion. **Figure 6.2** shows the four main agents of erosion: wind, moving water, gravity, and glaciers. Glaciers are large masses of ice that move across land. Visible signs of erosion are all around you. For example, water in streams becomes muddy after a storm because eroded silt and clay-sized particles have been mixed in it. You can observe erosion in action when a gust of wind blows soil across the infield at a baseball park. The force of the wind removes the soil and carries it away.

After rock fragments and sediments have been weathered out of the rock, they often are transported to new locations through the process of erosion. Eroded material is almost always carried downhill. Although wind can sometimes carry fine sand and dust to higher elevations, particles transported by water are almost always moved downhill. Eventually, even windblown dust and fine sand are pulled downhill by gravity. You will learn more about weathering and erosion in Chapter 7.

Reading Check **Summarize** what occurs during erosion.





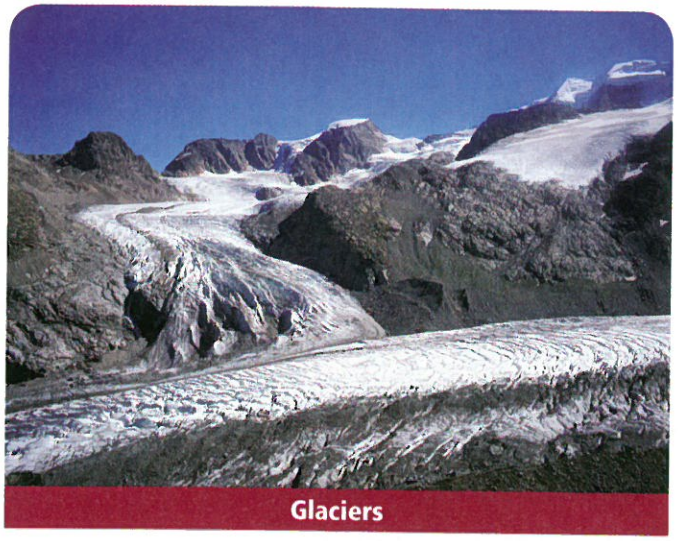


Figure 6.2 Rocks and sediment are eroded and transported by the main agents of erosion—wind, moving water, gravity, and glaciers.

MiniLab

Model Sediment Layering

How do layers form in sedimentary rocks? Sedimentary rocks are usually found in layers. In this activity, you will investigate how layers form from particles that settle in water.

Procedure

1. Read and complete the lab safety form.
2. Obtain 100 mL of **sediment** from a location specified by your teacher.
3. Place the sediment in a **200 mL jar with a lid.**
4. Add **water** to the jar until it is three-fourths full.
5. Place the lid on the jar securely.
6. Pick up the jar with both hands and turn it upside down several times to mix the water and sediment. Hesitate briefly with the jar upside down before tipping it up for the last time. Place the jar on a flat surface.
7. Let the jar sit for about 5 min.
8. Observe the settling process.

Analysis

1. **Illustrate** what you observed in a diagram.
2. **Describe** what type of particles settle out first.
3. **Describe** what type of particles form the topmost layers.

Deposition When transported sediments are deposited on the ground or sink to the bottom of a body of water, deposition occurs. During the MiniLab, what happened when you stopped turning the jar full of sediment and water? The sediment sank to the bottom and was deposited in layers with the largest grains at the bottom and the smallest grains at the top. Similarly, sediments in nature are deposited when transport stops. Perhaps the wind stops blowing or a river enters a quiet lake or an ocean. In each case, the particles being carried will settle out, forming layers of sediment with the largest grains at the bottom.

Energy of transporting agents Fast-moving water can transport larger particles better than slow-moving water. As water slows down, the largest particles settle out first, then the next largest, and so on, so that different-sized particles are sorted into layers. Such deposits are characteristic of sediment transported by water and wind. Wind, however, can move only small grains. For this reason, sand dunes are commonly made of fine, well-sorted sand, as shown in **Figure 6.3.** Not all sediment deposits are sorted. Glaciers, for example, move all materials with equal ease. Large boulders, sand, and mud are all carried along by the ice and dumped in an unsorted pile as the glacier melts. Landslides create similar deposits when sediment moves downhill in a jumbled mass.

Lithification

Most sediments are ultimately deposited on Earth in low areas such as valleys and ocean basins. As more sediment is deposited in an area, the bottom layers are subjected to increasing pressure and temperature. These conditions cause **lithification,** the physical and chemical processes that transform sediments into sedimentary rocks. *Lithify* comes from the Greek word *lithos*, which means *stone.*

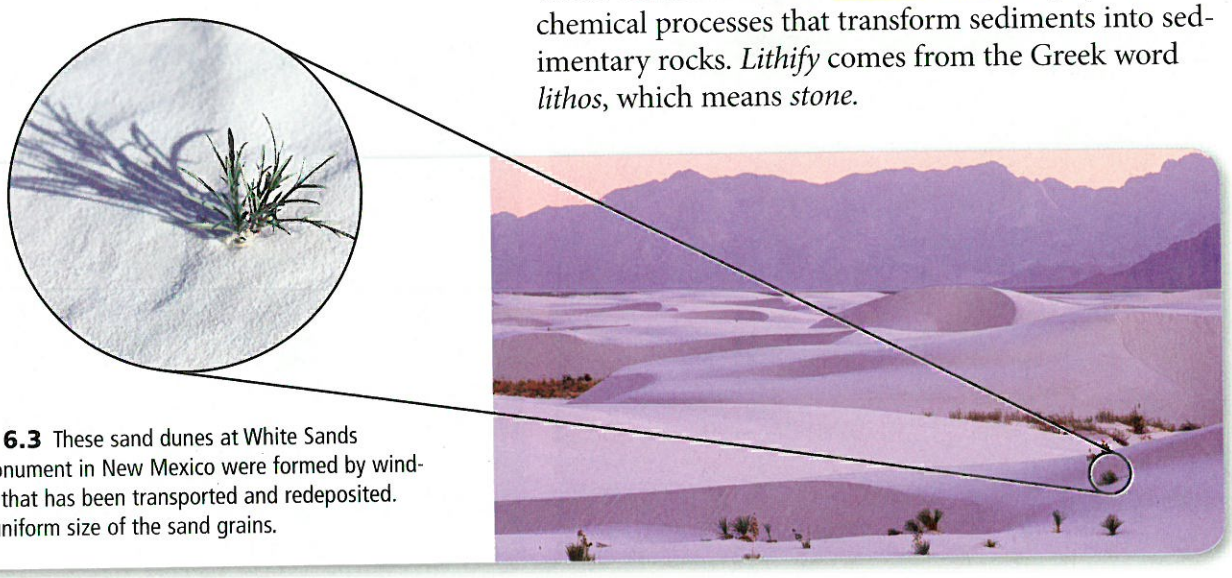


Figure 6.3 These sand dunes at White Sands National Monument in New Mexico were formed by wind-blown sand that has been transported and redeposited. Notice the uniform size of the sand grains.

Compaction Lithification begins with compaction. The weight of overlying sediments forces the sediment grains closer together, causing the physical changes shown in **Figure 6.4.** Layers of mud can contain up to 60 percent water, and these shrink as excess water is squeezed out. Sand does not compact as much as mud during burial. One reason is that individual sand grains, usually composed of quartz, do not deform under normal burial conditions. Grain-to-grain contacts in sand form a supporting framework that helps maintain open spaces between the grains. Groundwater, oil, and natural gas are commonly found in these spaces in sedimentary rocks.

Cementation Compaction is not the only force that binds the grains together. **Cementation** occurs when mineral growth glues sediment grains together into solid rock. This occurs when a new mineral, such as calcite ($CaCO_3$) or iron oxide (Fe_2O_3), grows between sediment grains as dissolved minerals precipitate out of groundwater. This process is illustrated in **Figure 6.5.**

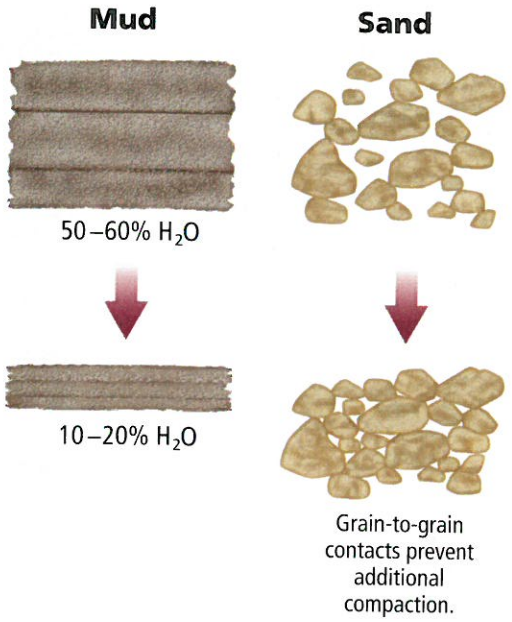


Figure 6.4 The high water content and flat shape of particles in mud cause it to compact greatly when subjected to the weight of overlying sediments.

Sedimentary Features

Just as igneous rocks contain information about the history of their formation, sedimentary rocks also have features and characteristics that help geologists interpret how they formed and the history of the area in which they formed.

Bedding The primary feature of sedimentary rocks is horizontal layering called **bedding.** This feature results from the way sediment settles out of water or wind. Individual beds can range in thickness from a few millimeters to several meters. There are two different types of bedding, each dependent upon the method of transport. However, the size of the grains and the material within the bedding depend upon many other factors.

FOLDABLES
Incorporate information from this section into your Foldable.

Figure 6.5 Minerals precipitate out of water as it flows through pore spaces in the sediment. These minerals form the cement that glues the sediments together.

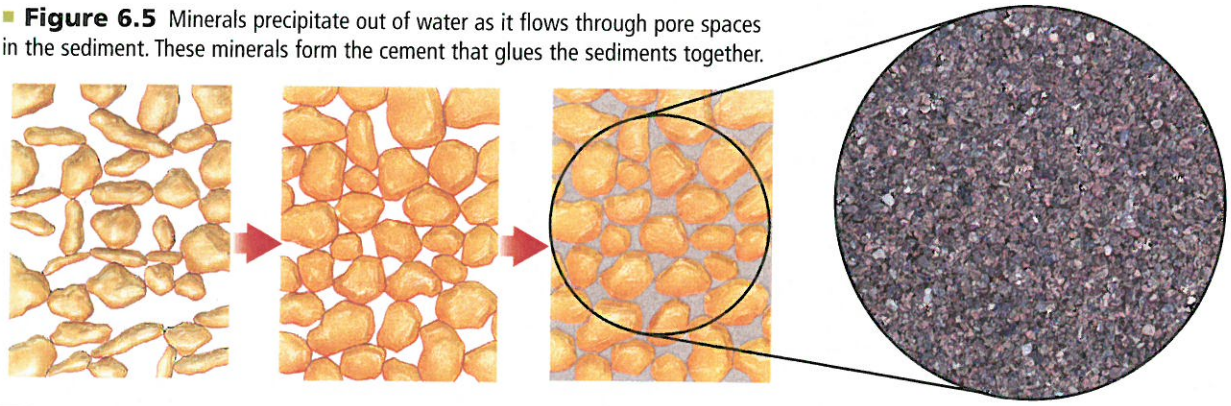


Figure 6.6 The graded bedding shown in this close-up of the Navajo Sandstone in Zion National Park records an episode of deposition during which the water slowed and lost energy.

CAREERS IN EARTH SCIENCE

Sedimentologist Studying the origin and deposition of sediments and their conversion to sedimentary rocks is the job of a sedimentologist. Sedimentologists are often involved in searching for and finding oil, natural gas, and economically important minerals. To learn more about Earth science careers, visit glencoe.com.

Graded bedding Bedding in which the particle sizes become progressively heavier and coarser toward the bottom layers is called **graded bedding.** Graded bedding is often observed in marine sedimentary rocks that were deposited by underwater landslides. As the sliding material slowly came to rest underwater, the largest and heaviest material settled out first and was followed by progressively finer material. An example of graded bedding is shown in **Figure 6.6.**

Cross-bedding Another characteristic feature of sedimentary rocks is cross-bedding. **Cross-bedding,** such as that shown in **Figure 6.7,** is formed as inclined layers of sediment are deposited across a horizontal surface. When these deposits become lithified, the cross-beds are preserved in the rock. This process is illustrated in **Figure 6.8.** Small-scale cross-bedding forms on sandy beaches and along sandbars in streams and rivers. Most large-scale cross-bedding is formed by migrating sand dunes.

Ripple marks When sediment is moved into small ridges by wind or wave action or by a river current, ripple marks form. The back-and-forth movement of waves forms ripples that are symmetrical, while a current flowing in one direction, such as in a river or stream, produces asymmetrical ripples. If a rippled surface is buried gently by more sediment without being disturbed, it might later be preserved in solid rock. The formation of ripple marks is illustrated in **Figure 6.8.**

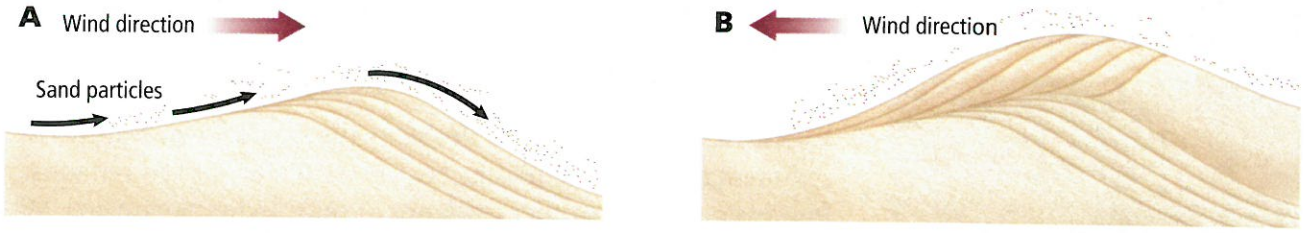
Figure 6.7 The large-scale cross-beds in these ancient dunes at Zion National Park were deposited by wind.

Visualizing Cross-Bedding and Ripple Marks

NATIONAL GEOGRAPHIC

Figure 6.8 Moving water and loose sediment result in the formation of sedimentary structures such as cross-bedding and ripple marks.

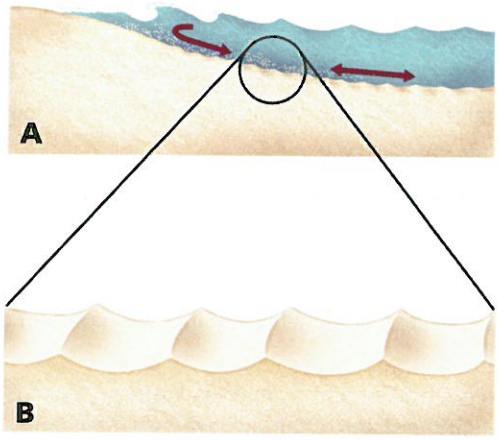
Cross-Bedding



Sand carried by wind gets deposited on the downwind side of a dune. As the wind changes direction, cross-bedding is formed that records this change in direction.

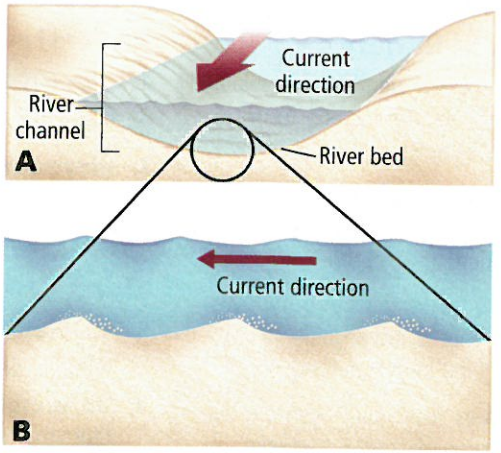
Sediment on the river bottom gets pushed into small hills and ripples by the current. Additional sediment gets deposited at an angle on the downcurrent side of these hills forming cross-beds. Eventually, it levels out or new hills form and the process begins again.

Symmetrical Ripple Marks



The back-and-forth wave action on a shore pushes the sand on the bottom into symmetrical ripple marks. Grain size is evenly distributed.

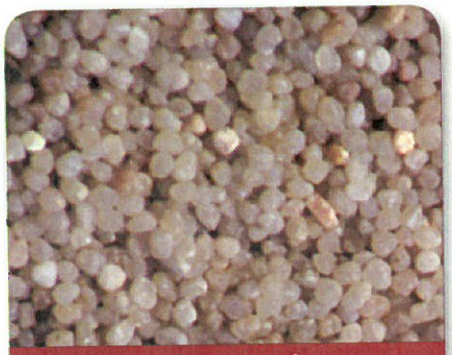
Asymmetrical Ripple Marks



Current that flows in one direction, such as that of a river, pushes sediment on the bottom into asymmetrical ripple marks. They are steeper upstream and contain coarser sediment on the upstream side.

Concepts In Motion To explore more about cross-bedding and ripple marks, visit glencoe.com.

Earth Science Online



Quartz sand

Carbonate sand

Figure 6.9 The carbonate sand has sharp, jagged pieces and is not as rounded and smooth as the quartz sand.

Sorting and rounding Close examination of individual sediment grains reveals that some have jagged edges and some are rounded. When a rock breaks apart, the pieces are angular in shape. As the sediment is transported, individual pieces knock into each other. The edges are broken off and, over time, the pieces become rounded. The amount of rounding is influenced by how far the sediment has traveled. Additionally, the harder the mineral, the better chance it has of becoming rounded before it breaks apart and becomes microscopic in size. As shown in **Figure 6.9,** quartz sand on beaches is nearly round while carbonate sand, which is made up of softer seashells and calcite, is usually more angular because it is deposited closer to the source of the sediment.

Evidence of past life Probably the best-known features of sedimentary rocks are fossils. Fossils are the preserved remains, impressions, or any other evidence of once-living organisms. When an organism dies, it sometimes is buried before it decomposes. If its remains are buried without being disturbed, it might be preserved as a fossil. During lithification, parts of the organism can be replaced by minerals and turned into rock, such as shells that have been mineralized. Fossils are of great interest to Earth scientists because fossils provide evidence of the types of organisms that lived in the distant past, the environments that existed in the past, and how organisms have changed over time. You will learn more about fossils and how they form in Chapter 21. You learned firsthand how fossils can be used to interpret past events when you completed the Launch Lab at the beginning of this chapter.

Section 6.1 Assessment

Section Summary

- The processes of weathering, erosion, deposition, and lithification form sedimentary rocks.
- Sediments are lithified into rock by the processes of compaction and cementation.
- Fossils are the remains or other evidence of once-living organisms that are preserved in sedimentary rocks.
- Sedimentary rocks might contain features such as horizontal bedding, cross-bedding, and ripple marks.

Understand Main Ideas

1. MAIN Idea **Describe** how sediments are produced by weathering and erosion.
2. **Sequence** Use a flowchart to show why sediment deposits tend to form layers.
3. **Illustrate** the formation of graded bedding.
4. **Compare** temperature and pressure conditions at Earth's surface and below Earth's surface, and relate them to the process of lithification.

Think Critically

5. **Evaluate** this statement: It is possible for a layer of rock to show both cross-bedding and graded bedding.
6. **Determine** whether you are walking upstream or downstream along a dry mountain stream if you notice that the shape of the sediment is getting more angular as you continue walking. Explain.

WRITING in Earth Science

7. Imagine you are designing a display for a museum based on a sedimentary rock that contains fossils of corals and other ocean-dwelling animals. Draw a picture of what this environment might have looked like, and write the accompanying description that will be posted next to the display.

Earth Science Online Self-Check Quiz glencoe.com