

# Chapter 6

## What You'll Learn

- How sedimentary rocks are formed.
- How metamorphic rocks are formed.
- How rocks continuously change from one type to another in the rock cycle.

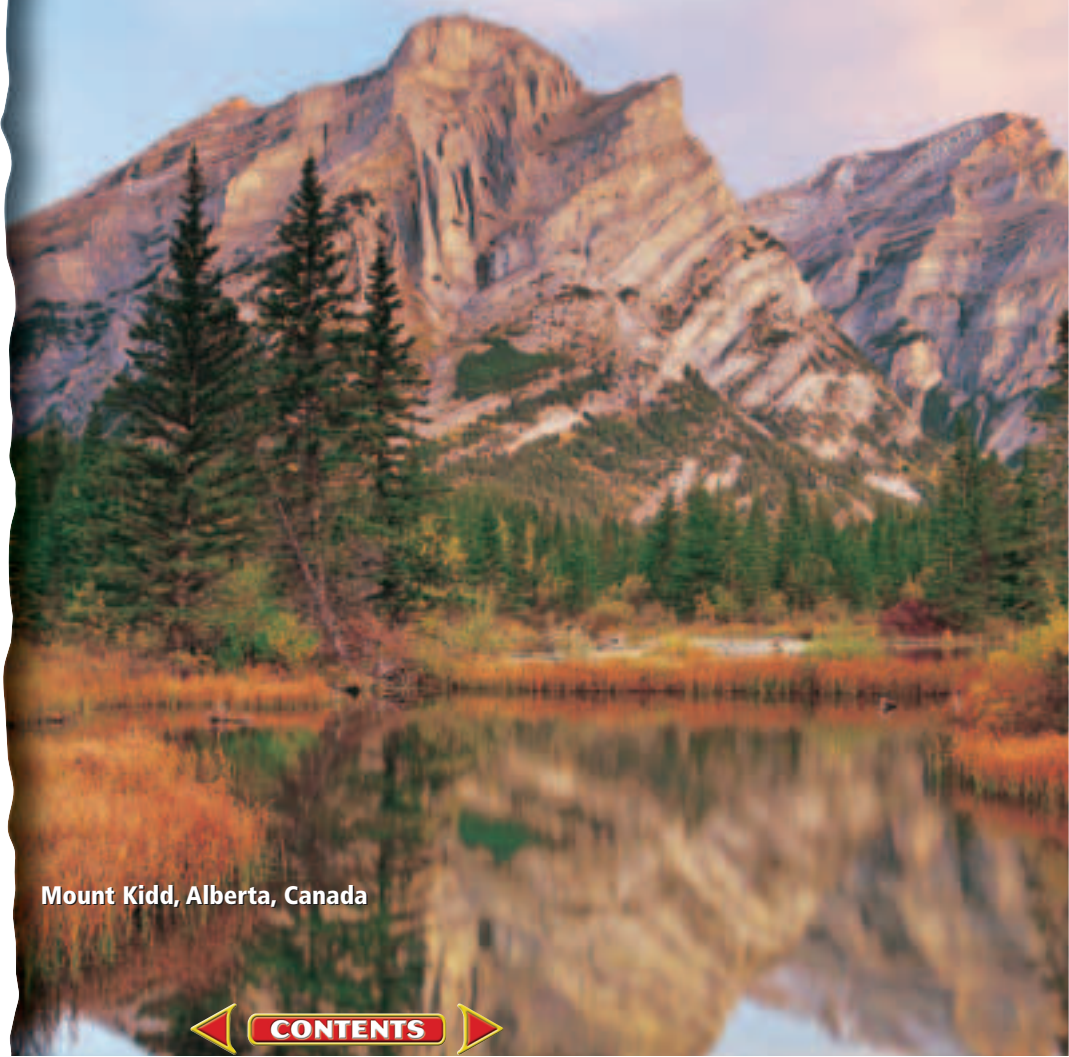
## Why It's Important

Sedimentary rocks provide information about surface conditions and organisms that existed in Earth's past. In addition, mineral resources are found in sedimentary and metamorphic rocks. The rock cycle further provides evidence that Earth is a dynamic planet, constantly evolving and changing.



To find out more about sedimentary and metamorphic rocks, visit the Earth Science Web Site at [earthgeu.com](http://earthgeu.com)

# Sedimentary and Metamorphic Rocks



Mount Kidd, Alberta, Canada

## Discovery Lab

## Model Sediment Layering

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

1. Obtain 100 mL of soil from a location specified by your teacher. Place the soil in a tall, narrow, jar.
2. Add water to the jar until it is three-fourths full. Put the lid on the jar so that it is tightly sealed.
3. Pick up the jar with both hands and turn it upside down several times to mix the water and soil.

4. Quickly turn the jar upright and set it on a flat surface.

**Observe** In your science journal, draw a diagram of what you observe. What type of particles settled out first? What type of particles form the topmost layers? How is this activity related to the layering that occurs in sedimentary rocks?



### SECTION

## 6.1

## Formation of Sedimentary Rocks

### OBJECTIVES

- **Sequence** the formation of sedimentary rocks.
- **Explain** the formation and classification of clastic sediments.
- **Describe** features of sedimentary rocks.

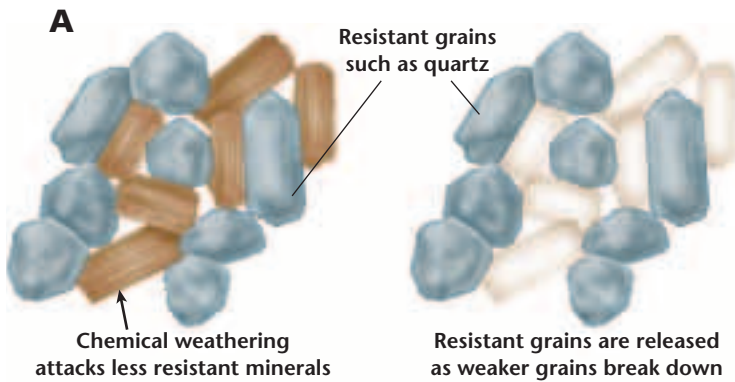
### VOCABULARY

<i>sediment</i>	<i>bedding</i>
<i>clastic</i>	<i>graded bedding</i>
<i>deposition</i>	<i>cross-bedding</i>
<i>lithification</i>	
<i>cementation</i>	

You learned in Chapter 5 that igneous rocks are the most common rocks in Earth's crust, yet when you look at the ground, you may not see igneous rocks. In fact, you usually don't see any solid rock at all. Why is this? Much of Earth's surface is covered with sediments. **Sediments** are pieces of solid material that have been deposited on Earth's surface by wind, water, ice, gravity, or chemical precipitation. When sediments become cemented together, they form sedimentary rocks. The formation of sedimentary rocks begins when weathering and erosion produce sediments.

### WEATHERING

Wherever Earth's crust is exposed at the surface, it is continuously being worn away by weathering, a set of physical and chemical processes that break rock into smaller pieces. Chemical weathering occurs when the minerals in a rock are dissolved or otherwise



**Figure 6-1** The process of chemical weathering is illustrated in **(A)**. Granite breaks apart easily under the effects of chemical weathering **(B)**.

chemically changed. Study *Figure 6-1*. 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, on the other hand, minerals remain chemically unchanged. Rock fragments simply break off of the solid rock along fractures or grain boundaries.

Weathering produces rock and mineral fragments known as **clastic** sediments. The word *clastic* comes from the Greek word *klastos*, meaning “broken.” Clastic sediments range in size from huge boulders to microscopic particles. *Table 6-1* summarizes the classification of clastic sediments based on size. Clastic sediment particles usually have worn surfaces and rounded corners caused by physical abrasion during erosion and transport.

## EROSION AND TRANSPORT

After rock fragments have been weathered out of outcrops, they are transported to new locations. The removal and movement of surface materials from one location to another is called erosion.

Particle Size	Sediment	Rock
> 256 mm 256–64 mm 64–2 mm	Gravel } Boulder Cobble Pebble	Conglomerate
2–0.062 mm	Sand	Sandstone
0.062–0.0039 mm	Silt	Siltstone
<0.0039 mm	Clay	Mudstone or shale



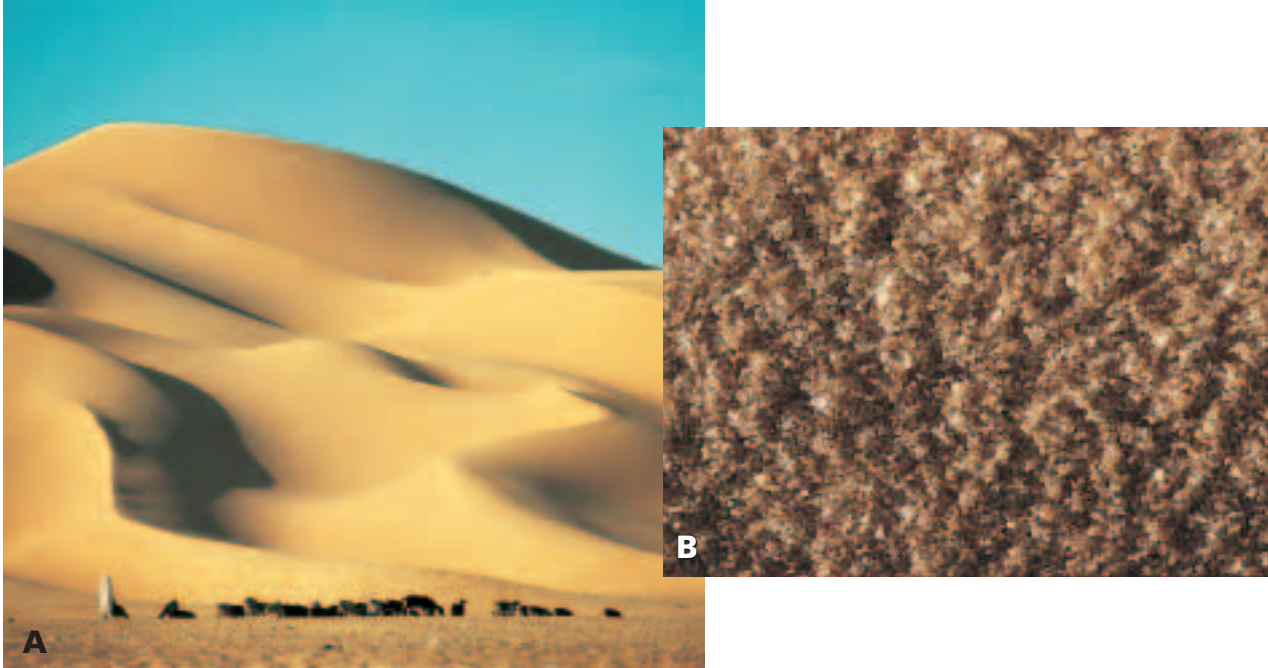
**Figure 6-2** shows the four main agents of erosion: wind, moving water, gravity, and glaciers. Visible signs of erosion are all around you. For example, water in streams becomes muddy after a storm because silt and clay particles have been added to it. The dust that collects on shelves in your home is another indication of erosion. Where do you think this dust comes from? How is it carried and how does it eventually settle on the shelves?

Eroded materials are almost always carried downhill. Although wind can sometimes carry fine sand and dust to higher elevations, particles transported by water are almost always moved downward. Eventually, even wind-blown dust and fine sand are pulled downhill by gravity. You will learn more about this in the next chapter.

**Deposition** When sediments are laid down on the ground or sink to the bottoms of bodies of water **deposition** occurs. During the *Discovery Lab* at the beginning of this chapter, what happened when you stopped moving the jar full of sediment and water? The sediment sank to the bottom and was deposited. Similarly, in nature, sediments are

**Figure 6-2** Winds blow sand into dunes on the Navajo Indian Reservation in Arizona **(A)**. The river Lethe cuts through the Valley of Ten Thousand Smokes in Katmai National Park, Alaska **(B)**. This landslide in Papua, New Guinea, carried the entire hillside 300 m into the canyon **(C)**. This terminal moraine was built up by the Athabasca Glacier in Jasper National Park, Alberta, Canada **(D)**.





**Figure 6-3** This large sand dune (**A**) in Algeria, Africa, is made up of fine sand such as this from Kalahari, South Africa (**B**).

deposited when transport stops. Perhaps the wind stops blowing or a river enters a quiet lake or the ocean. In each case, the particles being carried will settle out, forming layers of sediment. You observed this when you completed the *Discovery Lab* at the beginning of this chapter, that the sediment formed layers as it settled to the bottom of the jar. The sediment formed a layered deposit with the largest grains at the bottom and the smallest particles at the top. As the water in the jar slowed down, the largest particles settled out first. Why? Faster-moving water can transport larger particles. 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, such as the ones shown in *Figure 6-3A*, are commonly made of fine, well-sorted sand like the sand in *Figure 6-3B*.

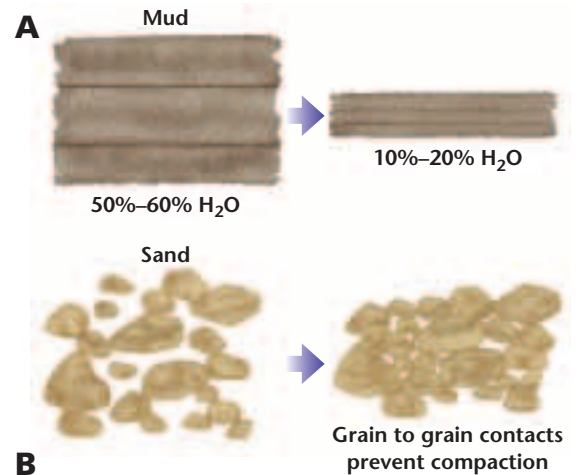
Not all sediment deposits are sorted. Glaciers, for example, move all materials with equal ease. Large boulders, sand, and mud are all carried along by the ice and dumped in an unsorted pile at the end of the glacier. Landslides create similar deposits when sediment moves downhill in a jumbled mass.

**Burial** Most sediments are ultimately deposited on Earth in depressions called sedimentary basins. These basins may contain layers of sediment that together are more than 8 km thick. As more and 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.”

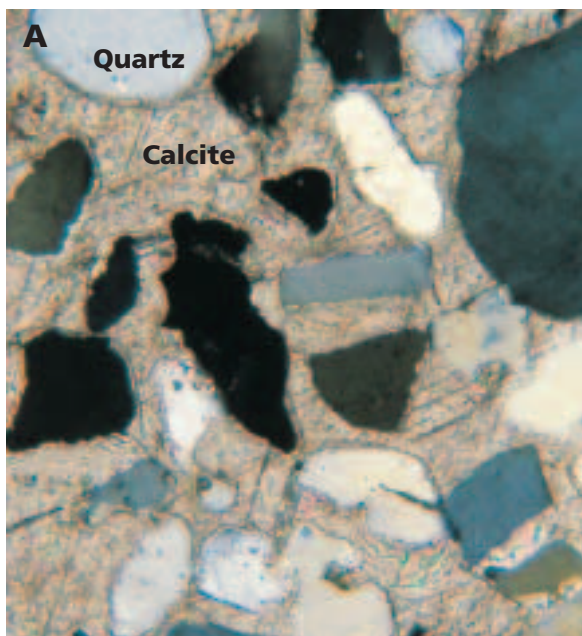
## LITHIFICATION

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 may contain up to 60 percent water, and these shrink as excess water is squeezed out. Sand, however, is usually well compacted during deposition, and resists additional compaction during burial. 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.

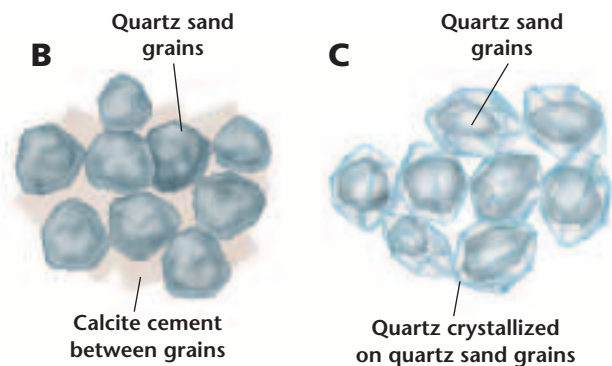
The temperature in Earth's crust increases with depth by about 30°C per kilometer. Sediments that are buried 3 to 4 km deep experience temperatures that are high enough to start the chemical and mineral changes that cause cementation. **Cementation** occurs when mineral growth cements sediment grains together into solid rock. There are two common types of cementation. The first type occurs when a new mineral, such as calcite ( $\text{CaCO}_3$ ) or iron oxide ( $\text{Fe}_2\text{O}_3$ ) grows between sediment grains as dissolved minerals precipitate out of groundwater. The second type occurs when existing mineral grains grow larger as more of the same mineral precipitates from groundwater and crystallizes around them. These two types of cementation are shown in **Figure 6-5**.



**Figure 6-4** Pressure and weight from overlying sediments causes flat clay particles to compact (A). The irregular shape of sand grains prevents similar amounts of compaction (B).



**Figure 6-5** Cementation occurs in one of two ways. Either a new mineral, such as the calcite shown in A, grows between the grains (B) or, the same mineral grows between and over the grains in a process called overgrowth (C).





## MiniLab

### What happened here?

**Interpret** animal activity from patterns of fossil footprints.



### Procedure

1. Study the photograph of a set of footprints that has been preserved in sedimentary rocks.
2. Write a description of how these tracks might have been made.
3. Draw your own diagram of a set of fossilized footprints that record the interactions of organisms in the environment.
4. Give your diagram to another student and have them interpret what happened.

### Analyze and Conclude

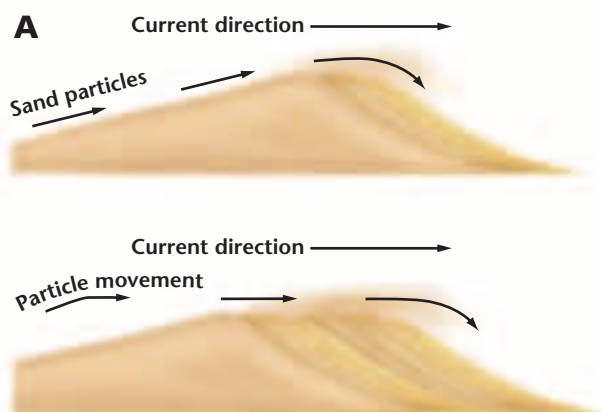
1. How many animals made the tracks shown?
2. What types of information can be inferred from a set of fossil footprints?
3. Did other students interpret your diagram the same way? What might have caused any differences?

## FEATURES OF SEDIMENTARY ROCKS

The primary feature of sedimentary rocks is horizontal layering, called **bedding**. Bedding can range from a millimeter-thick layer of shale to sandstone deposits several meters thick. The type of bedding depends upon the method of transport, while the size of the grains and the material within the bedding depend upon many factors.

Bedding in which the particle sizes become progressively heavier and coarser towards 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.

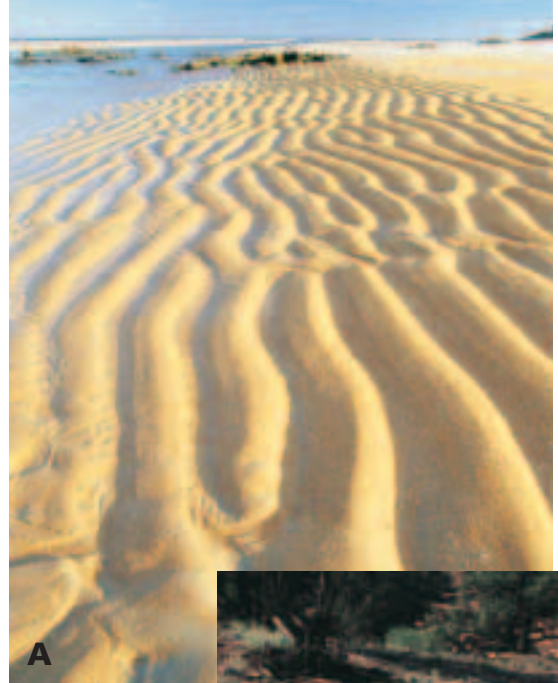
Another characteristic feature of sedimentary rocks is cross-bedding. As you can see in *Figure 6-6A*, **cross-bedding** is formed as inclined layers of sediment move forward across a horizontal surface. Small-scale cross-bedding can be observed at sandy beaches and along sandbars in streams and rivers. Most large-scale cross-bedding, such as that shown in *Figure 6-6B*, is formed by migrating sand dunes. Small sedimentary features, such as the ripple marks shown



**Figure 6-6** Cross-bedding is formed as sediment is carried forward across a layer of sediment, and cascades down the front face of the layer (**A**). Large-scale cross-bedded sandstones are common in Zion National Park (**B**).



**Figure 6-7** Given the right sedimentary conditions, these modern sand ripples (A) could become preserved like these ripple marks in Capitol Reef National Park, Utah (B).



A

in *Figure 6-7*, are also preserved in sedimentary rocks. Ripple marks form when sediment is moved into small ridges by wind or wave action, or by a river current. The back-and-forth movement of waves creates 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.

**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 may be buried before it decomposes. If its remains are further 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 fossilized shells. 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. By doing the *MiniLab* on the previous page, you can learn first-hand how fossils can be used to interpret past events.



B

## SECTION ASSESSMENT

1. How are clastic sediments formed, and how do scientists classify them?
2. Why do sediment deposits tend to form layers?
3. As sediments are buried, what two factors increase with depth? How do these factors cause lithification?
4. Compare and contrast graded bedding and cross-bedding.
5. **Thinking Critically** Is it possible for a layer of cross-bedded strata to show graded bedding as well? Explain.

### SKILL REVIEW

6. **Sequencing** Sequence the processes by which a sedimentary rock is formed from clastic sediments. For more help, refer to the *Skill Handbook*.





**OBJECTIVES**

- **Describe** the types of clastic sedimentary rocks.
- **Explain** how chemical sedimentary rocks form.
- **Describe** organic sedimentary rocks.
- **Recognize** the importance of sedimentary rocks.

**VOCABULARY**

clastic sedimentary rock  
porosity  
evaporite

The classification of sedimentary rocks is based on how they were formed. There are three main groups of sedimentary rocks: clastic, chemical, and organic. **Table 6-2** summarizes the classification system for sedimentary rocks.

**CLASTIC SEDIMENTARY ROCKS**

The most common type of sedimentary rocks, **clastic sedimentary rocks**, are formed from the abundant deposits of loose sediments found on Earth's surface. Clastic sedimentary rocks are further classified according to the sizes of their particles. This classification system was shown in **Table 6-1** on page 122.

**Coarse-Grained Clastics** Sedimentary rocks consisting of gravel-sized rock and mineral fragments are classified as coarse-grained clastics, as shown in **Figure 6-8**. What differences between these two rocks do you notice? Conglomerates are coarse-grained sedimentary rocks that have rounded particles, whereas breccias contain angular fragments. How are these different-shaped particles formed? Because of its relatively large mass, gravel is transported by high-energy flows of water, such as those generated by mountain streams, flooding rivers, some ocean waves, and glacial meltwater. During transport, gravel becomes abraded and rounded as the particles scrape against one another. This is why beach and river gravels are often well rounded. Conglomerates provide evidence that this type of transport occurred in the past. In contrast, the angularity of

**Table 6-2** Classification of Sedimentary Rocks

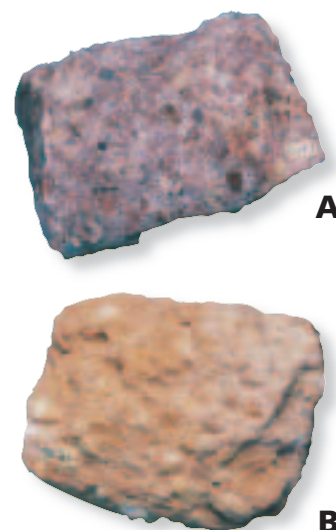
Rock Type	Rock Name	Method of Formation
<b>Clastic</b> Coarse-grained Medium-grained Fine-grained	Conglomerate or breccia Sandstone Shale	Lithification of clastic sediments
<b>Chemical</b> Calcite Halite Gypsum	Limestone Rock salt Rock gypsum	Precipitation of dissolved minerals from water
<b>Organic</b> Calcium carbonate—shells plant matter	Limestone Coal	Accumulation and lithification of remains of living things

particles in breccias indicates that the sediments from which they formed did not have time to become rounded. This suggests that the particles were transported only a short distance and deposited close to their source. Under what kinds of circumstances might this type of transport occur?


**Medium-Grained Clastics** In what types of environments is sand found? Stream and river channels, beaches, and deserts often contain abundant sand-sized sediments. Sedimentary rocks that contain sand-sized rock and mineral fragments are classified as medium-grained clastic rocks. When these medium-sized sediments are buried and lithified, sandstone is formed. Sandstone usually contains several features of interest to scientists. For example, because ripple marks and cross-bedding indicate the direction of current flow, geologists find sandstone layers particularly useful in mapping old stream and river channels.

Another important feature of sandstone is its relatively high porosity. **Porosity** is the percentage of open spaces between grains in a rock. Loose sand can have a porosity of up to 40 percent; some of its open spaces are maintained during the formation of sandstone. The incomplete cementation of mineral grains can result in porosities as high as 30 percent. When pore spaces are connected to one another, fluids can move through sandstone. This feature makes sandstone layers valuable as underground reservoirs of oil, natural gas, and groundwater.

**Fine-Grained Clastics** Sedimentary rocks consisting of silt and mud are called siltstone and mudstone. Siltstone is mostly composed of silt-sized grains, while shale is composed mostly of silt and clay-sized particles. Shale often breaks along thin layers, as shown in *Figure 6-9*. Unlike sandstone, this fine-grained sedimentary rock has very low porosity. It often forms barriers that hinder the movement of groundwater and oil.



**Figure 6-8** This coarse-grained breccia (A) has angular fragments, and the conglomerate (B) has rounded fragments.



**Using Math**

**Using Percentages**  
Assume that the volume of a layer of mud will decrease by 35 percent during burial and compaction. If the original sediment layer is 30 cm thick, what will be the thickness of the shale layer after compaction and lithification?

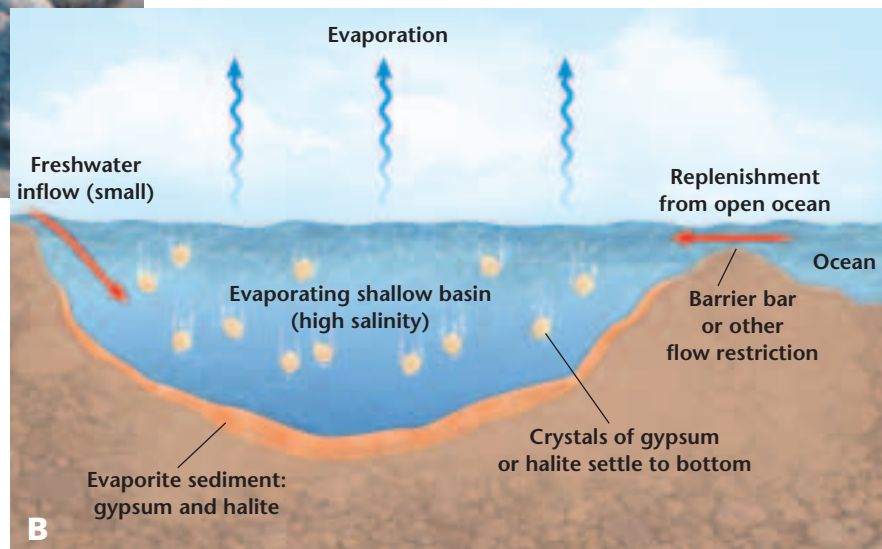
**Figure 6-9** The thin bedding that is characteristic of shale is clearly seen in this outcrop from Ontario, Canada.

## CHEMICAL SEDIMENTARY ROCKS

What happens when you allow a glass of saltwater to evaporate? Eventually, the water disappears and a layer of salt accumulates on the bottom of the glass. A similar process occurs in nature when chemical sedimentary rocks are formed. During chemical weathering, minerals can be dissolved and carried into lakes and oceans. As water evaporates from the lakes and oceans, the dissolved minerals are left behind. In arid regions, high evaporation rates can increase the concentration of dissolved minerals in bodies of water. The Great Salt Lake, shown in *Figure 6-10A*, is a well-known example of a lake that has high concentrations of dissolved minerals.

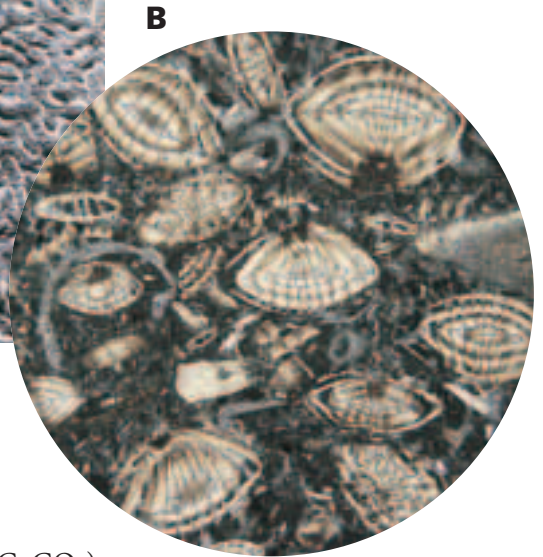
**Rocks Formed from Evaporation** When the concentration of dissolved minerals in a body of water reaches saturation, which is the point at which no more minerals can be dissolved in the water, crystal grains precipitate out of solution and settle to the bottom. The layers of chemical sedimentary rocks that form as a result are called **evaporites**. Evaporites most commonly form in arid regions, in oceans and in drainage basins on continents that have low water flow. Because little freshwater flows into these areas, the concentration of dissolved minerals remains high.

As more dissolved minerals are carried into the basins, evaporation continues to remove freshwater and maintain high mineral concentrations. Over time, thick layers of evaporite minerals can accumulate on the basin floor, as illustrated in *Figure 6-10B*.



**Figure 6-10** Evaporation of water from the Great Salt Lake, Utah, has resulted in salt precipitation on these boulders (**A**). The process of evaporite formation is illustrated in **B**.





**Figure 6-11** Fossils in organic sedimentary rocks may range in size from corals such as these in a limestone from South Florida (**A**), to these *Nummulites* microfossils (**B**) preserved in the limestones that were used to build the pyramids in Egypt.

Magnification: 12×

The three most common evaporite minerals are calcite ( $\text{CaCO}_3$ ), halite ( $\text{NaCl}$ ), and gypsum ( $\text{CaSO}_4$ ). Layers of these minerals are often mined for their chemical content.

**Organic Sedimentary Rocks** Organic sedimentary rocks are formed from the remains of once-living things. The most abundant organic sedimentary rock is limestone, which is composed primarily of calcite. Some organisms that live in the ocean use the calcium carbonate dissolved in seawater to make their shells. When these organisms die, their shells settle to the bottom of the ocean and can form thick layers of carbonate sediment. During burial and lithification, calcium carbonate precipitates out of the water, crystallizes between the grains of carbonate sediment, and forms limestone. Limestone is common in shallow water environments such as those in the Bahamas, where coral reefs thrive in 15 to 20 m of water just offshore. The skeleton and shell materials that are currently accumulating there will someday become limestone as well. Many types of limestone contain evidence of their biologic origin in the form of abundant fossils. As shown in *Figure 6-11*, these fossils range from large corals to microscopic unicellular organisms. Other organisms use silica to make their shells. These shells form sediment that is often referred to as siliceous ooze because it is rich in silica.

Another type of organic sedimentary rock, coal, forms from the remains of plant material. Over long periods of time, thick layers of vegetation slowly accumulate in swamps and coastal areas. When these layers are buried and compressed, they are slowly lithified into coal. Coal is composed almost entirely of carbon and can be burned for fuel. You will learn more about coal as an energy source in Chapter 25.



**Topic: Coral Reefs**

For an online update of coral reefs in the Bahamas, visit the Earth Science Web Site at [earthgeu.com](http://earthgeu.com)



**Activity:** Discuss the cause and significance of the major bleaching event of 1997-1998 in coral reefs around the world.

## IMPORTANCE OF SEDIMENTARY ROCKS

The characteristic textures and features of sedimentary rocks, such as cross-bedding, ripple marks, layering, and fossils, provide a geologic “snapshot” of surface conditions in Earth’s past. Fossils, for example, provide information about animals and plants that existed in the past. Other sedimentary features indicate the location and direction of flow of ancient rivers, the wave or wind direction over lakes and deserts, and ancient shoreline positions. Rock fragments found in conglomerates and breccias are large enough to easily identify what types of bedrock they were eroded from. By considering all of this information, geologists can reconstruct the nature of Earth’s surface at various times in the past. Thus, they can better understand how geologic changes occur over time.



### ENVIRONMENTAL CONNECTION

 **Energy Resources** The study of sedimentary rocks provides information about Earth’s past, but it also has great practical value. Many of the natural resources used by humans come from sedimentary rocks. For example oil, natural gas, and coal are found in sedimentary rocks. Uranium, which is used for nuclear power, is often mined from sandstone. Large deposits of phosphate, which is used for fertilizer, and iron, which is used to make steel, are also found in sedimentary rocks. Limestone is processed to make cement for the construction industry. Sandstone and limestone are often cut into blocks for use in walls and buildings. Were any sedimentary rocks used to construct your school? What sedimentary rocks were used in the construction of your home? 

## SECTION ASSESSMENT

1. Compare and contrast the main types of clastic sedimentary rocks.
2. Why do chemical sedimentary rocks form primarily in areas that have high rates of evaporation?
3. Why is coal an organic sedimentary rock?
4. What are some of the commercial values of sedimentary rocks?
5. **Thinking Critically** The original concentration of dissolved minerals in a restricted

ocean basin was enough to form only a thin evaporite layer. How, then, is it possible that thick evaporite layers formed there?

### SKILL REVIEW

6. **Comparing and Contrasting** Make a data table to compare and contrast the formation of the three types of sedimentary rock. For more help, refer to the *Skill Handbook*.



You have learned that increasing pressure and temperature during burial cause recrystallization and cementation of sediments. What happens when rocks are buried at even greater depths?

### CAUSES OF METAMORPHISM

Pressure and temperature increase with depth. When temperature or pressure becomes high enough, rocks melt and form magma. But what happens if the rocks do not quite reach the melting point? When high temperature and pressure combine to alter the texture, mineralogy, or chemical composition of a rock without melting it, a metamorphic rock forms. The word *metamorphism* is derived from the Greek words *meta*, meaning “change,” and *morphē* meaning “form.” During metamorphism, a rock changes form while remaining solid.

The high temperatures required for metamorphism ultimately are derived from Earth’s internal heat, either through deep burial or from nearby igneous intrusions. The high pressures required for metamorphism can be generated in two ways: from vertical pressure caused by the weight of overlying rock, or from the compressive forces generated as rocks are deformed during mountain building.

### TYPES OF METAMORPHISM

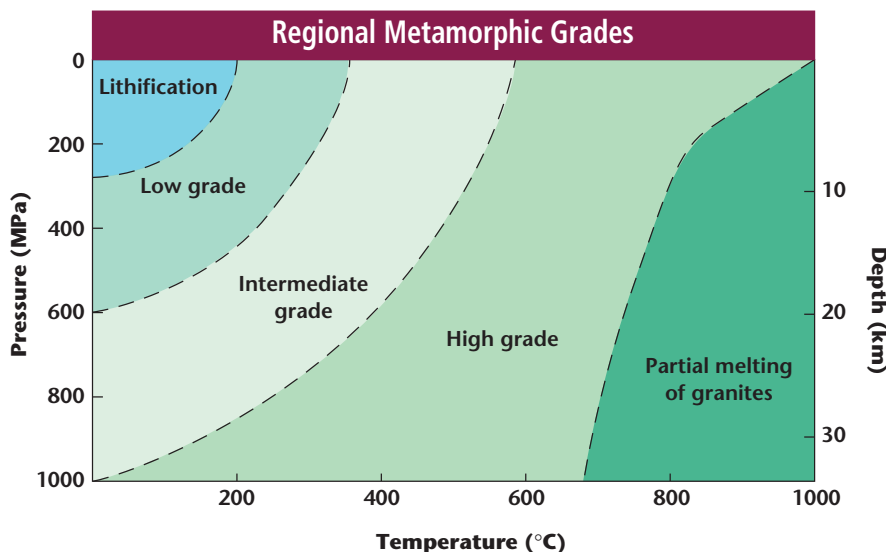
Different combinations of temperature and pressure result in different types of metamorphism, shown in **Figure 6-12**. Each combination produces a different group of metamorphic minerals and

### OBJECTIVES

- **Compare and Contrast** the different types and causes of metamorphism.
- **Distinguish** among metamorphic textures.
- **Explain** how mineral and compositional changes occur during metamorphism.
- **Understand** how rocks continuously change from one type to another in the rock cycle.

### VOCABULARY

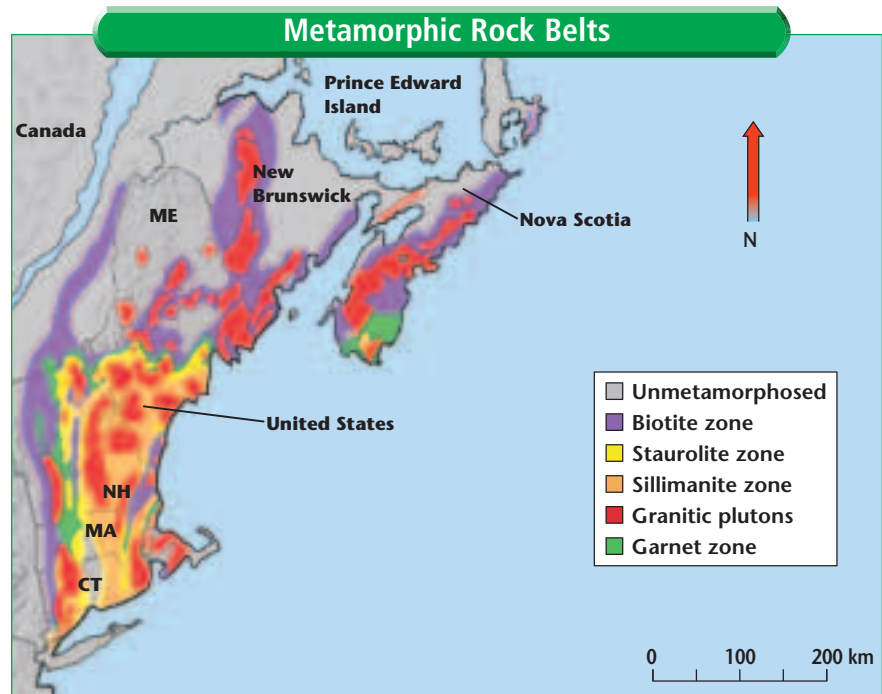
regional metamorphism  
 contact metamorphism  
 hydrothermal metamorphism  
 foliated  
 nonfoliated  
 porphyroblast  
 rock cycle



**Figure 6-12** The grade of metamorphism, whether it is low, medium or high, is dependent upon the pressure on the rocks, the temperature and the depth below the surface.

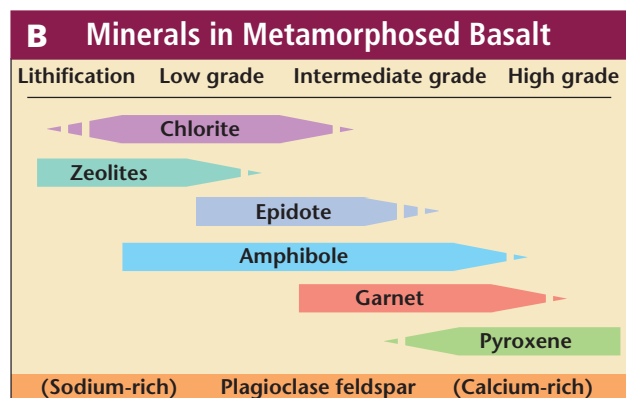
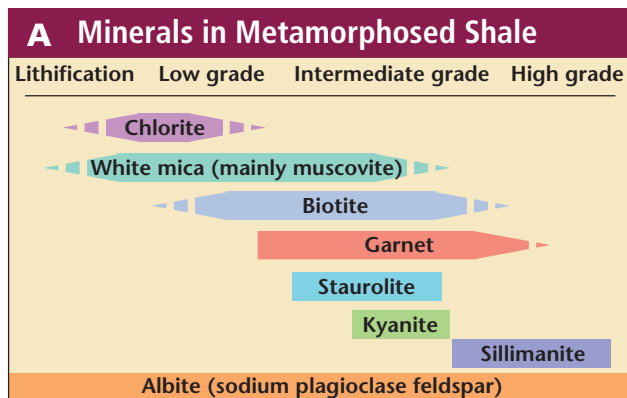


**Figure 6-13** The northeast portion of North America has undergone several episodes of regional metamorphism. The results can be seen in the distribution of metamorphic rocks.



textures. When high temperature and pressure affect large regions of Earth’s crust, they produce large belts of **regional metamorphism**. Regional metamorphism can be low grade, intermediate grade, and high grade. The grade of regional metamorphism reflects the relative intensity of temperature and pressure, with low-grade metamorphism reflecting the lowest temperature and pressure. *Figure 6-13* shows the regional metamorphic belt that has been mapped in the northeastern United States. Geologists have divided the belt into zones based upon the mineral groups found in the rocks. Some of the key minerals used to map metamorphic zones are listed in *Figure 6-14*. Knowing the temperatures that certain areas experienced when rocks were forming can help geologists locate economically valuable

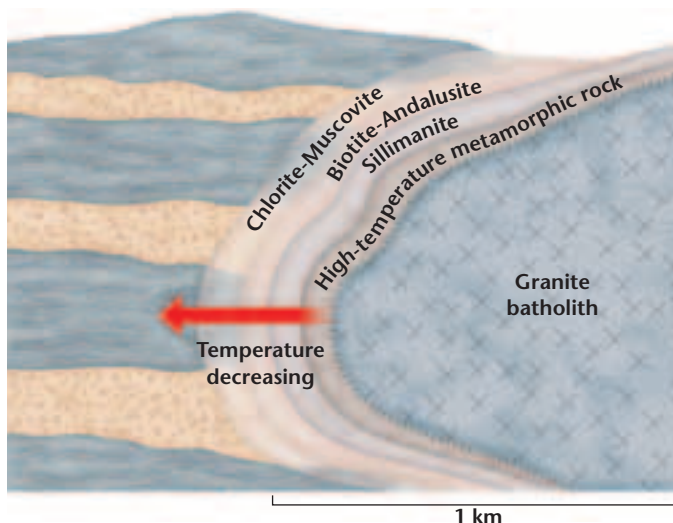
**Figure 6-14** Mineral changes in shale (**A**) and basalt (**B**), as a result of metamorphism follow a specific path. The grade of metamorphism (low, intermediate, or high) determines which minerals will form.



metamorphic minerals such as garnet and talc. An interesting connection between talc and asbestos, another metamorphic mineral, is described in the *Science in the News* feature at the end of this chapter.

When molten rocks, such as those in an igneous intrusion, come in contact with solid rock, a local effect called **contact metamorphism** occurs. High temperature and moderate-to-low pressure form the mineral assemblages that are characteristic of contact metamorphism. **Figure 6-15** shows zones of different minerals surrounding an intrusion. Why do you think these zones occur? Because temperature decreases with distance from an intrusion, metamorphic effects also decrease with distance. Recall from Chapter 4 that minerals crystallize at specific temperatures. Minerals that crystallize at high temperatures are found closest to the intrusion, where it is hottest. Contact metamorphism from extrusive igneous rocks is limited to thin zones. Normally, lava cools too quickly for the heat to penetrate very far into surface rocks.

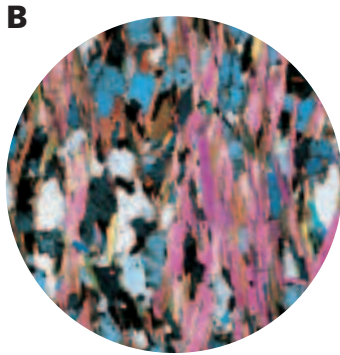
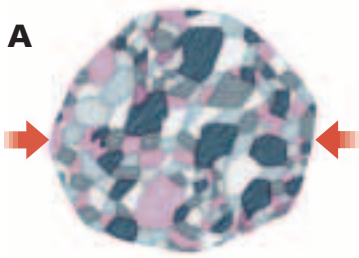
When very hot water reacts with rock and alters its chemistry and mineralogy **hydrothermal metamorphism** occurs. The word *hydrothermal* is derived from the Greek words *hydro*, meaning “water,” and *thermal*, meaning “heat.” Hydrothermal fluids can dissolve some minerals, break down others, and deposit new minerals. These types of changes caused the yellow color of the cliffs shown in **Figure 6-16**. Hydrothermal metamorphism is common around igneous intrusions and near active volcanoes.



**Figure 6-15** Contact metamorphism results in large-scale mineral changes with little deformation. Geologists can follow the occurrence of metamorphic minerals to locate the igneous intrusion.



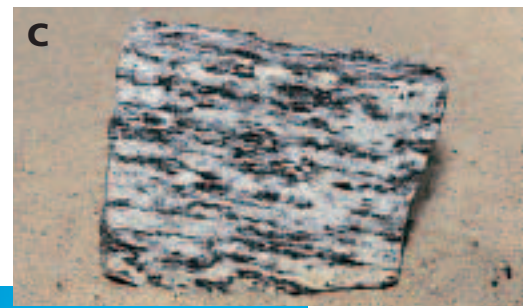
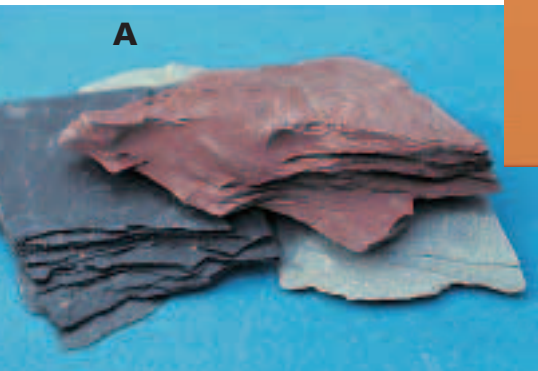
**Figure 6-16** Yellowstone National Park's name comes from the hydrothermally changed rocks of the area. These rocks are beautifully exposed in the Grand Canyon of the Yellowstone, Wyoming.



Magnification: 7×

**Figure 6-17** Compressional pressure causes elongate minerals to line up perpendicular to the pressure direction (A). This photomicrograph of a mica schist (B) shows the resulting foliation.

**Figure 6-18** These common foliated rocks are arranged in order of increasing metamorphic grade: slate (A), phyllite (B), gneiss (C), and schist (D).



## METAMORPHIC TEXTURES

Metamorphic rocks are classified into two textural groups: foliated and nonfoliated. Wavy layers and bands of minerals characterize **foliated** metamorphic rocks. High pressure during metamorphism causes minerals with flat or needlelike crystals to

form with their long axes perpendicular to the pressure, as shown in *Figure 6-17*. This parallel alignment of minerals creates the layers observed in foliated metamorphic rocks. The two most common types of foliated metamorphic rock are schist, which is derived from shale, and gneiss, which is derived from granite. Some common foliated metamorphic rocks are compared in *Figure 6-18*.

Unlike foliated rocks, **nonfoliated** metamorphic rocks lack mineral grains with long axes in one direction. Nonfoliated rocks are composed mainly of minerals that form with blocky crystal shapes. Two common examples of nonfoliated rocks, shown in *Figure 6-19*, are quartzite and marble. Quartzite is a hard, light-colored rock formed by the metamorphism of quartz-rich sandstone. Marble is formed by the metamorphism of limestone. Some marbles have very smooth textures that are formed by interlocking grains of calcite. Such marbles are sought by artists for sculptures.

**Porphyroblasts** Under certain conditions, new metamorphic minerals can grow quite large while the surrounding minerals remain small. The large crystals, which can range in size from a few millimeters to a few centimeters, are called **porphyroblasts**. Porphyroblasts are found in areas of both contact and regional metamorphism. These crystals resemble the very large crystals found in porphyritic igneous rocks but form not from magma but





**Figure 6-19** Despite the extreme temperature and pressures, cross-bedding and ripple marks are often preserved in quartzite **(A)**. Fossils, on the other hand, are never preserved in marble **(B)**.

in solid rock by the reorganization of atoms during metamorphism. Garnet, shown in *Figure 6-20*, is a mineral that commonly forms porphyroblasts.

### MINERAL CHANGES

How do minerals change without melting? Think back to the concept of fractional crystallization, discussed in Chapter 5. Minerals are stable at certain temperatures and crystallize from magma at different temperatures. Scientists have discovered that these stability ranges also apply to minerals in solid rock. During metamorphism, the minerals in a rock change into new minerals that are stable under the new temperature and pressure conditions. Minerals that change in this way are said to undergo solid-state alterations. Scientists have conducted experiments to identify the metamorphic conditions that create specific minerals. When these same minerals are found in rocks, scientists are able to interpret the conditions inside the crust during the rocks' metamorphism. Recall from page 134 that these conditions are temperature- and pressure-related, with low temperatures and pressures resulting in low-grade metamorphism. You will compare the changes in mineralogy as a result of high- and low-grade metamorphism in the *Problem-Solving Lab* on the next page.

### COMPOSITIONAL CHANGES

Most metamorphic rocks reflect the original chemical composition of the parent rock. Gneiss, for example, has the same general chemical composition as granite. In some instances, however, the chemistry of a rock can be altered along with its minerals and texture. This occurs because hot fluids migrate in and out of the rock during metamorphism, which can change the original composition of the rock. Chemical changes are especially common during contact metamorphism near igneous intrusions. Hydrothermal fluids invade the surrounding rocks and change their mineralogy, textures, and chemistry. Valuable ore deposits of gold, copper, zinc, tungsten, and lead are formed in this manner.

**Figure 6-20** This garnet mica schist comes from an exposure in Roxbury Falls, Connecticut.



## THE ROCK CYCLE

Metamorphic rocks are formed by the changing of other rocks. What types of rocks can metamorphic rocks be changed into? The three types of rock—igneous, sedimentary, and metamorphic—are grouped according to how they form. Igneous rocks crystallize from magma; sedimentary rocks form from cemented sediments; and metamorphic rocks form by changes in temperature and pressure. Once a rock forms, does it remain the same type of rock forever? Maybe, but probably not. Heat and pressure may change an igneous rock into a metamorphic rock. A metamorphic rock may be changed into another metamorphic rock or melted to form an igneous rock. Or, the metamorphic rock may be weathered and eroded into sediments that may become cemented into a sedimentary rock. In fact, any rock can be changed into any other type of rock. This continuous changing and remaking of rocks is called the **rock cycle**. The rock cycle is summarized in *Figure 6-21*. The arrows represent the different processes that change rocks into different types. Essentially, rocks are recycled into different rock types much like glass is recycled into different types of jars and bottles. You will learn more about the similarities and differences between rock types when you complete the *GeoLab* at the end of this chapter.

### Problem-Solving Lab

#### Interpreting Scientific Illustrations

**Determine which metamorphic minerals will form** The types of minerals found in metamorphic rocks depends on metamorphic grade and composition of the original rock. In this activity, you will compare how these factors affect metamorphic minerals.

#### Analysis

1. Study *Figure 6-14* on page 134, showing the different mineral groups that are created under different metamorphic conditions. What mineral is formed when shale and basalt are exposed to low-grade metamorphism?
2. What mineral is formed when shale is exposed to high-grade metamorphism

that is not found in basalts under the same conditions?

#### Thinking Critically

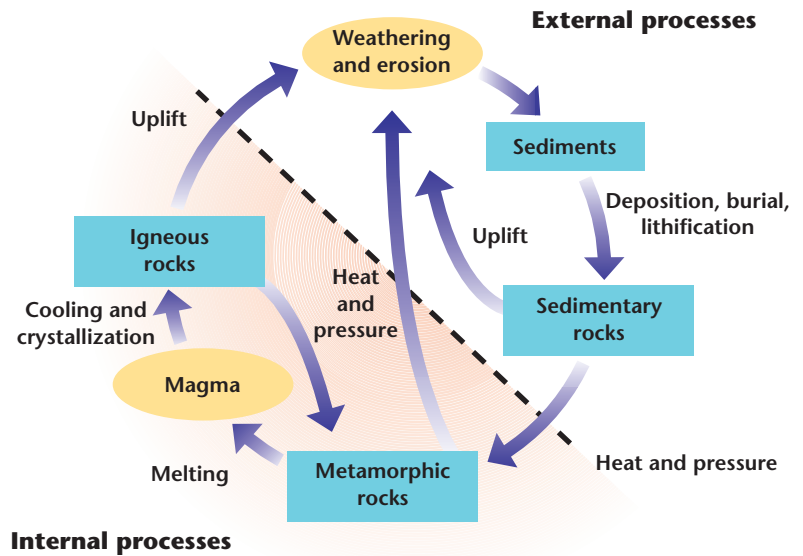
3. Compare the mineral groups you would expect to form from intermediate metamorphism of shale, basalt and limestone.
4. What are the major compositional differences between shale and basalt? How are these differences reflected in the minerals formed during metamorphism?
5. When limestones are metamorphosed, there is very little change in mineralogy, and calcite is still the dominant mineral. Explain why this happens.



## OTHER POSSIBLE PATHS

There is more than one path in the rock cycle. Sandstone might just as easily become uplifted and weathered back into sediments, thereby bypassing the metamorphic and igneous stages. Another possibility is that sandstone could become intruded by magma and melted, thereby directly becoming an igneous rock and bypassing metamorphism. Can you think of other possible paths? How might a metamorphic rock become a sedimentary rock?

The rocks of Earth's crust are constantly being recycled from one type to another. At any given time, magma is crystallizing, sediments are being cemented, and deeply buried rocks are metamorphosing. These processes take place underground, where they cannot be easily observed. However, as you have learned, not all phases of the rock cycle occur beneath Earth's surface. The processes that help shape Earth's landscapes are also part of the rock cycle. You will learn more about these surface processes in the next few chapters.



**Figure 6-21** The rocks of Earth, whether at the surface or below the crust, are always positioned somewhere on the rock cycle.

## SECTION ASSESSMENT

1. How can the chemical composition of a rock be changed during metamorphism?
2. What are the three main types of metamorphism? Compare and contrast the factors that cause each type.
3. How does quartzite differ from schist?
4. What causes foliated metamorphic textures?
5. How are the three types of rocks classified?
6. What parts of the rock cycle occur deep in Earth's crust?
7. **Thinking Critically** Which would you

expect to cause the greatest amount of contact metamorphism: an intrusion of basaltic magma or an intrusion of rhyolitic magma?

### SKILL REVIEW

8. **Interpreting Photos** Study *Figure 6-18C*. If this sample is in the exact position it was when it formed, from which direction did the compressional forces originate? What group of metamorphic minerals would you expect during high-grade metamorphism of shale? For more help, refer to the *Skill Handbook*.



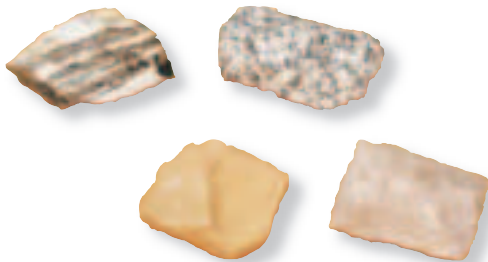
# Interpreting Changes in Rocks

**A**s the rock cycle continues, and rocks change from one type to another, more changes occur than meet the eye. Color, grain size, texture and mineral composition are easily observed and described visually. Yet, with mineral changes come changes in crystal structure and density. How can these be accounted for and described? Studying pairs of sedimentary and metamorphic rocks can show you how.

## Preparation

### Problem

How do the characteristics of sedimentary and metamorphic rocks compare?



### Materials

samples of sedimentary rocks and their metamorphic equivalents  
magnifying glass or hand lens  
paper  
pencil  
beam balance  
100-mL graduated cylinder or beaker  
large enough to hold the rock samples  
water

### Objectives

*In this GeoLab, you will:*

- **Describe** the characteristics of sedimentary and metamorphic rocks.
- **Determine** the density of different rock types.
- **Infer** how metamorphism changes the structure of rocks.

### Safety Precautions



Always wear safety goggles and an apron in the lab.



## Procedure

1. Prepare a data table similar to the one shown below.
2. Observe each rock sample. Record your observations in the data table.
3. Recall that density = mass/volume. Make a plan that will allow you to measure the mass and volume of a rock sample.
4. Determine the density of each rock sample and record this information in the data table.

## Analyze

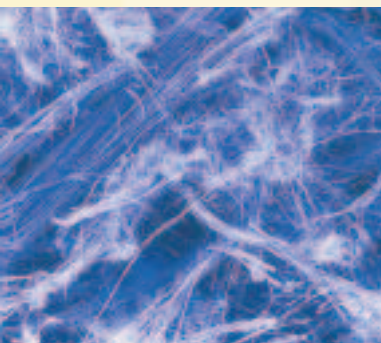
1. Compare and contrast a shale and a sandstone.
2. How does the grain size of a sandstone change during metamorphism?
3. What textural differences do you observe between a shale and a slate?
4. Compare the densities you calculated with other students. Does everybody have the same answer? What are some of the reasons that answers may vary?

## Conclude & Apply

1. Why does the color of a sedimentary rock change during metamorphism?
2. Compare the density of a slate and a quartzite. Which rock has a greater density? Explain.
3. Compare the densities of shale and slate, sandstone and quartzite, and limestone and marble. Does density always change in the same way? Explain the results that you observed.

DATA TABLE

Sample number	Rock Type	Specific characteristics	Mass	Volume	Density
1					
2					
3					
4					



## Good News—Crayons Safe

*The Consumer Products Safety Commission, after extensive testing, declared that crayons are safe for children to use. Although trace amounts of asbestos and asbestos-related fibers were found in many of the crayons tested, the amounts were not considered to be dangerous. No recall was issued, but crayon manufacturers were urged to create a new “recipe” for crayons to exclude the asbestos fibers.*

What do crayons have to do with rocks? A metamorphic mineral—talc—is used in the manufacture of crayons. In fact, it’s the properties of talc that led to the asbestos scare.

### Talc and Asbestos

Talc is a soft white mineral with a hardness of 1. It is used in many cosmetics and art supplies. Talc is often found in association with serpentine, which is the parent rock of asbestos. Asbestos comes from the mineral chrysotile, which breaks into tiny, hairlike fibers. Asbestos has been used in insulation and in fireproof fabrics and building products. However, in the 1960s and 1970s, it was discovered that inhaling asbestos fibers leads to lung cancer, asbestosis, and mesothelioma—each of which can be fatal. Beginning in the 1980s, virtually all uses of asbestos were banned in the United States and much of Europe.

### Blue, green, and asbestos?

Ground up talc is used as a hardener in crayons, which are basically a mixture of pigments, hardeners, and wax. Without talc, crayons would get too sticky to handle. However, when talc is ground, fibers that resemble asbestos are created. Testers aren’t sure whether the tiny amount of asbestos found in crayons comes from these asbestos-like fibers, from chrysotile contamination of the talc, or from both. They

point out, though, that if the talc fibers look so much like asbestos fibers, they are likely to have the same affect in the lungs.

The risk to children from the asbestos and asbestos-like fibers in crayons is extremely small. The amount of fibers present is very low, and, because the talc is embedded in wax, there is little likelihood that the fibers will be inhaled. The Consumer Product Safety Commission did a test that simulated one half-hour of hard coloring and found no airborne fibers. Still, crayon manufacturers understand that, when it comes to children, any slight risk is too much. All of the major crayon makers have decided to change their crayon formulas to eliminate all use of talc. The use of talc in children’s chalk, clay, and sand is also being investigated. The use of asbestos was phased out in the United States in 2001.

### Activity

Research the use of talc in other products. Why is talcum powder no longer recommended for infants? Does the use of talc in make-up expose teens to the same asbestos risk that crayons posed for younger children? Present your findings in a written report.

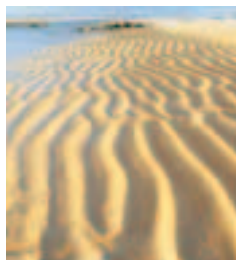


# CHAPTER 6 Study Guide

## Summary

### SECTION 6.1

#### Formation of Sedimentary Rocks



#### Main Ideas

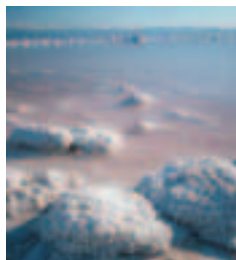
- The processes of weathering, erosion, deposition, burial, and lithification form sedimentary rocks.
- Clastic sediments are rock and mineral fragments produced by weathering and erosion. They are classified based on particle size.
- Sediments are lithified into rock by the processes of compaction and cementation.
- Sedimentary rocks can contain depositional features such as horizontal bedding, cross-bedding, and ripple marks.
- Fossils are the remains or other evidence of once-living things that are preserved in sedimentary rocks.

#### Vocabulary

bedding (p. 126)  
cementation (p. 125)  
clastic (p. 122)  
cross-bedding (p. 126)  
deposition (p. 123)  
graded bedding (p. 126)  
lithification (p. 124)  
sediment (p. 121)

### SECTION 6.2

#### Types of Sedimentary Rocks



#### Main Ideas

- There are three main classes of sedimentary rocks: clastic, which are formed from clastic sediments; chemical, which are formed from minerals precipitated from water; and organic, which are formed from the remains of once-living things.
- Clastic sedimentary rocks are classified by particle size and shape.
- Evaporites are chemical sedimentary rocks that form primarily in restricted ocean basins in regions with high evaporation rates.
- Limestone, composed primarily of calcite, is the most abundant organic sedimentary rock. Coal is another organic sedimentary rock.
- Sedimentary rocks provide geologists with information about surface conditions that existed in Earth's past.

#### Vocabulary

clastic sedimentary rock (p. 128)  
evaporite (p. 130)  
porosity (p. 129)

### SECTION 6.3

#### Metamorphic Rocks



#### Main Ideas

- Metamorphic rocks are formed when existing rocks are subjected to high temperature and pressure, which cause changes in the rocks' textures, mineralogy, and composition.
- The three main types of metamorphism are regional, contact, and hydrothermal.
- Metamorphic rocks are divided into two textural groups: foliated and nonfoliated.
- During metamorphism, minerals change into new minerals that are stable under the conditions of temperature and pressure at which they formed.
- The rock cycle is the set of processes whereby rocks continuously change into other types of rock.

#### Vocabulary

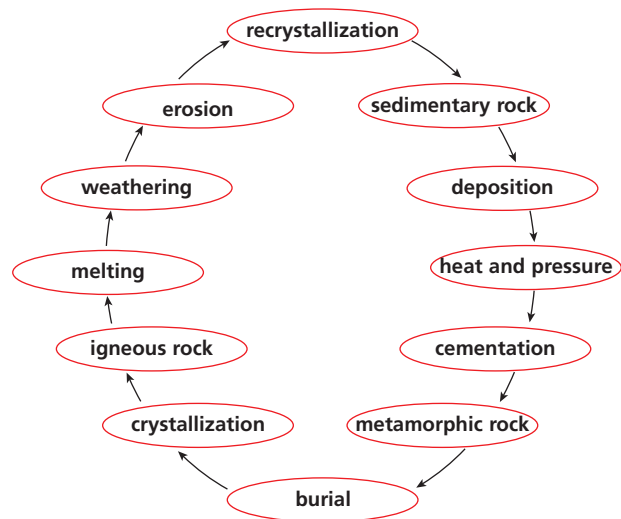
contact metamorphism (p. 135)  
foliated (p. 136)  
hydrothermal metamorphism (p. 135)  
nonfoliated (p. 136)  
porphyroblast (p. 136)  
regional metamorphism (p. 134)  
rock cycle (p. 138)

# CHAPTER 6 Assessment

## Understanding Main Ideas

- What are solid particles that have been deposited on Earth's surface called?
  - porphyroblasts
  - sediments
  - schists
  - quartzites
- What process breaks solid rock into smaller pieces?
  - deposition
  - cementation
  - weathering
  - metamorphism
- What agent of erosion can usually move only sand-sized or smaller particles?
  - landslides
  - glaciers
  - water
  - wind
- Which of the following is an example of a medium-grained clastic sedimentary rock?
  - conglomerate
  - breccia
  - evaporite
  - sandstone
- Which of the following are formed by the chemical precipitation of minerals from water?
  - sandstones
  - coal beds
  - salt beds
  - shale
- Which of the following would you expect to have the greatest porosity?
  - sandstone
  - gneiss
  - shale
  - quartzite
- Which of the following is a common mineral found in both organic and chemical sedimentary rocks?
  - calcite
  - quartz
  - garnet
  - biotite
- By what process are surface materials removed and transported from one location to another?
  - weathering
  - erosion
  - deposition
  - cementation
- What mineral commonly forms porphyroblasts?
  - quartz
  - garnet
  - talc
  - calcite

- What are the two primary causes of lithification?
- Why is the term *clastic* appropriate for particles weathered from solid rock?
- Describe the two main types of cementation.
- How are the three types of sedimentary rocks classified?
- Rearrange the terms below to create a concept map of the rock cycle.



- What are the two most common types of foliated metamorphic rocks?
- What are porphyroblasts, and how do they form?
- What parts of the rock cycle occur at Earth's surface?

## Test-Taking Tip

**WORDS ARE EASY TO LEARN** Whenever you hear or read a word that you cannot define, jot it down on an index card. Then look it up in the dictionary and write the definition on the back of the card. Try to write a sentence or draw a picture using the word, too. Practice saying the word aloud until you are comfortable with it.

# CHAPTER 6 Assessment

## Applying Main Ideas

- How can chemical weathering assist physical weathering?
- Glaciers move very slowly, yet they are able to carry large particles with ease. Why?
- How does graded bedding form?
- Geologists have uncovered a mudstone layer containing mud cracks and ripple marks. This layer lies beneath a layer of sandstone. Explain how these structures and layers might have formed during the deposition of the sediments.
- What information about sedimentary environments can be interpreted from a breccia?
- What is the source of the calcite found in organically formed limestone?
- What type of rock is marble? What characteristics make it well suited for sculptures?
- How might a sedimentary rock become another sedimentary rock without first changing into another rock type?

## Thinking Critically

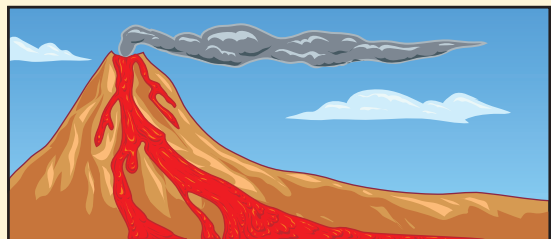
- Why are sand dunes commonly composed of fine, well-sorted sand?
- Why do muds lose more volume during compaction than sands do?
- How could you tell the difference between sedimentary rocks formed from an underwater landslide and sedimentary rocks formed from a landslide on Earth's surface?
- Sand is often found between the larger grains of conglomerates, but large particles are seldom found in sandstone. Why is this?
- Would you expect foliated metamorphic textures in rocks that have undergone contact metamorphism? Why or why not?

## Standardized Test Practice

- What initiates the process that turns sediments into sedimentary rocks?
  - bedding
  - burial
  - cementation
  - compaction
- Which sedimentary rock is used to make cement for the construction industry?
  - shale
  - sandstone
  - phosphate
  - limestone
- Which of the following are rocks composed of minerals that form with blocky crystal shapes?
  - foliated
  - nonfoliated
  - porphyroblasts
  - phenocrysts

### INTERPRETING SCIENTIFIC ILLUSTRATIONS

Use the illustration below to answer question 4.



- Which rocks are most likely to metamorphose from a lava flow?
  - only the rocks in the crater of the volcano, where the lava is hottest
  - rocks in the crater and rocks along the top half of the mountain
  - all the rocks on the mountain
  - all the rocks reached by the lava flow



For a **preview** of Earth's composition, study this GeoDigest before you read the chapters. After you have studied the chapters, you can use the GeoDigest to **review** the unit.

# Composition of Earth

## Matter and Atomic Structure

**Elements** Atoms are the basic building blocks of matter. They are made of protons, which have positive electrical charges; electrons, which have negative electrical charges; and neutrons, which are neutral. Protons and neutrons make up the nucleus of an atom; electrons surround the nucleus in energy levels. An element is a substance consisting of atoms with a specific number of protons in their nuclei. Examples of elements include hydrogen, neon, gold, carbon, and uranium. Isotopes of an element differ by the number of neutrons in their nuclei. All elements are mixtures of isotopes. The number of electrons in the outermost energy levels of atoms determines their chemical behavior. Elements with the same number of electrons in their outermost energy levels have similar chemical properties.

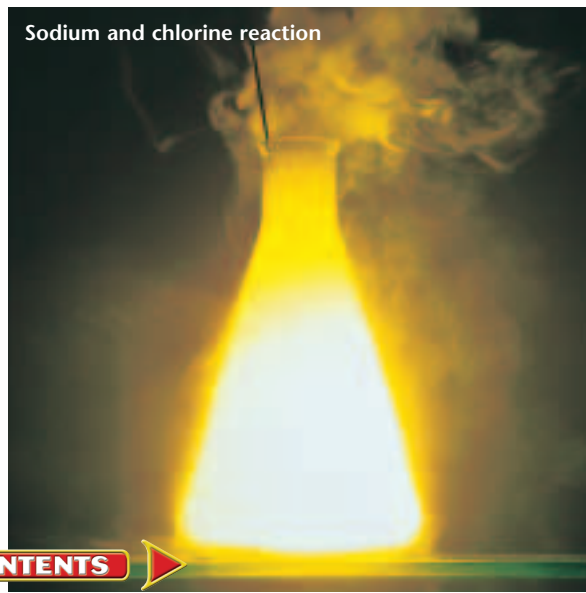
**How Atoms Combine** Atoms of different elements combine to form compounds. Molecular compounds are formed when atoms are held together by the sharing of electrons in covalent bonds. Atoms also combine ionically. Ions are electrically charged atoms or groups of atoms. Positive and negative ions attract each other and form ionic compounds. Acids are solutions containing hydrogen ions. Bases are solutions containing hydroxide ions. Acids and bases can neutralize each other. A mixture is a combination of components that retain their identities and can still be distinguished. A solution is a mixture in which the components can no longer be distinguished as separate. Solutions can be liquid, solid, or gaseous.

**States of Matter** On Earth, matter exists in three physical states: solid, liquid, and gas. The universe also contains a fourth state of matter: plasma. Most solids have crystalline structures. Atoms, ions, or molecules in crystals are arranged in regular geometric patterns. Most rocks are polycrystalline materials. Liquids are densely packed arrangements of mobile particles. Gases are widely separated, individual particles. Plasmas are hot, highly ionized, electrically conductive gases. Changes of state involve thermal energy. Melting and evaporation absorb thermal energy, whereas freezing and condensation release thermal energy.

## Minerals

A mineral is a naturally occurring, inorganic solid with a specific chemical composition and a definite crystalline structure. There are at least 3000 known minerals in Earth's crust. Minerals form from

Sodium and chlorine reaction



magma or from solution. Most minerals are formed from the eight most common elements in Earth's crust. Oxygen readily combines with other elements to form a diverse group of minerals, including silicates, carbonates, and oxides. Minerals are virtually everywhere. Your body needs many of the elements found in minerals to survive, such as iron, calcium, and sodium. Some minerals are found as ores. A mineral is an ore if it contains a useful substance that can be mined at a profit. Ores from deep within Earth are removed by underground mining. Ores close to Earth's surface are obtained from open-pit mines. If responsible procedures are not followed, mining can cause environmental damage. Gems, such as diamonds and rubies, are valuable minerals that are prized for their rarity and beauty. The presence of trace elements can make one variety of a mineral more colorful and thus more prized than other varieties of the same mineral. For example, amethyst which contains traces of manganese, is a gem form of quartz.

**Identifying Minerals** Minerals can be identified based on their physical and chemical properties. The most reliable way to identify a mineral is to use a combination of tests of color, hardness, and density, among other characteristics. A mineral's color is generally the result of trace elements within the mineral. Texture describes how a mineral feels. Luster describes how a mineral reflects light. Cleavage and fracture describe how a mineral breaks. A mineral's streak, its color in powdered form, its hardness, and its density are also methods of identification. Special properties of minerals, such as magnetism, can also be used for identification purposes.

## Igneous Rocks

**Formation and Types** Igneous rocks, formed by the cooling and crystallization of magma, may be intrusive or extrusive. Intrusive rocks form inside

Earth's crust; extrusive rocks form at or near Earth's surface. Minerals crystallize from magma in a sequential pattern known as Bowen's reaction series. Different minerals melt and crystallize at different temperatures in the processes of partial melting and fractional crystallization. Igneous rocks are classified as felsic, intermediate, mafic, and ultramafic, depending upon their mineral compositions. Igneous groups are further identified by crystal size, also called texture. For example, extrusive rocks, which cool more rapidly than intrusive rocks, are generally more fine grained meaning they have small crystals. Early forming minerals may have well-shaped crystals, while later-forming minerals have irregular shapes. Porphyritic textures contain both large and small crystals.

**Igneous Rock Resources** Igneous rocks are often used as building materials because of their strength, durability, and beauty. Valuable ore deposits and gem crystals are often associated with igneous intrusions. For example, diamonds are found in rare types of igneous intrusions known as kimberlite pipes.



Diopside  
on panchéite

## Vital Statistics

### Top Ten Diamond-Mining Countries

Country	Mine Production (in carats)
Botswana	15 000 000
Australia	13 400 000
Russia	11 500 000
South Africa	4 000 000
Kinshasa	3 500 000
Canada	2 000 000
Namibia	1 990 000
Angola	1 080 000
Ghana	649 000
Liberia	600 000



Metamorphic rock, Ontario, Canada

## Sedimentary and Metamorphic Rocks

**Formation and Types** Sedimentary rocks are formed by weathering, erosion, deposition, burial, and lithification. Clastic sediments are rock and mineral fragments produced by weathering and erosion. Lithification occurs through the processes of compaction and cementation. Sedimentary rocks can be identified by depositional features such as horizontal bedding, cross-bedding, and ripple marks. Sedimentary rocks often contain the remains or evidence of once-living things: fossils. Sedimentary rocks also provide geologists with information about surface conditions that existed in Earth's past. Clastic sedimentary rocks form from sediments and are classified by particle size and shape. Chemical sedimentary rocks are formed from minerals precipitated from water. Such rocks include evaporites, which form primarily in restricted ocean basins in regions of high evaporation. Organic sedimentary rocks are formed from the remains of once-living things. Limestone and coal are organic sedimentary rocks.

## Metamorphism and the Rock Cycle

Metamorphic rocks are formed when existing rocks are subjected to high temperature and pressure, which cause changes in the rocks' texture, mineralogy, and composition. The three main types of metamorphism are regional, contact, and hydrothermal. The two textural groups of metamorphic rocks are foliated and nonfoliated. During metamorphism, minerals change into new minerals that are stable for the temperature and pressure conditions under which they formed. Geologists use the stability ranges for these minerals to infer the history of Earth's crust. Metamorphism is part of the rock cycle, whereby rocks continuously change into other types of rock. Any type of rock can be changed into any other type of rock.

### FOCUS ON CAREERS

#### Sculptor

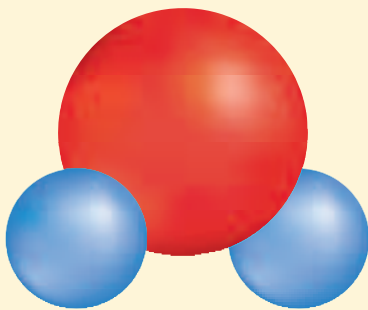
Sculptors use rocks, minerals, and other Earth materials to create works of art. Many sculptors cast in bronze, an alloy of copper and tin. Others carve the metamorphic rock marble. Sculptors usually refine their talents in art schools or in the art departments of universities. A good understanding of the materials used is critical to creating a sculpture. The sculptor must know which tools to use on rocks of different hardnesses, how a material will fracture, and how a material in an outdoor sculpture will hold up in weather.



## ASSESSMENT

## Understanding Main Ideas

- How are atoms best described?
  - negatively charged
  - the building blocks of matter
  - isotopes
  - energy levels surrounded by nuclei
- Hydrogen, neon, gold, carbon, and uranium are examples of what?
  - elements
  - energy levels
  - protons
  - nuclei
- What is a combination of components that retain their identities called?
  - an ionic solution
  - acids and bases
  - hydroxide ions
  - a mixture
- How are atoms, ions, or molecules in crystals arranged?
  - as widely separated particles
  - as densely packed mobile particles
  - in regular geometric patterns
  - in solution
- What is a useful substance that can be mined at a profit called?
  - calcium
  - hematite
  - an ore
  - a mineral
- Which of the following tests is the most reliable means of identifying a mineral?
  - hardness
  - streak
  - density
  - a combination of tests
- Where do intrusive igneous rocks form?
  - on Earth's surface
  - inside Earth's crust
  - in the ocean
  - in Bowen's reaction series
- What is a kimberlite pipe?
  - an igneous intrusion
  - an igneous extrusion
  - a durable gem
  - an extrusive igneous rock
- How are clastic sedimentary rocks classified?
  - by particle color
  - by ripple marks
  - by the presence of fossils
  - by particle size and shape
- What is the process whereby rocks continuously change into other types of rocks?
  - the rock cycle
  - metamorphism
  - porphyry
  - erosion



Model of a water molecule

## Thinking Critically

- Why would a tossed salad be classified as a mixture?
- Compare and contrast texture and luster.
- Describe how clastic sedimentary rocks are formed.