

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.

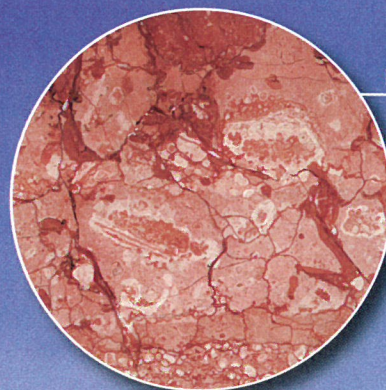
6.3 Metamorphic Rocks

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

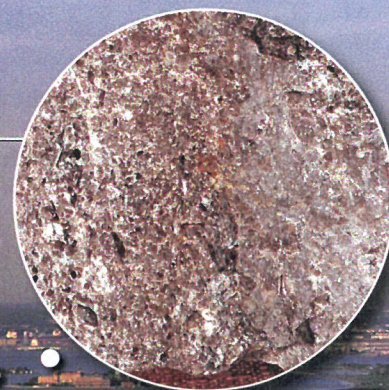
GeoFacts

- The exterior of the Empire State Building is made of limestone, marble, granite, and metal.
- 5663 m³ of Indiana limestone and granite, 929 m² of Rose Famosa and Estrallante marble, and 27,870 m² of Hauteville and Rocheron marble were used in the building's construction.
- Overall, the Empire State Building weighs 331,122.43 metric tons.

Marble



Limestone



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.

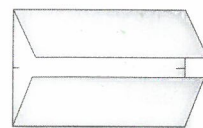
Analysis

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?

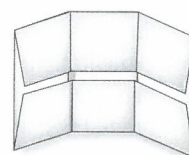
FOLDABLES™ Study Organizer

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

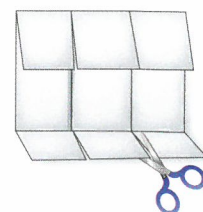
- ▶ **STEP 1** Mark the middle of a vertical sheet of paper. Fold the top and bottom to the middle to form two flaps.



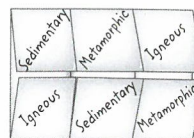
- ▶ **STEP 2** Fold into thirds.



- ▶ **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

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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.

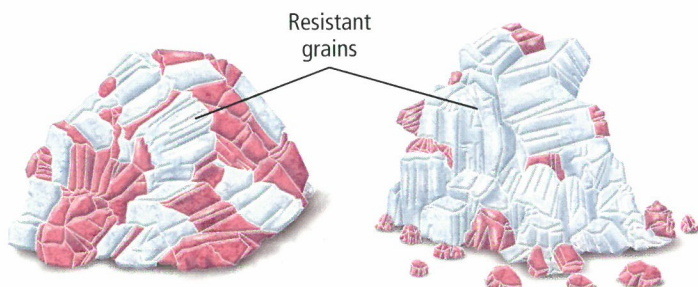
Weathering and Erosion

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.

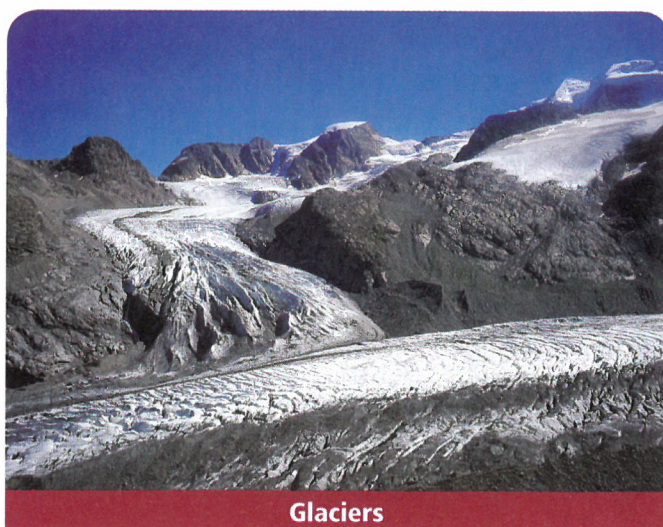
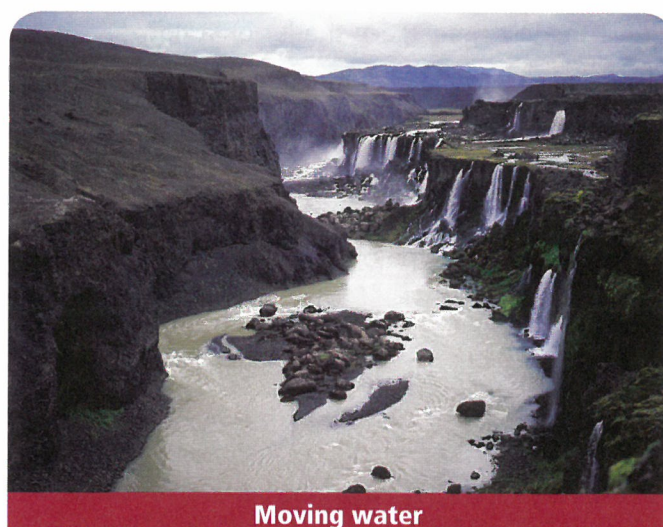
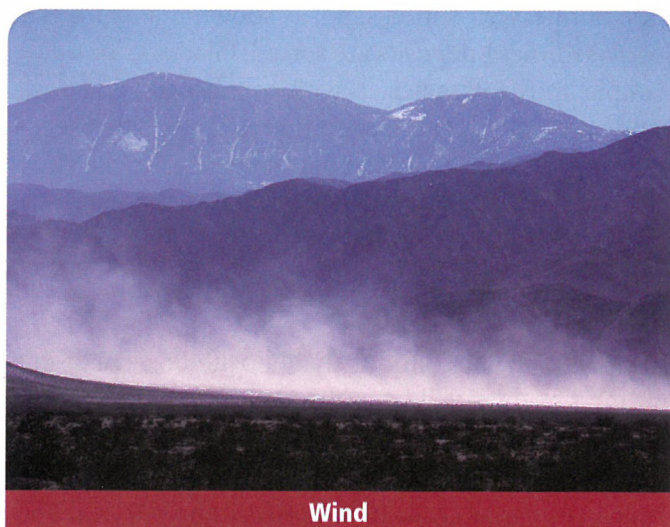


Erosion The removal and transport of sediment is called erosion. **Figure 6.2** shows the four main agents of erosion: wind, moving water, gravity, and glaciers. Glaciers are large masses of ice that move across land. Visible signs of erosion are all around you. For example, water in streams becomes 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.



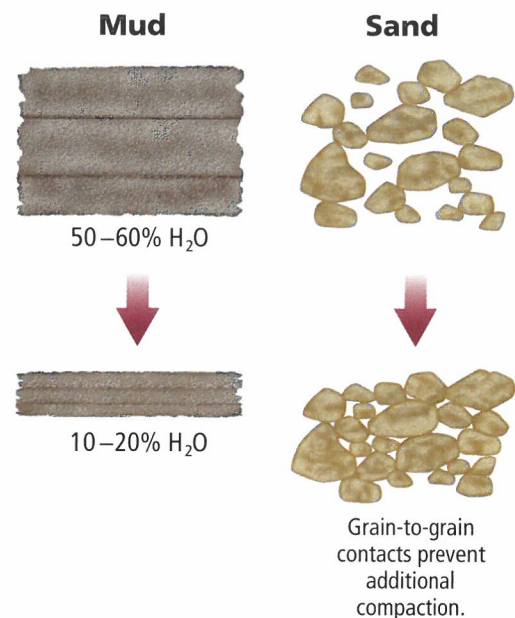
Compaction Lithification begins with compaction. The weight of overlying sediments forces the sediment grains closer together, causing the physical changes shown in **Figure 6.4**. Layers of mud can contain up to 60 percent water, and these shrink as excess water is squeezed out. Sand does not compact 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**.

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.

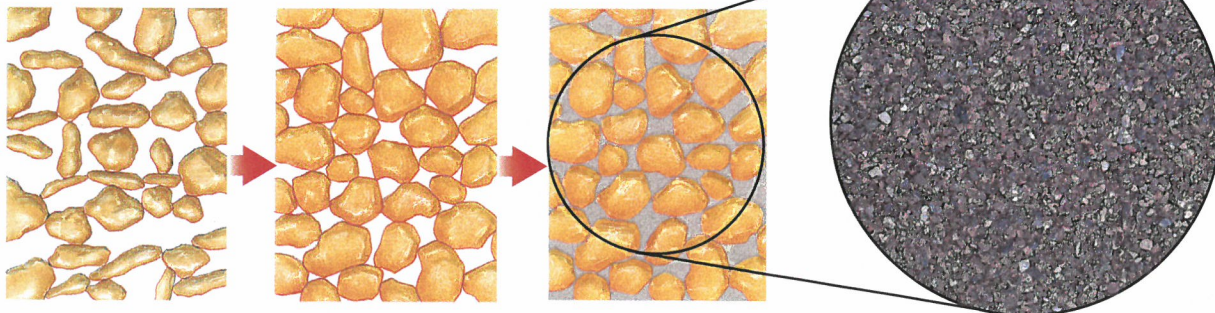


■ **Figure 6.4** The high water content and flat shape of particles in mud cause it to compact greatly when subjected to the weight of overlying sediments.

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

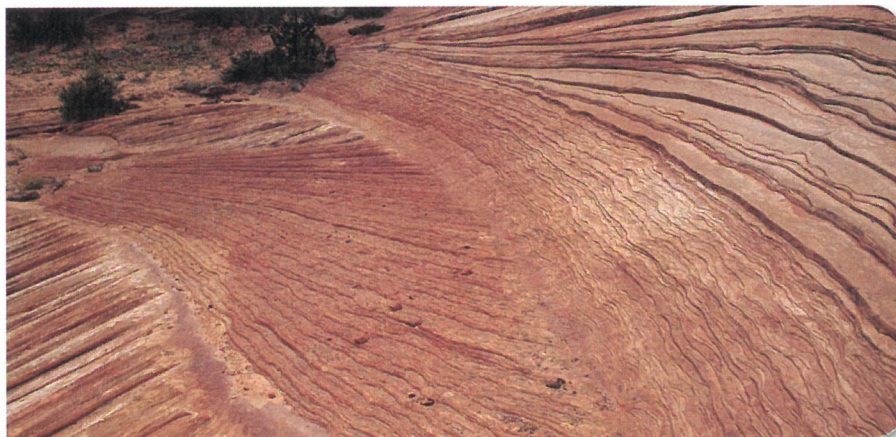
Sedimentologist Studying the origin and deposition of sediments and their conversion to sedimentary rocks is the job of a sedimentologist. Sedimentologists are often involved in searching for and finding oil, natural gas, and economically important minerals. To learn more about Earth science careers,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

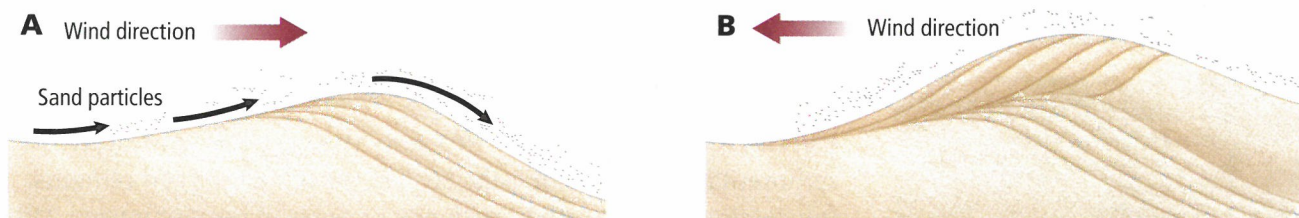
■ **Figure 6.7** The large-scale cross-beds in these ancient dunes at Zion National Park were deposited by wind.



Visualizing Cross-Bedding and Ripple Marks

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

Cross-Bedding

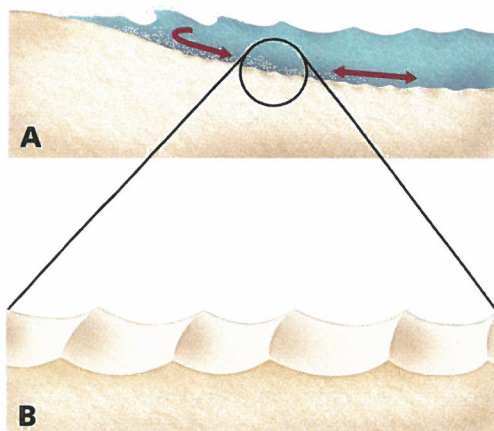


Sand carried by wind gets deposited on the downwind side of a dune. As the wind changes direction, cross-bedding is formed that records this change in direction.



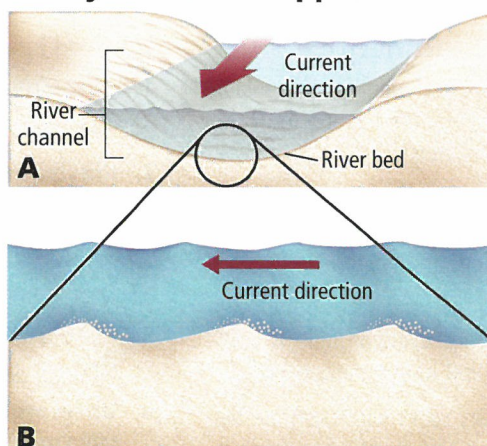
Sediment on the river bottom gets pushed into small hills and ripples by the current. Additional sediment gets deposited at an angle on the downcurrent side of these hills forming cross-beds. Eventually, it levels out or new hills form and the process begins again.

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.

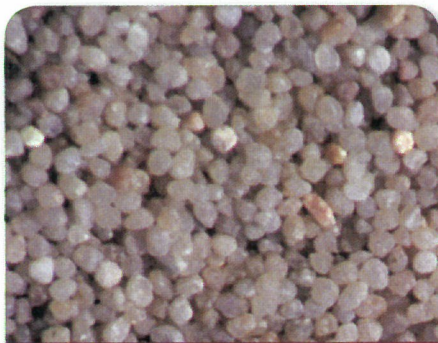
Asymmetrical Ripple Marks



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 first-hand 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.

Section 6.2

Objectives

- **Describe** the types of clastic sedimentary rocks.
- **Explain** how chemical sedimentary rocks form.
- **Describe** biochemical sedimentary rocks.

Review Vocabulary

saturated: the maximum possible content of dissolved minerals in solution

New Vocabulary

clastic sedimentary rock
clastic
porosity
evaporite

Types of Sedimentary Rocks

MAIN Idea

Sedimentary rocks are classified by their mode of formation.

Real-World Reading Link If you have ever walked along the beach or along a riverbank, you might have noticed different sizes of sediments. The grain size of the sediment determines what type of sedimentary rock it can become.

Clastic Sedimentary Rocks

The most common sedimentary rocks, **clastic sedimentary rocks**, are formed from the abundant deposits of loose sediments that accumulate on Earth's surface. The word **clastic** comes from the Greek word *klastos*, meaning *broken*. These rocks are further classified according to the sizes of their particles. As you read about each rock type, refer to **Table 6.1** on the next page, which summarizes the classification of sedimentary rocks based on grain size, mode of formation, and mineral content.

Coarse-grained rocks Sedimentary rocks consisting of gravel-sized rock and mineral fragments are classified as coarse-grained rocks, samples of which are shown in **Figure 6.10**. Conglomerates have rounded, gravel-sized particles. 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. Lithification turns these sediments into conglomerates.

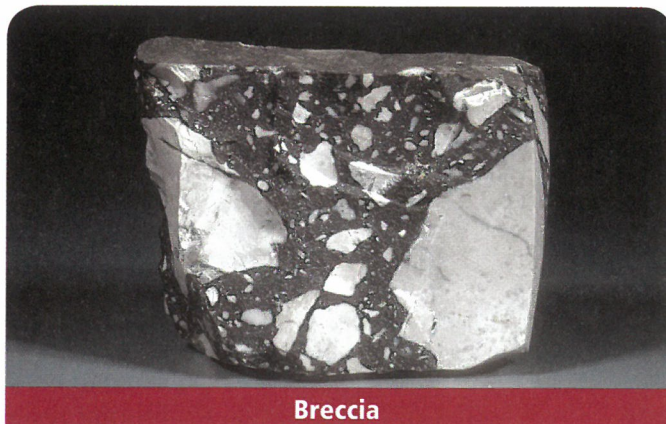
In contrast, breccias are composed of angular, gravel-sized particles. The angularity indicates that the sediments from which they formed did not have time to become rounded. This suggests that the particles were transported only a short distance and deposited close to their source. Refer to **Table 6.1** to see how these rocks are named.

■ **Figure 6.10** Conglomerates and breccias are made of coarse sediments that have been transported by high-energy water.

Infer the circumstances that might cause the types of transport necessary for each to form.



Conglomerate



Breccia

Table 6.1

Classification of Sedimentary Rocks

Classification	Texture/Grain Size	Composition	Rock Name
Clastic	coarse (> 2 mm)	Fragments of any rock type—quartz, chert } rounded and quartzite common } angular	conglomerate breccia
	medium (1/16 mm to 2 mm)	quartz and rock fragments quartz, potassium feldspar and rock fragments	sandstone arkose
	fine (1/256 mm–1/16 mm)	quartz and clay	siltstone
	very fine ($< 1/256$ mm)	quartz and clay	shale
Biochemical	microcrystalline with conchoidal fracture	calcite (CaCO_3)	micrite
	abundant fossils in micrite matrix	calcite (CaCO_3)	fossiliferous limestone
	oolites (small spheres of calcium carbonate)	calcite (CaCO_3)	oolitic limestone
	shells and shell fragments loosely cemented	calcite (CaCO_3)	coquina
	microscopic shells and clay	calcite (CaCO_3)	chalk
	variously sized fragments	highly altered plant remains, some plant fossils	coal
Chemical	fine to coarsely crystalline	calcite (CaCO_3)	crystalline limestone
	fine to coarsely crystalline	dolomite (Ca,MgCO_3 (will effervesce if powdered)	dolostone
	very finely crystalline	quartz (SiO_2)—light colored —dark colored	chert flint
	fine to coarsely crystalline	gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$)	rock gypsum
	fine to coarsely crystalline	halite (NaCl)	rock salt

VOCABULARY

ACADEMIC VOCABULARY

Reservoir

a subsurface area of rock that has enough porosity to allow for the accumulation of oil, natural gas, or water

The newly discovered reservoir contained large amounts of natural gas and oil.

Medium-grained rocks 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. Refer to **Table 6.1** for a listing of rocks with sand-sized particles. Sandstone usually contains several features of interest to scientists. For example, because ripple marks and cross-bedding indicate the direction of current flow, geologists use sandstone layers to map ancient 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 these open spaces are maintained during the formation of sandstone, often resulting 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 rocks Sedimentary rocks consisting of silt- and clay-sized particles are called fine-grained rocks. Siltstone and shale are fine-grained clastic rocks. These rocks represent environments such as swamps and ponds which have still or slow-moving waters. In the absence of strong currents and wave action, these sediments settle to the bottom where they accumulate in thin horizontal layers. Shale often breaks along thin layers, as shown in **Figure 6.11**. Unlike sandstone, fine-grained sedimentary rock has low porosity and often forms barriers that hinder the movement of groundwater and oil. **Table 6.1** shows how these rocks are named.

 **Reading Check Identify** the types of environments in which fine-grained rocks form.

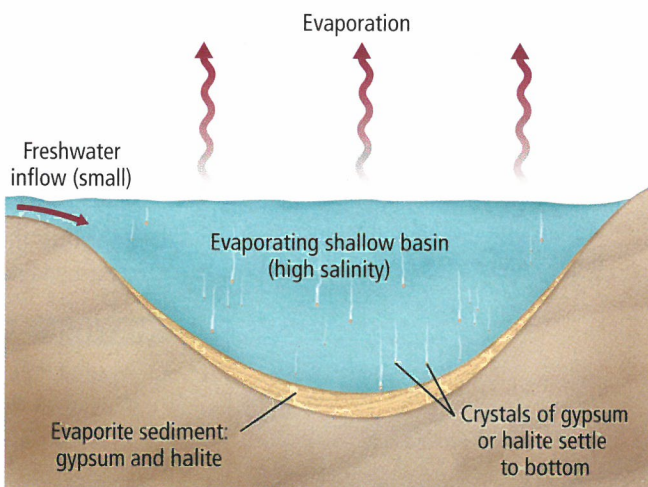
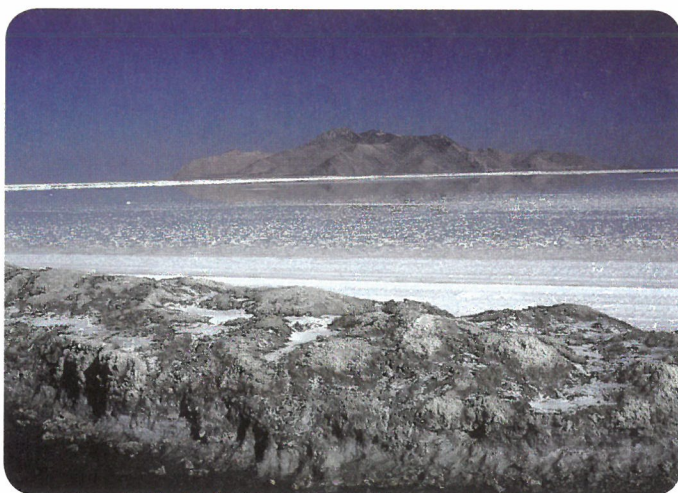
Chemical and Biochemical Sedimentary Rocks

The formation of chemical and biochemical rocks involves the processes of evaporation and precipitation of minerals. During 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 6.12**, is an example of a lake that has high concentrations of dissolved minerals.

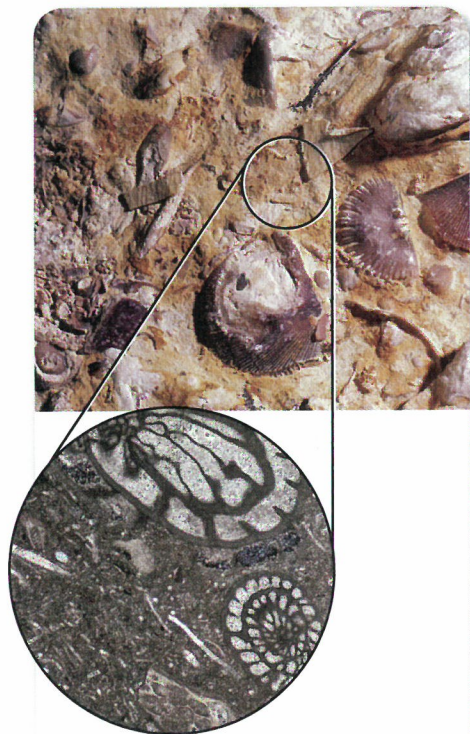
Chemical sedimentary rocks When the concentration of dissolved minerals in a body of water reaches saturation, crystal grains precipitate out of solution and settle to the bottom. As a result, layers of chemical sedimentary rocks form, most of which are called **evaporites**. Evaporites most commonly form in arid regions 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. Even 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 6.12**.



■ **Figure 6.11** The very fine-grained sediment that formed this shale was deposited in thin layers in still waters.



■ **Figure 6.12** The constant evaporation from a body of salt water results in precipitation of large amounts of salt. This process has been occurring in the Great Salt Lake in Utah for approximately 18,000 years.



■ **Figure 6.13** Limestone can contain many different fossil organisms. Geologists can interpret where and when the limestone formed by studying the fossils within the rock.

Biochemical sedimentary rocks Biochemical sedimentary rocks are formed from the remains of once-living organisms. The most abundant of these rocks is limestone, which is composed primarily of calcite. Some organisms that live in the ocean use the calcium carbonate that is 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 skeletal and shell materials that are currently accumulating there will someday become limestone as well. Many types of limestone contain evidence of their biological origin in the form of abundant fossils. As shown in **Figure 6.13**, these fossils can range from large-shelled organisms to microscopic, unicellular organisms. Not all limestone contains fossils. Some limestone has a crystalline texture, some consists of tiny spheres of carbonate sand, and some is composed of fine-grained carbonate mud. These are listed in **Table 6.1**.

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. Siliceous ooze becomes lithified into the sedimentary rock chert, which is also listed in **Table 6.1**.

Section 6.2 Assessment

Section Summary

- Sedimentary rocks can be clastic, chemical, or biochemical.
- Clastic rocks form from sediments and are classified by particle size and shape.
- Chemical rocks form primarily from minerals precipitated from water.
- Biochemical rocks form from the remains of once-living organisms.
- Sedimentary rocks provide geologists with information about surface conditions that existed in Earth's past.

Understand Main Ideas

1. **MAIN Idea** **State** the type of sedimentary rock that is formed from the erosion and transport of rocks and sediments.
2. **Explain** why coal is a biochemical sedimentary rock.
3. **Calculate** the factor by which grain size increases with each texture category.
4. **Analyze** the environmental conditions to explain why most chemical sedimentary rocks form mainly in areas that have high rates of evaporation.

Think Critically

5. **Propose** a scenario to explain how it is possible to form additional layers of evaporites in a body of seawater when the original amount of dissolved minerals in the water was enough to form only a thin evaporite.
6. **Examine** the layers of shale in **Figure 6.11** and explain why shale contains no cross-bedding or ripple marks.

MATH in Earth Science

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

Section 6.3

Objectives

- ▶ **Compare and contrast** the different types and causes of metamorphism.
- ▶ **Distinguish** among metamorphic textures.
- ▶ **Explain** how mineral and compositional changes occur during metamorphism.
- ▶ **Apply** the rock cycle to explain how rocks are classified.

Review Vocabulary

intrusive: rocks that form from magma that cooled and crystallized slowly beneath Earth's surface

New Vocabulary

foliated
nonfoliated
regional metamorphism
contact metamorphism
hydrothermal metamorphism
rock cycle

Metamorphic Rocks

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

Real-World Reading Link When you make a cake, all of the individual ingredients that you put into the pan change into something new. When rocks are exposed to high temperatures, their individual characteristics also change into something new and form a completely different rock.

Recognizing Metamorphic Rock

The rock layers shown in **Figure 6.14** have been metamorphosed (meh tuh MOR fohzd)—this means that they have been changed. How do geologists know that this has happened? 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 reach the melting point? When high temperature and pressure combine and change the texture, mineral composition, 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 *morphé*, meaning *form*. During metamorphism, a rock changes form while remaining solid.

The high temperatures required for metamorphism are ultimately derived from Earth's internal heat, either through deep burial or from nearby igneous intrusions. The high pressures required for metamorphism come from deep burial or from compression during mountain building.

■ **Figure 6.14** Strong forces were required to bend these rock layers into the shape they are today.

Hypothesize the changes that occurred to the sediments after they were deposited.





■ **Figure 6.15** Metamorphic minerals, such as mica, staurolite, garnet, and talc (shown above, clockwise from top left), occur in many colors, shapes, and crystal sizes. Colors can be dark or bright and crystal form can be unique.

Metamorphic minerals How do minerals change without melting? Think back to the concept of fractional crystallization, discussed in Chapter 5. Bowen's reaction series shows that all minerals are stable at certain temperatures and they crystallize from magma along a range of 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 the same minerals are identified in rocks, scientists are able to interpret the conditions inside the crust during the rocks' metamorphism. **Figure 6.15** shows some common metamorphic minerals.

✓ **Reading Check Explain** what metamorphic minerals are.

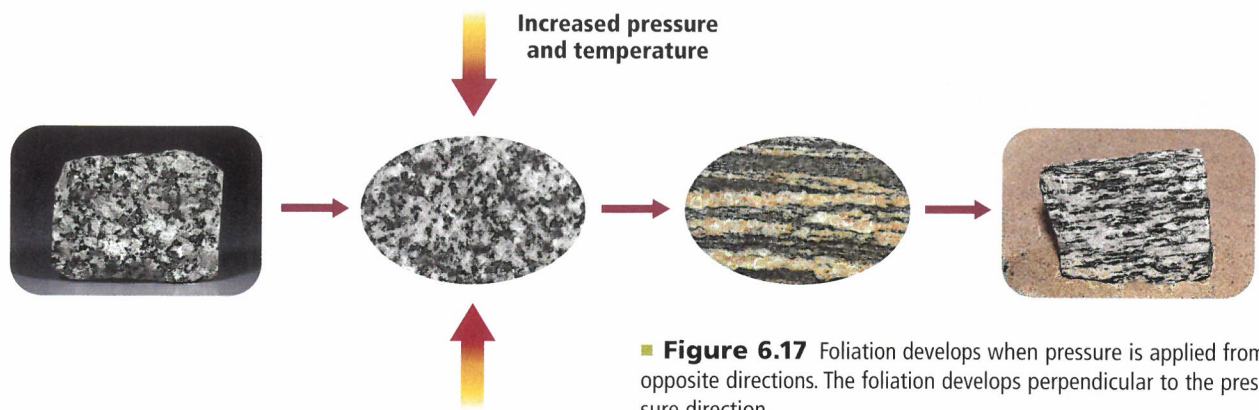
Metamorphic textures Metamorphic rocks are classified into two textural groups: foliated and nonfoliated. Geologists use metamorphic textures and mineral composition to identify metamorphic rocks. **Figure 6.16** shows how these two characteristics are used in the classification of metamorphic rocks.

Foliated rocks 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.

■ **Figure 6.16** Increasing grain size parallels changes in composition and development of foliation. Grain size is not a factor in nonfoliated rocks.

Metamorphic Rock Identification Chart

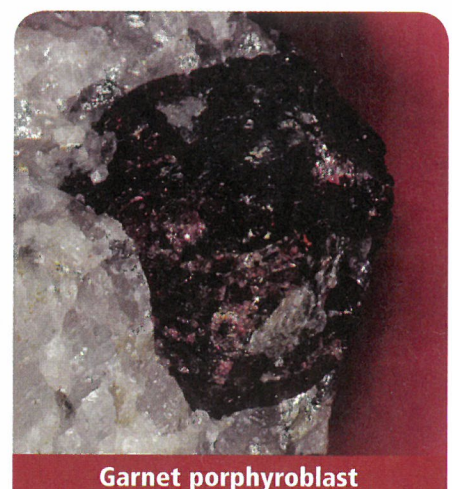
Texture		Composition					Rock Name
Foliated	Layered		CHLORITE	MICA	QUARTZ		SLATE
		Fine-grained					PHYLLITE
		Coarse-grained					SCHIST
	Banded	Coarse-grained			FELDSPAR	AMPHIBOLE PYROXENE	GNEISS
Nonfoliated	Fine- to coarse-grained		Quartz				QUARTZITE
			Calcite or dolomite				MARBLE

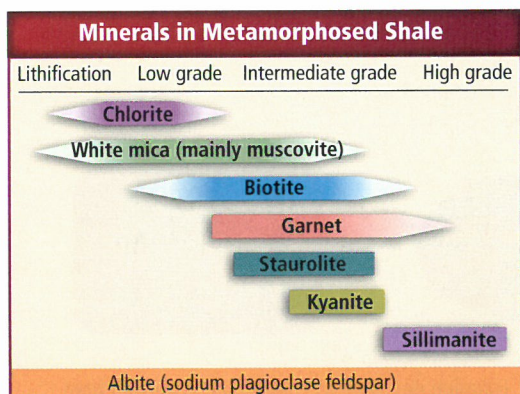


Nonfoliated rocks Unlike foliated rocks, **nonfoliated** metamorphic rocks are composed mainly of minerals that form with blocky crystal shapes. Two common examples of nonfoliated rocks, shown in **Figure 6.18**, are quartzite and marble. Quartzite is a hard, often light-colored rock formed by the metamorphism of quartz-rich sandstone. Marble is formed by the metamorphism of limestone. Some marbles have smooth textures that are formed by interlocking grains of calcite. These marbles are often used in sculptures. Fossils are rarely preserved in metamorphic rocks.

Under certain conditions, new metamorphic minerals can grow 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. Although these crystals resemble the very large crystals that form in pegmatite granite, they are not the same. Instead of forming from magma, they form in solid rock through the reorganization of atoms during metamorphism. Garnet, shown in **Figure 6.18**, is a mineral that commonly forms porphyroblasts.

■ **Figure 6.18** As a result of the extreme heat and pressure during metamorphism, marble rarely contains fossils. Metamorphism does not, however, always destroy cross-bedding and ripple marks, which can be seen in some quartzites. Garnet porphyroblasts can grow to be quite large in some rocks.





■ **Figure 6.19** Metamorphism of shale results in the formation of minerals that provide the wide variety of color observed in slate.

Grades of Metamorphism

Different combinations of temperature and pressure result in different grades of metamorphism. Low-grade metamorphism is associated with low temperatures and pressures and a particular suite of minerals and textures. High-grade metamorphism is associated with high temperatures and pressures and a different suite of minerals and textures. Intermediate-grade metamorphism is in between low- and high-grade metamorphism.

Figure 6.19 shows the minerals present in metamorphosed shale. Note the change in composition as conditions change from low-grade to high-grade metamorphism. Geologists can create metamorphic maps by plotting the location of metamorphic minerals. Knowing the temperatures that certain areas experienced when rocks were forming helps geologists locate valuable metamorphic minerals such as garnet and talc. Studying the distribution of metamorphic minerals helps geologists to interpret the metamorphic history of an area.

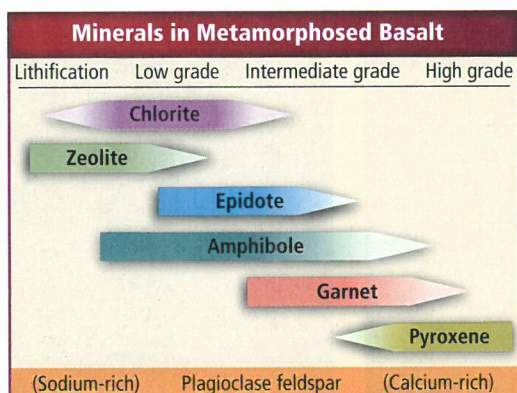
Types of Metamorphism

The effects of metamorphism can be the result of contact metamorphism, regional metamorphism, or hydrothermal metamorphism. The minerals that form and the degree of change in the rocks provide information as to the type and grade of metamorphism that occurred.

PROBLEM-SOLVING LAB

Interpret Scientific Illustrations

Which metamorphic minerals will form? The minerals that form in metamorphic rocks depend on the metamorphic grade and composition of the original rock. The figure below and **Figure 6.19** show the mineral groups that form under different metamorphic conditions.

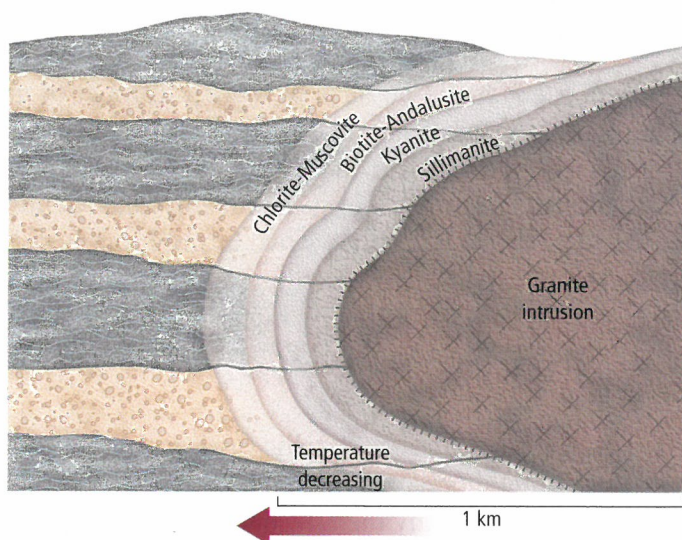


Analysis

1. What mineral is formed when shale and basalt are exposed to low-grade metamorphism?
2. Under high-grade metamorphism, what mineral is formed in shale but not in basalt?

Think Critically

3. **Compare** the mineral groups that you would expect to form from intermediate-grade metamorphism of shale and basalt.
4. **Describe** the major compositional differences between shale and basalt. How are these differences reflected in the minerals formed during metamorphism?
5. **Explain** When limestone is metamorphosed, there is little change in mineral composition. Calcite is still the dominant mineral. Explain why this happens.



■ **Figure 6.20** Contact metamorphism from the intrusion of this granite batholith has caused zones of metamorphic minerals to form.

Apply what you know about contact metamorphism to determine the type of rock that is now present along the edge of the intrusion.

Regional metamorphism When high temperature and pressure affect large regions of Earth's crust, they produce large belts of **regional metamorphism**. The metamorphism can range in grade from low to high grade. Results of regional metamorphism include changes in minerals and rock types, plus folding and deforming of the rock layers that make up the area. The folded rock layers shown in **Figure 6.14** experienced regional metamorphism.

Contact metamorphism When molten material, such as that in an igneous intrusion, comes in contact with solid rock, a local effect called **contact metamorphism** occurs. High temperature and moderate-to-low pressure form mineral assemblages that are characteristic of contact metamorphism. **Figure 6.20** shows zones of different minerals surrounding an intrusion. Because temperature decreases with distance from an intrusion, metamorphic effects also decrease with distance. Recall from Chapter 5 that minerals crystallize at specific temperatures. Metamorphic minerals that form at high temperatures occur closest to the intrusion, where it is hottest. Because lava cools too quickly for the heat to penetrate far into surface rocks, contact metamorphism from extrusive igneous rocks is limited to thin zones.

Hydrothermal metamorphism When very hot water reacts with rock and alters its chemical and mineral composition, **hydrothermal metamorphism** occurs. The word *hydrothermal* is derived from the Greek words *hydro*, meaning *water*, and *thermal*, meaning *heat*. As hot fluids migrate in and out of the rock during metamorphism, the original mineral composition and texture of the rock can change. Chemical changes are common during contact metamorphism near igneous intrusions and active volcanoes. Valuable ore deposits of gold, copper, zinc, tungsten, and lead are formed in this manner. The gold deposited in the quartz shown in **Figure 6.21** is the result of hydrothermal metamorphism.

VOCABULARY

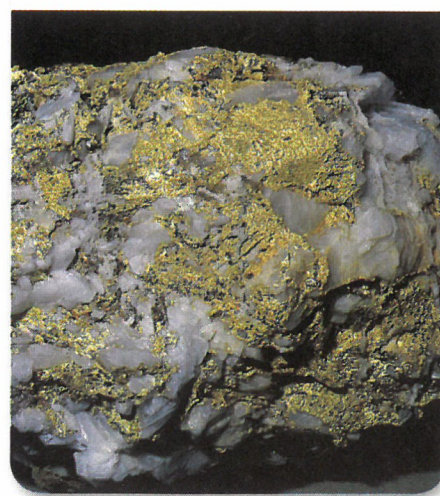
SCIENCE USAGE V. COMMON USAGE

Intrusion

Science usage: the placement of a body of magma into preexisting rock

Common usage: joining or coming into without being invited

■ **Figure 6.21** When the hydrothermal solution in the quartz cooled, gold veins formed.



Economic Importance of Metamorphic Rocks and Minerals

The modern way of life is made possible by a great number of naturally occurring Earth materials. We need salt for cooking, gold for trade, other metals for construction and industrial purposes, fossil fuels for energy, and rocks and various minerals for construction, cosmetics, and more. **Figure 6.22** shows two examples of how metamorphic rocks are used in construction. Many of these economic mineral resources are produced by metamorphic processes. Among these are the metals gold, silver, copper, and lead, as well as many significant nonmetallic resources.

Metallic mineral resources Metallic resources occur mostly in the form of metal ores, although deposits of pure metals are occasionally discovered, many metallic deposits are precipitated from hydrothermal solutions and are either concentrated in veins or spread throughout the rock mass. Native gold, silver, and copper deposits tend to occur in hydrothermal quartz veins near igneous intrusions or in contact metamorphic zones. However, most hydrothermal metal deposits are in the form of metal sulfides such as galena (PbS) or pyrite (FeS_2). The iron ores magnetite and hematite are oxide minerals often formed by precipitation from iron-bearing hydrothermal solutions.



Reading Check State what resources hydrothermal metamorphism produces.

Nonmetallic mineral resources Metamorphism of ultrabasic igneous rocks produces the minerals talc and asbestos. Talc, with a hardness of 1, is used as a dusting powder, as a lubricant, and to provide texture in paints. Because it is not combustible and has low thermal and electric conductivity, asbestos has been used in fireproof and insulating materials. Prior to the recognition of its cancer-causing properties, it was also widely utilized in the construction industry. Many older buildings still have asbestos-containing materials. Graphite, the main ingredient of the lead in pencils, may be formed by the metamorphism of coal.

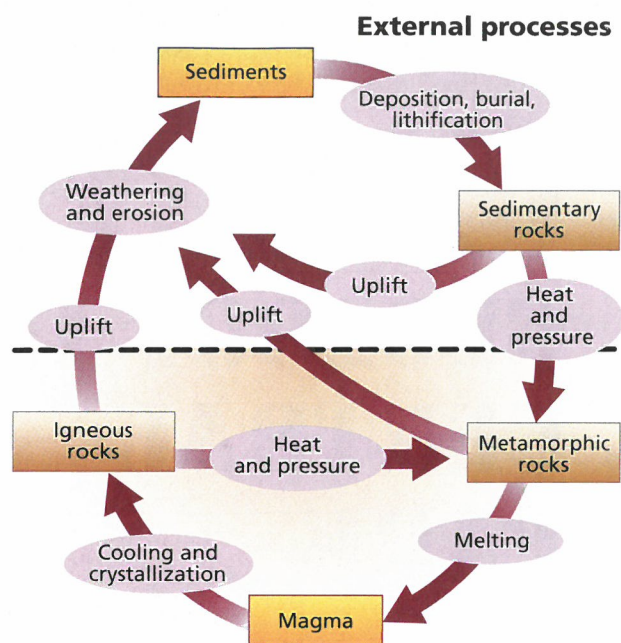
■ **Figure 6.22** Marble and slate are metamorphic rocks that have been used in construction for centuries.



The Rock Cycle

Metamorphic rocks form when other rocks change. 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 or precipitated sediments; and metamorphic rocks form from changes in temperature and pressure.

Once a rock forms, does it remain the same type of rock always? Possibly, but it most likely will not. Heat and pressure can change an igneous rock into a metamorphic rock. A metamorphic rock can be changed into another metamorphic rock or melted to form an igneous rock. Alternately, the metamorphic rock can be weathered and eroded into sediments that might become cemented into a sedimentary rock. In fact, any rock can be changed into any other type of rock. The continuous changing and remaking of rocks is called the **rock cycle**. The rock cycle is summarized in **Figure 6.23**. The arrows represent the different processes that change rocks into different types.



Internal processes

■ **Figure 6.23** Rocks are continually being changed above and beneath Earth's surface. The rock cycle shows some of the series of changes rocks undergo.

Section 6.3 Assessment

Section Summary

- The three main types of metamorphism are regional, contact, and hydrothermal.
- The texture of metamorphic rocks can be foliated or nonfoliated.
- During metamorphism, new minerals form that are stable under the increased temperature and pressure conditions.
- The rock cycle is the set of processes through which rocks continuously change into other types of rocks.

Understand Main Ideas

1. **MAIN Idea Summarize** how temperature increases can cause metamorphism.
2. **Summarize** what causes foliated metamorphic textures to form.
3. **Apply** the concept of the rock cycle to explain how the three main types of rocks are classified.
4. **Compare and contrast** the factors that cause the three main types of metamorphism.

Think Critically

5. **Infer** which steps in the rock cycle are skipped when granite metamorphoses to gneiss.
6. **Predict** the location of an igneous intrusion based on the following mineral data. Muscovite and chlorite were collected in the northern portion of the area of study; garnet and staurolite were collected in the southern portion of the area.

MATH in Earth Science

7. Gemstones often form as porphyroblasts. Gemstones are described in terms of carat weight. A carat is equal to 0.2 g or 200 mg. A large garnet discovered in New York in 1885 weighs 4.4 kg and is 15 cm in diameter. What is the carat weight of this gemstone?

ON SITE: GEOLOGY IN CENTRAL PARK

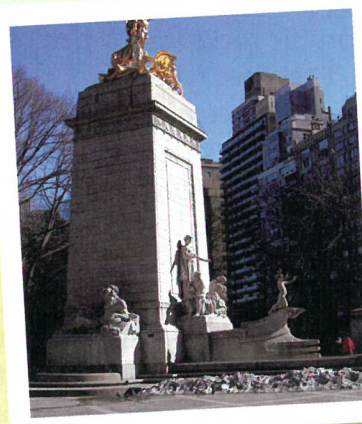
Some people travel to remote locations of the world to see different types of rock. However, examples of rocks often can easily be found in urban areas. Central Park in New York City is an excellent place to find examples of igneous, sedimentary, and metamorphic rock, both naturally occurring and used for sculptures, monuments, and bridges.

The Obelisk

Weighing 221 tons and standing 21 m high, Cleopatra's Needle is the oldest human-made object in Central Park. The granite was quarried in Egypt more than 3000 years ago in 1475 B.C. The sculpture remained in Egypt until 1879, when it was moved to the United States. Granite is more resistant to weathering than other types of rock, and engravings made in granite can be read for hundreds of years, making it an excellent rock for the construction of monuments.



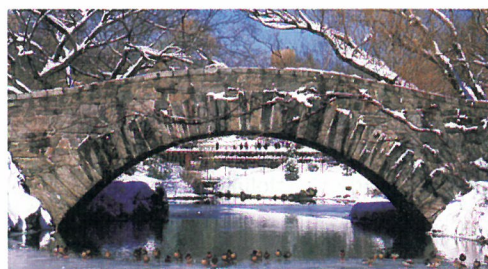
Cleopatra's Needle



Maine Monument

The Maine Monument Located at the main entrance to Central Park, the Maine Monument is an immense structure made of marble, limestone, and bronze. The massive bow of a ship that makes up the base of the monument was sculpted out of marble, a type of metamorphic rock. A bronze statue sits atop a 15-m limestone pylon.

Schist and gneiss These two types of metamorphic rock occur naturally in Central Park. Outcroppings of these rocks, formed from sedimentary or igneous rock under intense heat and pressure, can be found throughout the park. The Gapstow Bridge was constructed using the local bedrock.



Gapstow Bridge

WRITING in Earth Science

Promotional Brochure Research more information about the type of rock used to build structures and that occur naturally in your area. Create a promotional brochure that describes a tour focused on local geology. To learn more about the different types of rock, visit glencoe.com.

GEO LAB

INTERPRET CHANGES IN ROCKS

Background: As 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 rocks can show you how.

Question: *How do the characteristics of sedimentary or igneous rocks compare to metamorphic rocks?*

Materials

samples of sandstone, shale, limestone, granite, quartzite, slate, marble, and gneiss
magnifying lens
paper
beam balance
100-mL graduated cylinder or beaker that is large enough to hold the rock samples
water

Safety Precautions

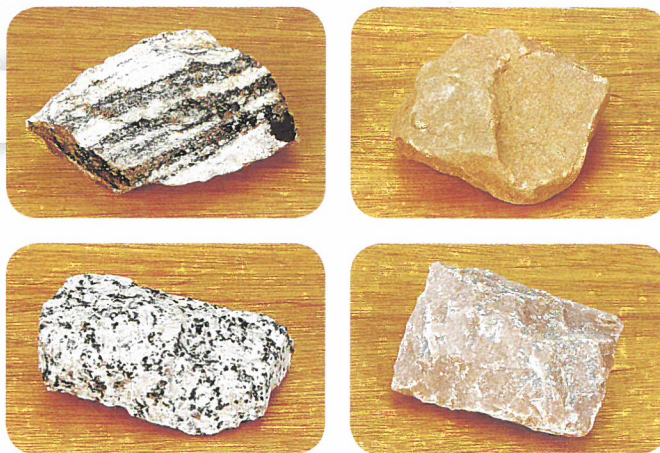


Procedure

1. Read and complete the lab safety form.
2. Prepare a data table similar to the one at the right. Adjust the width of the columns as needed.
3. Observe each rock sample. Record your observations in the data table.
4. Recall that $\text{density} = \text{mass}/\text{volume}$. Make a plan that will allow you to measure the mass and volume of a rock sample.
5. Determine the density of each rock sample, and record this information in the data table.

Analyze and Conclude

1. **Compare and contrast** sandstone and quartzite.
2. **Describe** how the grain size of sandstone changes during metamorphism.



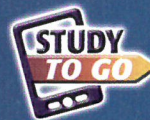
Sample Data Table

Sample Number	1	2	3	4
Rock type				
Specific characteristics				
Mass				
Volume				
Density				

3. **Describe** the textural differences you observe between shale and slate.
4. **Infer** Compare your calculated densities to those calculated by other students. Infer why yours might differ.
5. **Explain** why the color of a sedimentary rock may change during metamorphism.
6. **Evaluate** the changes in density between shale and slate, sandstone and quartzite, limestone and marble, and granite and gneiss. Does density always change? Explain your results.

SHARE YOUR DATA

Peer Review Discuss your results with other groups in your class. Speculate on the reasons for variations in mass, volume, and density.



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

Vocabulary

Key Concepts

Section 6.1 Formation of Sedimentary Rocks

- bedding (p. 137)
- cementation (p. 137)
- cross-bedding (p. 138)
- graded bedding (p. 138)
- lithification (p. 136)
- sediment (p. 134)

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

Section 6.2 Types of Sedimentary Rocks

- clastic (p. 141)
- clastic sedimentary rock (p. 141)
- evaporite (p. 143)
- porosity (p. 142)

- MAIN Idea** Sedimentary rocks are classified by their mode of formation.
- Sedimentary rocks can be clastic, chemical, or biochemical.
 - Clastic rocks form from sediments and are classified by particle size and shape.
 - Chemical rocks form primarily from minerals precipitated from water.
 - Biochemical rocks form from the remains of once-living organisms.
 - Sedimentary rocks provide geologists with information about surface conditions that existed in Earth's past.

Section 6.3 Metamorphic Rocks

- contact metamorphism (p. 149)
- foliated (p. 146)
- hydrothermal metamorphism (p. 149)
- nonfoliated (p. 147)
- regional metamorphism (p. 149)
- rock cycle (p. 151)

- MAIN Idea** Metamorphic rocks form when preexisting rocks are exposed to increases in temperature and pressure and to hydrothermal solutions.
- The three main types of metamorphism are regional, contact, and hydrothermal.
 - The texture of metamorphic rocks can be foliated or nonfoliated.
 - During metamorphism, new minerals form that are stable under the increased temperature and pressure conditions.
 - The rock cycle is the set of processes through which rocks continuously change into other types of rocks.

Vocabulary Review

Complete the sentences below using vocabulary terms from the Study Guide.

1. Compaction and cementation of clastic sediments result in _____.
2. Sedimentary layers that are deposited on an angle are called _____.
3. Cooling and crystallization, igneous rocks, uplift, and weathering and erosion describe a path along the _____.
4. Hot fluids that come in contact with solid rock result in _____.

Replace the italicized word with the correct vocabulary term from the Study Guide.

5. *Cementation* occurs when sediment gets deposited as the energy of the water decreases.
6. *Foliated* rocks have square, blocky crystals.

Write a sentence using each pair of words.

7. contact metamorphism, regional metamorphism
8. porosity, clastic sedimentary rock
9. sediment, bedding
10. clastic, evaporite

Understand Key Concepts

11. Which clastic sediment has the smallest grain size?
 - A. sand
 - B. clay
 - C. pebbles
 - D. silt
12. Which is a coarse-grained clastic rock that contains angular fragments?
 - A. limestone
 - B. conglomerate
 - C. sandstone
 - D. breccia
13. Which is a biochemical rock that contains fossils?
 - A. chert
 - B. limestone
 - C. sandstone
 - D. breccia
14. Which process forms salt beds?
 - A. deposition
 - B. cementation
 - C. evaporation
 - D. lithification
15. Which does not cause metamorphism?
 - A. lithification
 - B. hydrothermal solutions
 - C. heat
 - D. pressure

Use the diagram below to answers Questions 16 and 17.

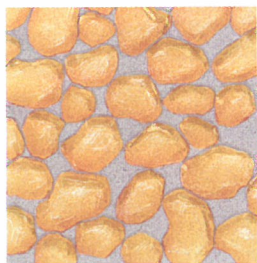


16. Which term best describes this rock's texture?
 - A. crystalline
 - B. nonfoliated
 - C. foliated
 - D. clastic
17. From what igneous rock does this sample usually form?
 - A. rhyolite
 - B. basalt
 - C. granite
 - D. gabbro

18. Which agent of erosion can usually move only sand-sized or smaller particles?
 - A. landslides
 - B. glaciers
 - C. water
 - D. wind
19. Which would you expect to have the greatest porosity?
 - A. sandstone
 - B. gneiss
 - C. shale
 - D. quartzite
20. By what process are surface materials removed and transported from one location to another?
 - A. weathering
 - B. erosion
 - C. deposition
 - D. cementation

Constructed Response

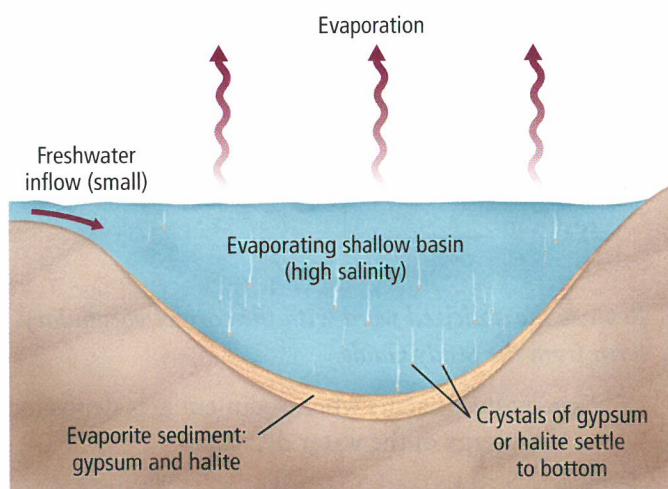
Use the diagram to answer Question 21.



21. **Describe** how the grains in the diagram become glued together.
22. **Summarize** the main difference between coquina and fossiliferous limestone. Use **Table 6.1** for help.
23. **Calculate** A sandstone block has a volume of 1 m^3 and a porosity of 30 percent. How many liters of water can this block hold?
24. **Illustrate** the two conditions necessary to form a foliated metamorphic rock.
25. **Compare and contrast** the modes of lithification for sand and mud.

26. **Classify** the following types of sediments as either poorly sorted or well sorted: dune sand, landslide material, glacial deposits, and beach sand.
27. **Analyze** the effect that precipitation of calcite or iron oxide minerals has on clastic sediments.
28. **Compare and contrast** the character and formation of breccia and conglomerate.

Use the diagram below to answer Question 29.



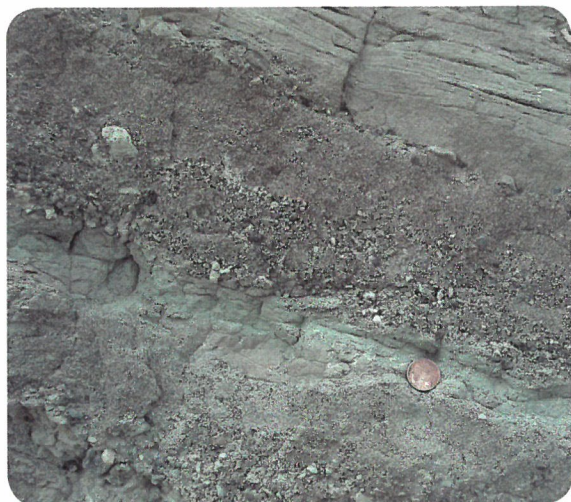
29. **Evaluate** the effect that an opening to the ocean would have on this environment.

Think Critically

30. **Incorporate** what you know about crystal form to explain why marble, even if formed under high pressure, does not show foliation.
31. **Compose** a statement to explain why the sedimentary rock coal does not meet the standard definition of a rock—an aggregate of minerals.
32. **CAREERS IN EARTH SCIENCE** Some sedimentologists work in sand and gravel pits where they analyze the material to best decide where and how it should be used. Infer why it is important for the sedimentologists to understand what would happen to the porosity of sand if finer-grained sediment were mixed in with the sand.
33. **Illustrate** an oil reservoir made up of layers of sandstone and shale. Indicate the position of the oil within the rocks.

34. **Assess** whether ripple marks and animal footprints preserved in sandstone are fossils. Explain your reasoning.

Use the figure below to answer Questions 35 and 36.



35. **Evaluate** the sediment in the layers in the figure. What type of bedding is this, and how well is it sorted? Explain.
36. **Infer** Look at **Figure 6.2** and explain which agents of erosion can produce the layers shown.
37. **Deduce** why glass on a quartz sand beach becomes rounded and frosted, while glass on a carbonate sand beach stays sharp and glassy.

Concept Mapping

38. Use the following terms to create a concept map that organizes sedimentary features: *ripple marks*, *graded bedding*, *horizontal bedding*, *asymmetrical*, *symmetrical*, *river current*, *wave action*, *wind deposited*, and *water deposited*. Some terms can be used more than once.

Challenge Question

39. **Hypothesize** At an approximate ocean depth of 4000 km, the carbonate compensation depth occurs. Below this depth, no calcium carbonate precipitates and no shells accumulate on the ocean floor. Hypothesize why this condition exists.

Additional Assessment

40. **WRITING in Earth Science** Imagine that you are planning a geologic walking tour of your community. Create a brochure highlighting the various natural building stones that are used in homes and buildings in your town or neighborhood.



Document-Based Questions

Data obtained from: Mineral Commodity Summaries. January 2006. United States Geological Survey.

Dimension stone is natural rock material used in construction, for monuments, and home interiors, such as kitchen countertops and floors. The principal rock types used are granite, limestone, marble, sandstone, and slate. Global resources of dimension stone are virtually limitless. Production of dimension stone in the United States and elsewhere has been steadily increasing.

Dimension Stone Production	U.S. Sold or Used (tonnage)	U.S. Sales or Uses (by value)
Limestone	39%	34%
Granite	29%	39%
Sandstone	14%	9%
Misc. stone	10%	7%
Marble	7%	6%
Slate	1%	5%

41. Construct a graph comparing the amount of dimension stone used by the value of the types of dimension stone.
42. Propose an explanation for why the value of granite is the highest of the dimension stones listed.

Cumulative Review

43. Compare and contrast the terms *science* and *technology*. (**Chapter 1**)
44. What is the formula of the ionic compound magnesium chloride? (**Chapter 3**)
45. Explain the concepts of partial melting and fractional crystallization. (**Chapter 5**)

Standardized Test Practice

Multiple Choice

Use the illustration below to answer Questions 1 and 2.



- Which rocks are most likely to metamorphose from the 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
- As the lava cools and crystallizes, what type of rock will form?
 - sedimentary
 - metamorphic
 - extrusive igneous
 - intrusive igneous
- What is NaCl commonly known as?

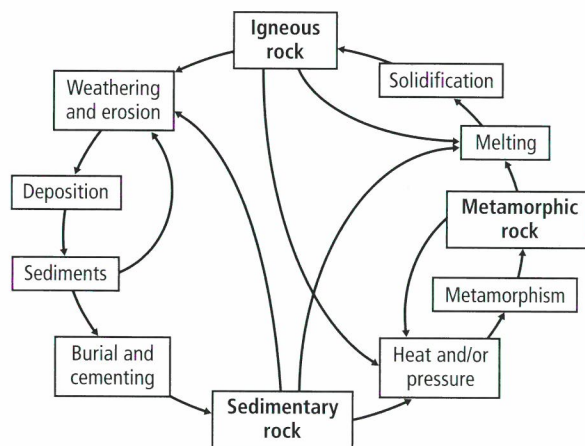
A. table salt	C. water
B. sugar	D. natural chlorine
- What initiates the process that changes sediments into sedimentary rocks?

A. bedding	C. cementation
B. burial	D. compaction
- Identify the unit that is NOT an example of the Le Système International D'Unités (SI).

A. metric ton	C. ampere
B. kilogram	D. Fahrenheit
- Which rocks are composed of minerals that form with blocky crystal shapes?

A. foliated	C. porphyroblasts
B. nonfoliated	D. phenocrysts

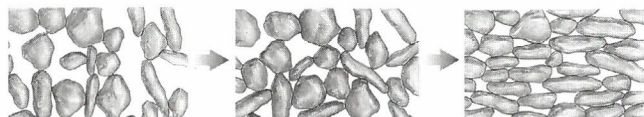
Use the diagram below to answer Questions 7 and 8.



- Based on the diagram, which is the most reasonable hypothesis?
 - Igneous rocks have layers caused by deposition.
 - Sedimentary rocks contain grains of other rocks.
 - Metamorphic rocks never have layers.
 - Sedimentary rocks are always the same color.
- According to the rock cycle shown above, what most likely happens after the deposition of sediment?
 - Weathering forms more sediment.
 - Magma cools and forms igneous rock.
 - Heat and pressure cause the sediment to melt.
 - Cementation occurs and forms sedimentary rock.
- Where are valence electrons located?
 - every energy level
 - middle energy levels
 - the outermost energy level
 - the innermost energy level
- Which sedimentary rock is used to make cement for the construction industry?
 - shale
 - sandstone
 - phosphate
 - limestone

Short Answer

Use the illustration below to answer Questions 11 and 12.

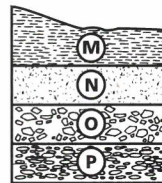


11. What do you notice about the formation of sedimentary rock above?
12. Does this process represent compaction or cementation? Describe the difference between the two.
13. The results of an experiment show that as temperature increases, enzyme activity decreases. Describe what a line graph made from this data would look like.
14. Define *luster*. Why is it difficult to use luster to identify minerals?
15. What process does Bowen's reaction series illustrate?
16. Boron has an atomic number of 5. Describe an atom of boron with a mass number of 10 and an atom of boron with a mass number of 11 in terms of their atomic particles. What is unique about these two atoms of boron?
17. Briefly describe the process by which magma becomes igneous rock.
18. How does studying sedimentary rock layers and understanding how they form help paleontologists learn about Earth's history?

Reading for Comprehension

Sedimentary Rock Layers

Paleontologists wanted to study the sedimentary rock layers and their contents of a particular area. The diagram shows a cross section of the rock layers they studied. The table shows the data the scientists were able to collect.



Age of Sedimentary Rock Layers			
Layer	Composition	Estimated Age (years)	Depth (meters)
M	sedimentary rock	100,000	0-4
N	sedimentary rock	Unknown	5-7
O	sedimentary rock	6 million	8-9
P	sedimentary rock	6.1 million	9-10

19. What could the paleontologists have recorded to improve their study?
 - A. time of year
 - B. age of layer N
 - C. location of the work site
 - D. mass of the sedimentary rocks
20. If fossils of a species were found in Layers O and P, but not M and N, which could you conclude?
 - A. The species does not exist anywhere on Earth today.
 - B. The species evolved into a completely different species.
 - C. The species became extinct less than 100,000 years ago.
 - D. The species disappeared from the area around 6 mya.

NEED EXTRA HELP?

If You Missed Question . . .

Review Section . . .

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
6.3	5.1	3.2	6.1	1.2	6.3	6.3	6.3	3.1	6.2	6.1	6.1	1.3	4.1	5.1	3.1	5.1	6.1

Surface Processes on Earth

Chapter 7

Weathering, Erosion, and Soil

BIG Idea Weathering and erosion are agents of change on Earth's surface.

Chapter 8

Mass Movements, Wind, and Glaciers

BIG Idea Movements due to gravity, winds, and glaciers shape and change Earth's surface.

Chapter 9

Surface Water

BIG Idea Surface water moves materials produced by weathering and shapes the surface of Earth.

Chapter 10

Groundwater

BIG Idea Precipitation and infiltration contribute to groundwater, which is stored in underground reservoirs until it surfaces as a spring or is drawn from a well.

CAREERS IN EARTH SCIENCE

Glaciologist This glaciologist is studying the Antarctic ice sheet by recording its vibrations. Glaciologists study the movement, formation, and effects of glaciers on landscapes. Information gathered by glaciologists provides insight into Earth's geologic history as well as its future.

WRITING in Earth Science

Visit glencoe.com to learn more about glaciologists. Write a news report about a recent discovery on the Antarctic ice sheet.

