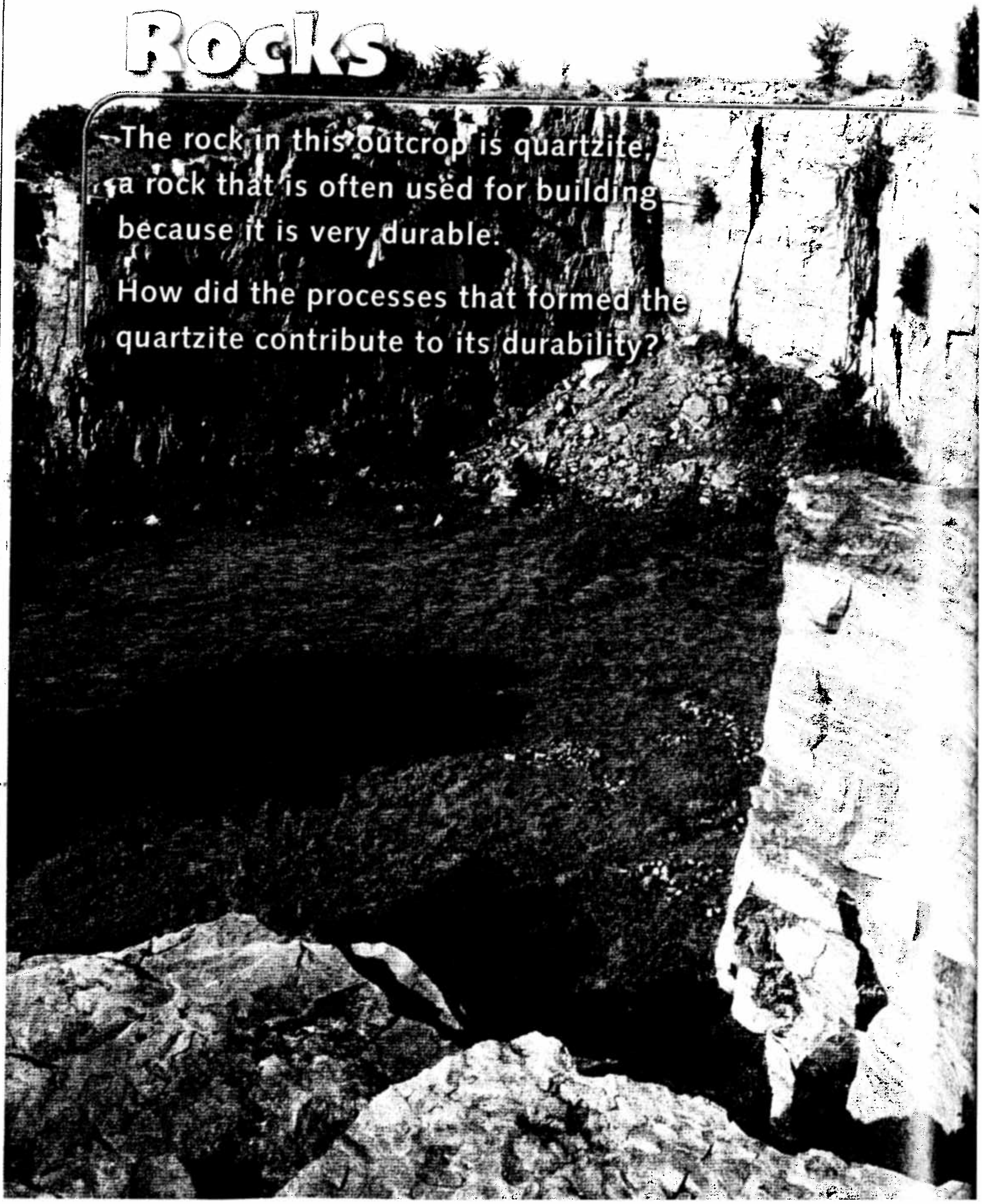
CHAPTER 6

Rocks



The rock in this outcrop is quartzite, a rock that is often used for building because it is very durable.

How did the processes that formed the quartzite contribute to its durability?

CHAPTER 6

PREVIEW

▶ FOCUS QUESTIONS

In this chapter you will study rocks and learn more about the key questions listed below.

Section 1 What is a rock, and what is the rock cycle?

Section 2 How do igneous rocks form and how are they classified?

Section 3 How do the different types of sedimentary rocks form?

Section 4 How do metamorphic rocks form and what are their characteristics?

▶ REVIEW TOPICS

As you investigate rocks, you will need to use information from earlier chapters.

- mineral **(p. 96)**
- crystal **(p. 98)**
- rock-forming minerals **(p. 104)**
- the relationship among element, mineral, and rock **(p. 96)**
- silicates **(p. 100)**

▶ READING STRATEGY

CONNECT

Note the rocks you see and use every day. Make connections between your experience and what you are reading. Especially note information in the text that seems to contradict your experience.

INTERNET RESOURCES
CLASSZONE.COM

At our Web site, you will find the following Internet support :

DATA CENTER

EARTH NEWS

VISUALIZATIONS
- Views of Rocks
- Sediment Deposition
- Clastic Sedimentary Rock Formation
- Metamorphic Rock Formation

LOCAL RESOURCES

CAREERS

INVESTIGATIONS
- How Do Rocks Undergo Change?
- How Do Igneous Rocks Form?
- What Kind of Rock Is This?

6.1

KEY IDEA

Three major types of rocks are formed, broken down, and reformed in a recurring process called the rock cycle.

KEY VOCABULARY

- rock
- igneous
- magma
- sedimentary
- sediment
- metamorphic
- rock cycle

How Rocks Form

If you could dig a hole straight down through Earth's crust, what would you see? At first, you might find layers of soft dirt, sand, or clay. Eventually you would find the sturdy base on which we live, the solid material called rock.

What Is a Rock?

An understanding of Earth's processes requires knowledge about rocks and how they form. In general, a **rock** is a group of minerals bound together. Rocks can consist largely of one mineral or can be composed of several different minerals in varying quantities. In the granite rock shown below, four minerals are readily visible and identifiable; other minerals may be present in much smaller amounts. Other types of granites may be composed only of feldspar and quartz.

Rocks are found in Earth's crust and mantle. The rocks of the mantle are seldom seen at the surface and are largely similar. The crust, however, contains many different types of rocks. These rocks can be classified according to the processes by which they are formed:

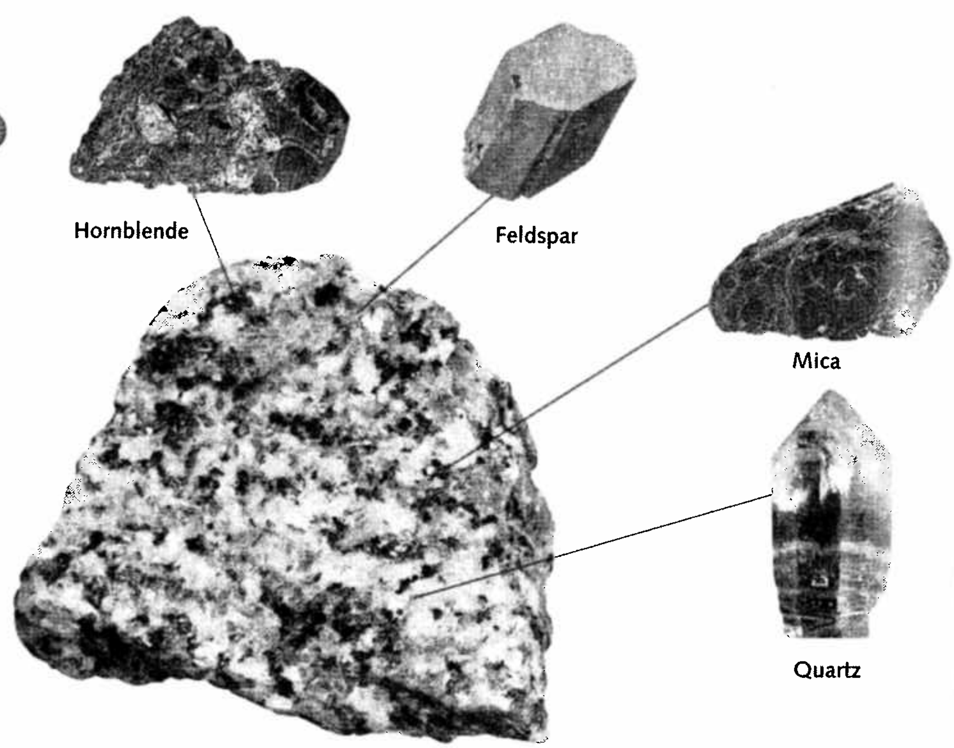
- **Igneous** (IHG-nee-uhs) rocks are formed by the cooling and hardening of hot, molten rock, or **magma,** from inside Earth.
- **Sedimentary** (SEHD-uh-MEHN-tuh-ree) rocks are formed by the compaction and cementing of layers of sediments. **Sediments** are materials such as rock fragments, plant and animal remains, and minerals that settle out of solution onto lake and ocean bottoms.
- **Metamorphic** (MEHT-uh-MOR-fihk) rocks are formed by the effect of heat and pressure on other rocks.

VOCABULARY STRATEGY

The word *igneous* comes from *ignis,* the Latin word for fire. *Sedimentary* comes from *sedimentum,* the Latin word meaning "the act of settling." *Metamorphic* is based on the Greek word *metamorphoun,* which means "to transform."

VISUALIZATIONS
CLASSZONE.COM

Examine rocks from a satellite view and zoom in to a microscopic view.
Keycode: ES0601



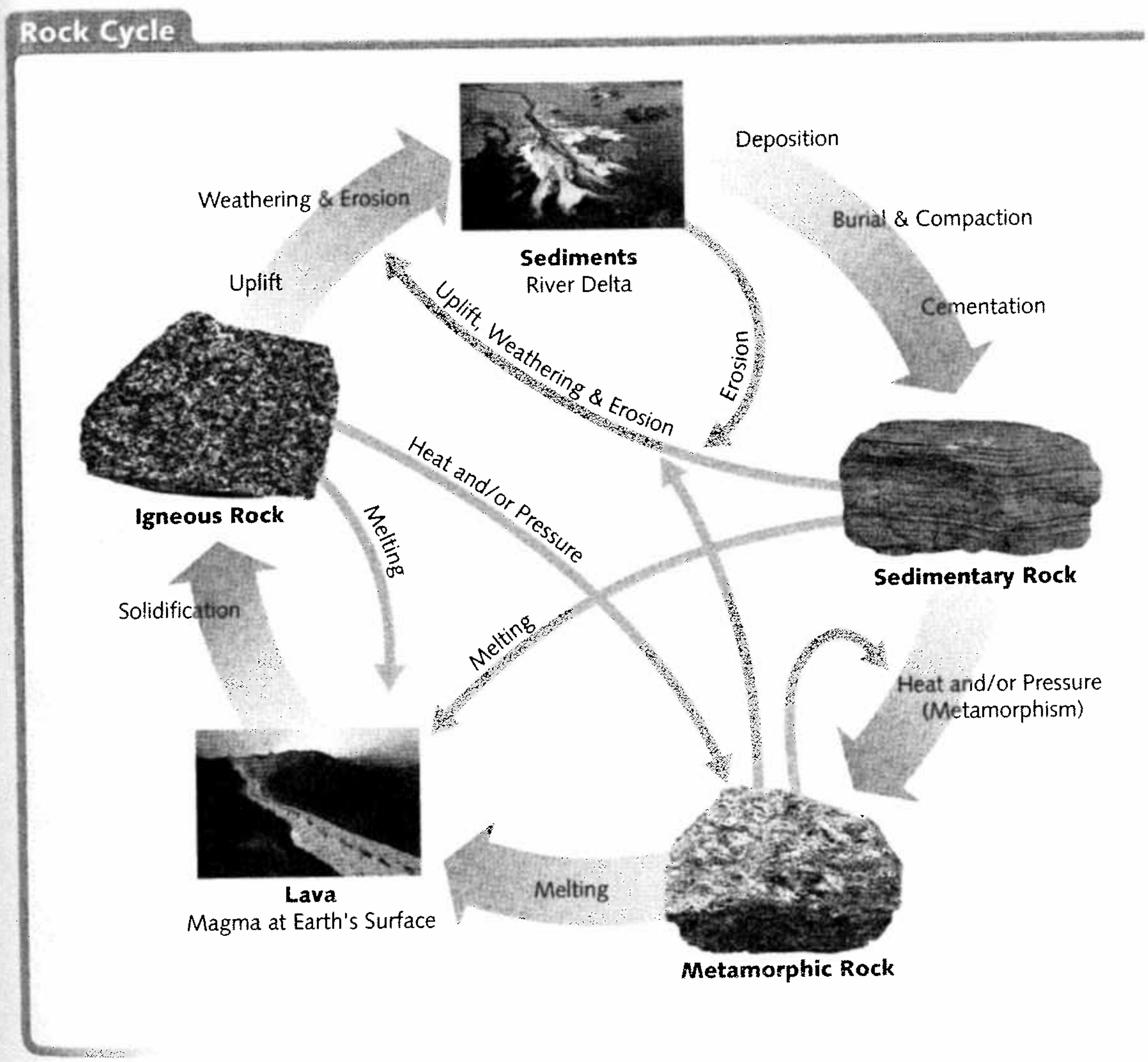
GRANITES vary in composition, but the minerals shown here are often present. Due to differences in their formation, a hand sample of a mineral will look different from a crystal of the same mineral that is part of a rock.

The Rock Cycle

Rocks form from other rocks. Classifying the rocks of the crust according to their origins shows how closely related they are. The **rock cycle** is the repeated series of events by which rock gradually and continually changes from one type to another. The diagram of the rock cycle below illustrates a simplified model of this continuous process of rock formation and change.

INVESTIGATIONS
CLASSZONE.COM

How Do Rocks Undergo Change?
Follow a rock through various paths of the rock cycle.
Keycode: ES0602



Magma from deep below Earth's surface is the source of all Earth's rocks. When this molten rock approaches or reaches the surface, it cools and solidifies to become igneous rock.

Once at the surface, igneous rocks are slowly broken down by weathering and erosion, forming sediments. As later sediments accumulate on top of earlier layers, the buried sediments begin to compact and cement together. In this way, the sediments become sedimentary rocks.

Over time, these sedimentary rocks are buried beneath other sediments or are caught in movements of Earth's crust that expose them to high temperature and/or pressure. In either case, heat, pressure, or both cause sedimentary rocks to acquire new characteristics, thus becoming metamorphic rocks.

Sometimes crustal movements force rocks deep into Earth. The rocks may become so hot that they melt into magma. The magma may then harden into igneous rocks to complete the rock cycle.

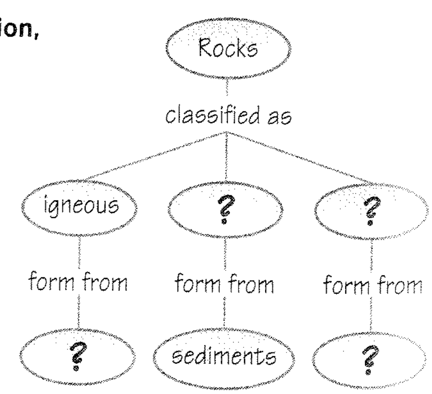
This description of the rock cycle is a simplified model of rock formation and change. This model is useful because it presents a clear "map" of the basic processes, the transformation of rock from one form to another. A complete model of the rock cycle would be very complex and include many variations on and departures from the basic cycle the model illustrates. That is, the transformation of rock does not always move from igneous to sedimentary to metamorphic rock. For example, an igneous rock may become a metamorphic rock without first becoming sediments and then sedimentary rock.

The rock cycle illustrated on the previous page shows several possible variations from the model. For example, igneous rock may melt back into magma before it can become any other type of rock. A sedimentary rock may weather back into sediment without first becoming a metamorphic rock. Some metamorphic rocks change into different metamorphic rocks instead of melting into magma.

Some sediments are created completely outside the rock cycle by means other than weathering. For example, sometimes sediments drop out of, or precipitate from, chemical solutions. Also, the bodies of some organisms have hard, mineral-rich shells or similar structures. When these organisms die, the structures can break down to form sediments.

6.1 Section Review

1. **Using the information in this section, copy and complete the concept map at right.**



2. **Distinguish between a rock and a mineral. How are they similar? How are they different?**
3. **Describe the most direct cycle of relationships between the three major rock types. Then create a chart of the other ways that rocks change. First list the rock, then the process it undergoes, and finally the result.**
4. CRITICAL THINKING **According to the information in this section, what are the similarities and differences between igneous rocks and metamorphic rocks?**
5. PAIRED ACTIVITY **Create a concept map that shows at least three different ways in which metamorphic rock can be formed and changed.**

Igneous Rocks

Although all igneous rocks begin as magma, they have a variety of compositions and textures. Their differences are the result of variations in the composition of the magma and in the formation process.

6.2

KEY IDEA

Igneous rocks form from magma in distinct ways and can be classified based on mineral composition and texture.

KEY VOCABULARY

- felsic
- mafic
- pluton
- batholith

Igneous Rock Formation

As with other rocks, igneous rocks are classified by their mineral composition and texture. Some igneous rocks form from volcanic ash. Most form directly from magma. The location of the magma determines the rate at which it cools, which determines the texture of the resulting rocks. Igneous rocks formed from underground magma are called intrusive igneous rocks. Those formed at Earth's surface are called extrusive igneous rocks.

The Starting Material

Magma may be classified as felsic, mafic, or an intermediate form. **Felsic** (FEHL-sihk) magma is thick and slow-moving. It contains large amounts of silica (SiO_2) and smaller amounts of the elements calcium, iron, and magnesium. This magma typically hardens into rocks of light-colored silicate minerals such as quartz and orthoclase feldspar.

Compared with felsic magma, **mafic** (MAF-ihk) magma is hotter, thinner, and more fluid, containing large amounts of iron and magnesium and much lower amounts of silica. Rocks formed from mafic magma usually contain large amounts of dark silicate minerals such as hornblende, augite, and biotite.

Underground Magma

Magma may harden slowly or quickly. The rate of cooling and the texture of the rock that forms depend on where the cooling occurs. Magma trapped deep in Earth's crust hardens very slowly to form intrusive igneous rocks. Evidence suggests that massive bodies of intrusive rock may take thousands of years to cool underground. Intrusive rocks appear at Earth's surface when they are uplifted and the overlying rock is worn away.

LAVA This lava is magma that poured onto Earth's surface during a volcanic eruption. It will harden to form extrusive igneous rock. Magma that hardens below the surface forms intrusive igneous rocks.

Intrusive rocks have a coarse texture because the magma from which they formed cooled very slowly. Slowly cooling magma remains liquid for a long time, and its atoms move about quickly and freely. As you may recall from Section 5.2, large, well-defined crystals form only when space is available for crystal growth. The longer the magma stays liquid, the longer the atoms are free to move and the larger the crystals become. Such intrusive rocks have a granular, or coarse-grained, texture.

At the Surface

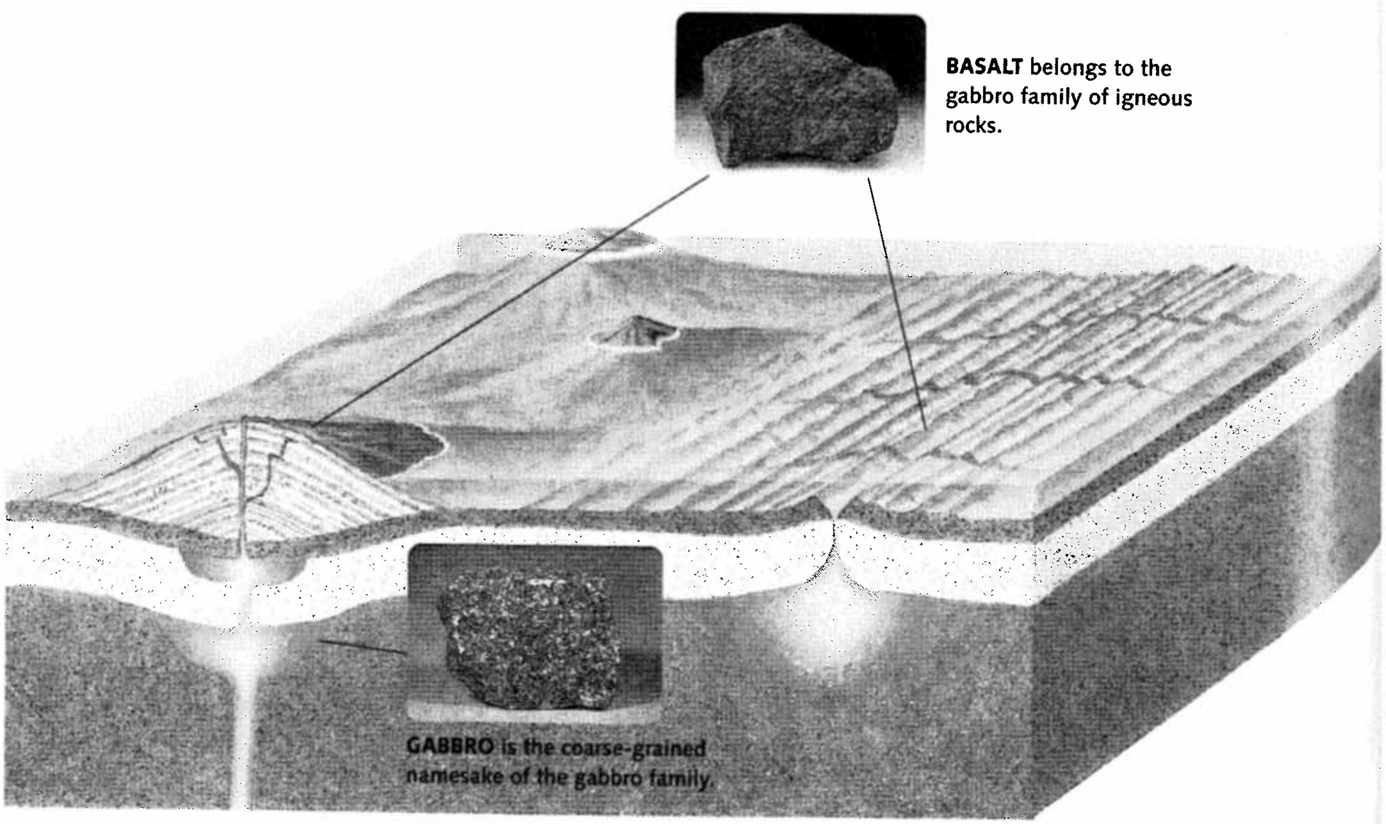
VOCABULARY STRATEGY

The words *intrusive* and *extrusive* share a word root that means "push" or "thrust." The prefix *ex-* changes the meaning to "pushed out." The prefix *in-* alters the meaning to "pushed between or within."

When magma pours onto Earth's surface during a volcanic eruption, it is called lava. That lava, when cooled and hardened, is known as volcanic rock or extrusive igneous rock. Extrusive rock hardens rapidly, sometimes within a few hours or days. However, it can take years for large lava flows to cool and harden completely. You will learn more about lava in Chapter 9.

The particles within rapidly cooling magma have little time to move around. Crystals have such a short time to form that extrusive rocks may have only microscopic crystals or no crystals at all. Extrusive rocks with tiny crystals have a fine-grained texture. Those without crystals are smooth as glass and so are said to have a glassy texture.

Sometimes underground magma begins cooling slowly, as it would during the formation of intrusive rocks, but then is suddenly forced to the surface. During the period of slow cooling, some large crystals form. However, once the partially crystallized magma arrives at the surface, the remaining liquid cools quickly. Microscopic crystals form around the larger, original crystals. The result is porphyry (POR-fuh-ree), an igneous rock in which large crystals are surrounded by a fine-grained mass of rock.



BASALT belongs to the gabbro family of igneous rocks.

GABBRO is the coarse-grained namesake of the gabbro family.

Magma also reaches Earth's surface when expelled forcefully into the air as ash. The ash settles onto Earth's surface and, if present in large enough amounts, may eventually be buried and compressed into a rock called tuff. Although tuff originates from volcanic particles, some scientists consider it a transitional rock, sharing features of both igneous and sedimentary rocks.

INVESTIGATIONS
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How Do Igneous Rocks Form? Watch animations of igneous minerals crystallizing. Examine images of real rocks and classify how each one formed.
Keycode: ES0603

Igneous Rock Descriptions

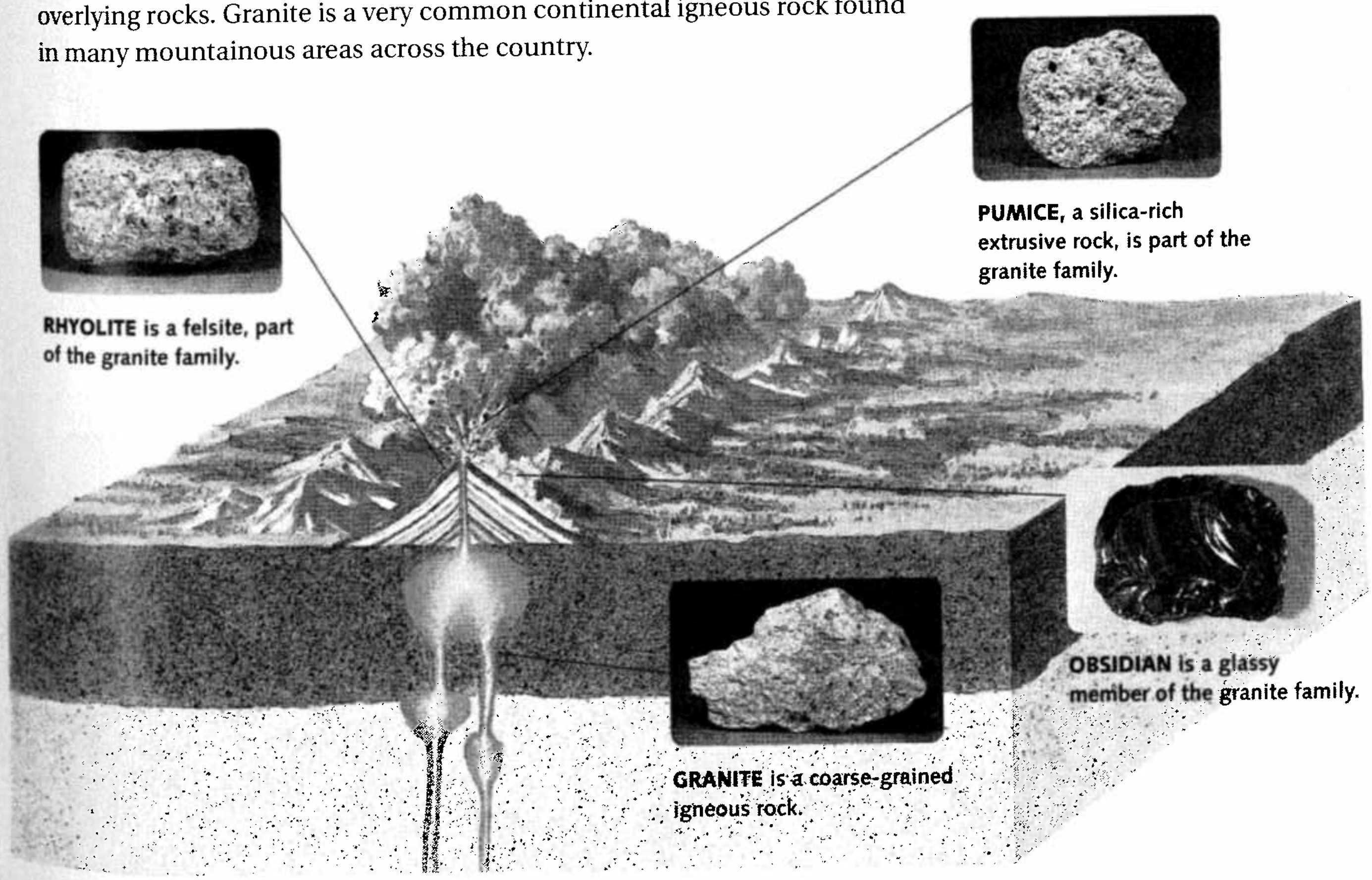
Igneous rocks are grouped into families according to mineral composition. A family may include intrusive and extrusive rocks. Where an igneous rock forms determines its texture, so each family may have coarse-grained, fine-grained, and glassy members. Specific igneous rocks can be recognized by their mineral composition and texture.

Granite Family

Rocks in the granite family form from felsic magmas. These rocks are usually coarse-grained because their slow-rising, "sticky" parent magmas tend to cool slowly underground. Members of this family typically contain quartz, feldspar (orthoclase, plagioclase, or both), mica, and hornblende.

Granite, for which this family is named, is one of the coarsest-grained rocks in the family. Because granites often contain large amounts of light-colored feldspar, the color of this mineral usually determines the color of the granite. Granite usually ranges from white or gray to pink.

Granite is an intrusive igneous rock. It appears at the surface only after it is uplifted, and after erosion has removed thousands of meters of overlying rocks. Granite is a very common continental igneous rock found in many mountainous areas across the country.



PUMICE, a silica-rich extrusive rock, is part of the granite family.

RHYOLITE is a felsite, part of the granite family.

OBSIDIAN is a glassy member of the granite family.

GRANITE is a coarse-grained igneous rock.

Scientific Thinking

HYPOTHESIZE

In an ancient Mesopotamian site in modern-day Iraq, archaeologists discovered rectangular slabs of rock that looked very much like basalt. However, the scientists realized that the ancient Mesopotamians had made the rock out of river silt, possibly because they lacked stone for building or grinding grain.

Based on what you know about basalt formation, propose a process that the Mesopotamians might have used to change river silt into flat, rectangular basalt-like slabs.

Obsidian, a volcanic rock with a glassy texture, is moderately hard (about 5 on the Mohs scale) and brittle, with conchoidal fracture. Obsidian's chemical composition resembles that of granite and other light-colored rocks, so it is considered a member of the granite family. However, obsidian is usually dark brown or black due to tiny amounts of dark-colored iron oxides scattered throughout the rock.

Pumice is formed from silica-rich lava that hardened as steam and other gases bubbled out of it. It resembles a sponge because of its many holes and air pockets. It is often light enough to float on water.

The granite family also includes felsite, the general name for any light-colored, fine-grained rock. Rhyolite, a fine-grained rock that ranges from light gray to pink, is a common example.

Gabbro Family

The gabbro family consists of mafic rocks. They are dark in color and denser than rocks in the granite family. The dark minerals pyroxene and olivine, as well as plagioclase feldspar, are the most plentiful minerals in a gabbro rock. Other minerals often found in gabbros are amphibole and biotite. Gabbro, this family's namesake, is a coarse-grained rock, very dark in color.

The most common rock in the gabbro family is basalt. It has a composition similar to that of gabbro, but it is fine-grained. Basalt is typically dark gray or black and is the igneous rock that makes up the ocean floor. On land, basalt is the most common rock formed from lava flows.

Other members of the gabbro family include diabase, basalt glass, and scoria. The texture of diabase is finer than that of gabbro but coarser than that of basalt. Basalt glass resembles obsidian but is mafic. Scoria, like pumice, is full of holes. However, scoria is made of denser minerals, and because its holes are commonly larger, it is unlikely to float.

Diorite Family

Members of the diorite family have an intermediate composition that is neither felsic nor mafic but has characteristics of both. Their colors tend to be medium grays and greens—darker than the granites and lighter than the gabbros. Diorite, a coarse-grained rock, has less quartz than granite and less plagioclase feldspar than gabbro. Andesite is a fine-grained member of the diorite family.

SUMMARY Igneous Rocks

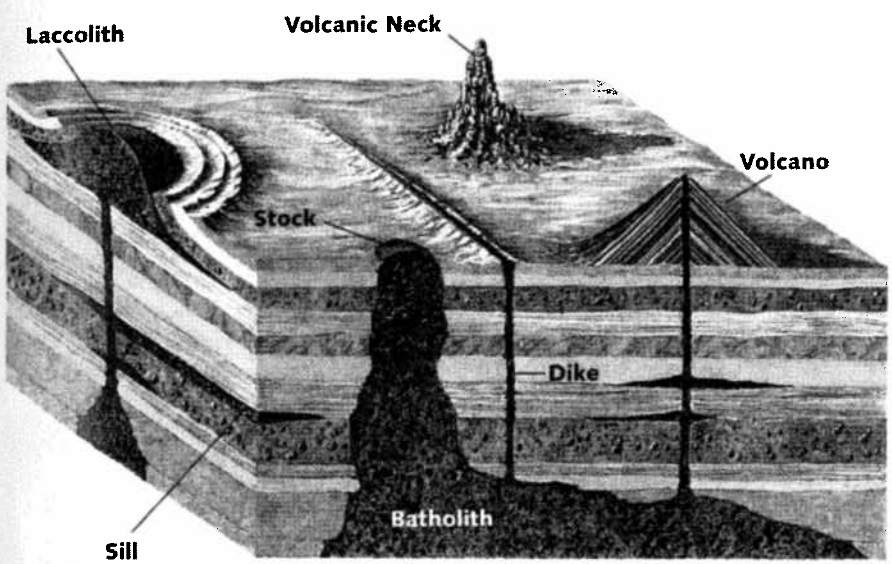
Texture	Chemical Composition				
	felsic	felsic-intermediate	intermediate	mafic	ultramafic
coarse-grained	granite	granodiorite	diorite	gabbro	peridotite, dunite, pyroxenite
				diabase	
fine-grained	rhyolite		andesite	basalt	
glassy	obsidian			basalt glass	
porous	most pumice			scoria	

Other Igneous Rocks

Igneous rock compositions do not occur as distinct categories but as a range, loosely separated by gradual boundaries. For example, granodiorite is a coarse-grained rock with a transitional composition between that of granite and diorite. Some rocks, including coarse-grained, dark, and dense pyroxenite, dunite, and peridotite, have a chemical composition described as ultramafic. Ultramafic rocks consist chiefly of mafic minerals, the ferromagnesian silicates olivine and pyroxene. Scientists hypothesize that these rocks are similar to those of Earth's mantle.

Igneous Intrusions

Volcanoes give only a hint of the amount and the activity of the magma that exists below Earth's surface. Forces deep within Earth may push magma into fractures in the bedrock. Sometimes magma is squeezed between rock layers, forcing the overlying rocks upward to form domes. Great masses of magma may solidify far below the surface to form the cores of mountains.

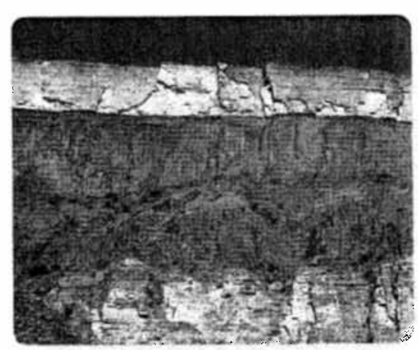


TYPES OF IGNEOUS FORMATIONS

In general, any igneous intrusion—a rock mass that forms when magma cools inside Earth's interior—may be called a **pluton.** Dikes, sills, laccoliths, and volcanic necks are sometimes called plutons. However, some scientists identify only the largest, thickest intrusions as plutons. A pluton reaches Earth's surface only after uplift, weathering, or both take place.

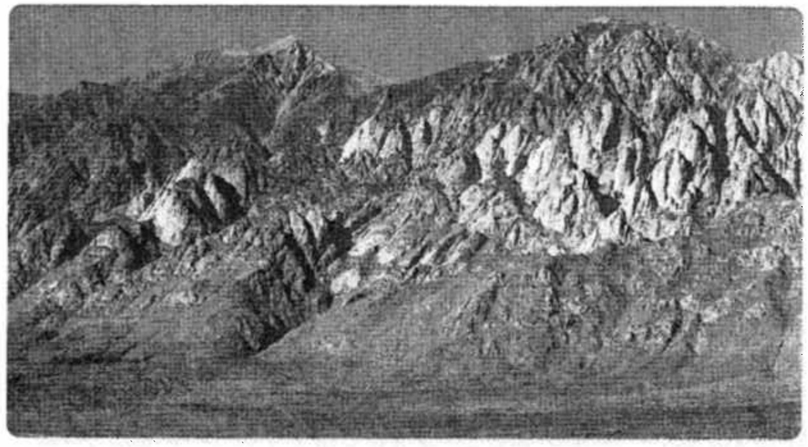
As the diagram above indicates, dikes and sills are sheets of magma intruded into previously formed rock. A dike is a sheet of igneous rock that cuts across rock layers vertically or at a steep angle. Dikes form when magma intrudes into angled cracks. Dikes may be hundreds of kilometers long and can range from about a centimeter to many meters thick. They are common in regions of volcanic activity.

As you can see above, a sill is a sheet of igneous rock that lies parallel to the layers it intrudes. A sill forms when magma is forced between, not across, rock layers. Sills can be hundreds of meters thick and many



SILL The dark rock layer above is a sill, a type of igneous intrusion, located in Big Bend National Park, Texas.

BATHOLITH The Sierra Nevada in California is part of a batholith, the largest of the igneous intrusions.



kilometers long. The exposed sill that makes up the Palisades along the Hudson River in New York is about 80 kilometers long.

Some magmas are stiff and do not flow easily. Instead of spreading into sheets, these magmas can bulge upward to form domed masses called laccoliths. (See the illustration on page 125.) The rock layers above a laccolith are also pushed upward to form a dome. Laccoliths exist in the Henry Mountains in Utah.

As an inactive volcano erodes, a volcanic neck may be exposed. A volcanic neck is the central plug of hardened magma left after the volcanic material around it has worn away.

Batholiths, the largest of all plutons, form the cores of many of Earth's mountain ranges. They are usually made of either granite or granodiorite and can span tens of thousands of square kilometers. A batholith is exposed through uplift and erosion of the overlying rock layers. A small batholith, in which less than 100 square kilometers is exposed at the surface, is called a stock. The largest batholith in North America forms the core of the Coast Range of southern Alaska and British Columbia, Canada.

6.2 *Section Review*

1. Create a Venn diagram that illustrates the differences and similarities between felsic and mafic magmas.
2. Why do igneous rocks have different textures?
3. What types of igneous rocks do not belong to any of the three major igneous rock families? What traits set them apart?
4. Describe the factors that might cause magma to form a laccolith instead of a sill.
5. **CRITICAL THINKING** Stone arrowheads are made by chipping smooth, curved pieces from a rock to form a sharply pointed triangle with razor-sharp edges. Which rock, obsidian or gabbro, would make a better arrowhead? Why?
6. **CHEMISTRY** A sample of magma flows very quickly. Would you expect it to contain high or low amounts of silica? Why?

Sedimentary Rocks

Although Earth's crust consists primarily of igneous rock, most of the crust's surface is covered by sedimentary rock.

Formation of Sedimentary Rocks

In simple terms, sedimentary rock forms through the compacting and cementing of layers of sediment. However, sedimentary rocks are classified by three basic formation processes.

Clastic Rocks

Clastic sedimentary rocks are formed from fragments of other rock. The fragments come from the weathering of igneous, metamorphic, and sedimentary rocks. The fragments may be the size of pebbles, gravels, grains of sand, tiny particles of silt, or microscopic flakes of clay.

The formation of clastic rocks begins with the movement and relocation of the fragments. The majority of these rock fragments are collected and moved by running water. When carried by a stream or river, the fragments become smooth and rounded from rubbing against one another and the stream bed. The farther the particles are carried, the more rounded they become. When a stream flows into a body of water, such as a lake or an ocean, it typically slows down and drops all but the smallest particles, as illustrated below. Waves and currents may then redistribute the sediment over great distances.

Larger pebbles and gravels are often the first to drop out and settle in the shallow water near shore. Next to settle are the smaller sands and finally, in calm water, the silts and clays. The sorting process is not always

6.3

KEY IDEA

The three major types of sedimentary rocks are categorized by the way they form and by their distinctive features.

KEY VOCABULARY

- **cementation**
- **stratification**
- **fossil**

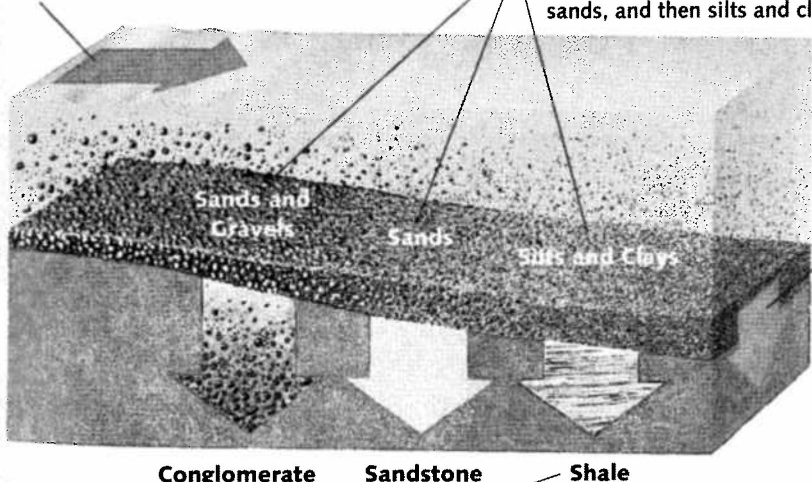
VISUALIZATIONS
CLASSZONE.COM

Observe how sediments are deposited.
Keycode: ES0604

Sorting of Sediments

1 A river moves sediments into a lake.

2 Particles are "sorted" by size. The largest gravels are first to be deposited, followed by sands, and then silts and clays.



3 Over time, the sediments are buried and compacted. The particles may become cemented together.

4 Conglomerates form from the larger particles, sandstones from sands, and shale from silt and clay.

VISUALIZATIONS CLASSZONE.COM

Observe an animation of clastic sedimentary rocks forming.
Keycode: ES0605

perfect. Sand is sometimes found mixed with pebbles and gravels in shallow water or with silts and clays in deeper water.

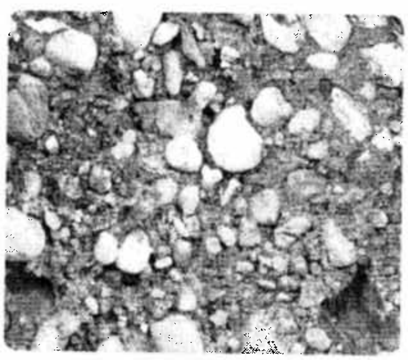
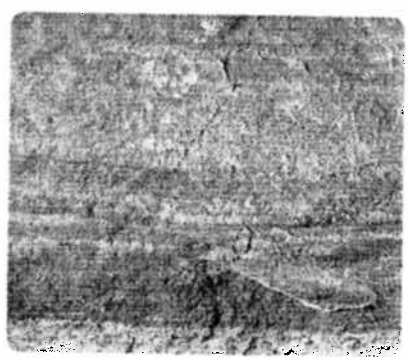
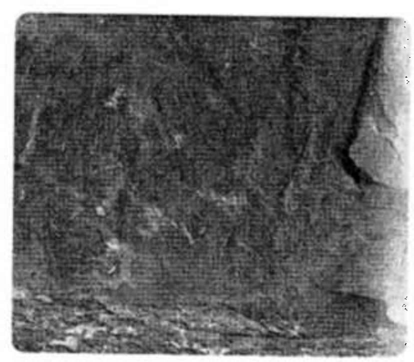
Loose sediments become solid clastic rock when particles of sediments become cemented. Ocean water, lake water, and groundwater all contain natural cements in the form of dissolved minerals. These natural cements include silica (SiO_2), calcite ($CaCO_3$), iron oxide (such as hematite, Fe_2O_3), and clay minerals. When minerals fill the spaces between sand grains, pebbles, or other rock particles, they bind the fragments together in a process called **cementation.** Over time, cement transforms loose sediments into bound sedimentary rock. The type of cement influences a rock's color. Rocks with silica and calcite tend to be gray or white, while iron-based cements help form red, brown, or rust-colored rocks. In some sedimentary rocks, though, the pressure of overlying sediments enables fine sediments to stick together without cement.

Conglomerates are the coarsest clastic rocks. A typical conglomerate is a cemented mix of rounded fragments (typically pebbles and sand grains) that were deposited in rough water. Quartz is a common ingredient because it is so durable. Breccia (BREHCH-ee-uh) is a conglomerate made of angular fragments surrounded by finer grains.

Sandstones made of quartz sand grains are rough, gritty, and durable if they are well cemented. Although cement and fine particles tend to fill the spaces between such fragments, up to 30 percent of a sandstone may be unfilled space. As a result, a sandstone is typically both porous (filled with small holes) and permeable (capable of having water pass through it).

Silts and clays (usually tiny flakes of clay minerals) form shale. The spaces between the clay particles in shale are so small that it is virtually impermeable. Shales are smooth, soft, and easily broken.

SUMMARY Clastic Sedimentary Rocks

		
Conglomerate	**Sandstone**	**Shale**
large fragments ranging from gravel to boulders	particles up to about the size of the head of a pin	sediments about the size of flour particles
any mineral composition	commonly quartz grains	clay minerals such as kaolinite
porosity and permeability depend on the degree of cementation	often highly porous often highly permeable	not very porous nearly impermeable

Chemical Rock

The water in seas, lakes, swamps, and underground reservoirs often contains dissolved minerals. Chemical sediments form when these minerals precipitate, or fall out of solution. Precipitation can occur through evaporation or through chemical action—as, for example, when dissolved ions combine to form new minerals. Common chemical sedimentary rocks are rock salt, rock gypsum, and some limestones.

Rock salt, or halite, occurs in thick layers in many parts of the world. Rock gypsum occurs in layers or as nearly pure veins of the mineral gypsum. Although they are uncommon, limestones of chemical origin may form when tiny grains of calcite are deposited on the bottoms of seas or lakes. These limestones are often gray or tan, compact and dense, and smooth to the touch.

ROCK SALT FLAT at Bonneville, Utah

ORGANIC LIMESTONE CLIFFS in Dover, England

Organic Rock

An organic sedimentary rock forms from sediments consisting of the remains of plants and animals. Common organic sedimentary rocks are limestone and coal. Although coal consists primarily of carbon, it is formed from the fossilized remains of plants. The formation of coal is discussed in more detail in Chapter 7.

Organically formed limestones contain the mineral calcite. Limestone formation begins when water dissolves calcite out of rocks on land and carries it in the form of calcium ions to an ocean or lake. There, certain organisms use the ions to produce calcium carbonate shells or other support structures. Clams, corals, and some algae are just a few of these organisms, many of which live in shallow water near ocean shores. When the organisms die, their calcium-rich remains pile up on the ocean floor. The type of sedimentary rock formed from these sediments depends on the type of structures and on the environment in which it forms. For example, the rock coquina develops when masses of whole or mostly whole shells are cemented together by minerals in ocean water. More often, waves break the shells into fragments. In time these fragments may become cemented into limestones. Limestones that form near shore may contain large amounts of clay. Those that form farther from shore may be almost pure calcite.

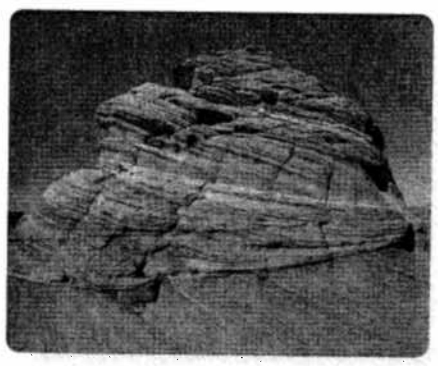
Features of Sedimentary Rocks

The single most characteristic feature of sedimentary rocks is **stratification**, the arrangement of visible layers.

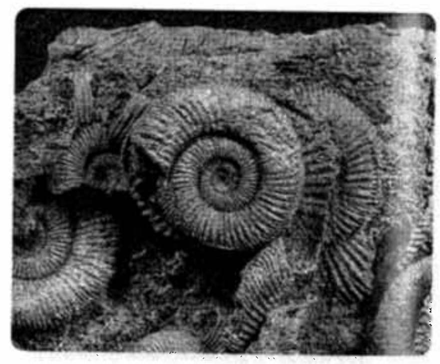
STRATIFICATION A change in the type of sediment being laid down in one place results in the formation of a new rock layer. For example, when sand is deposited on top of clay, a layer of sandstone may form on top of a layer of shale. In this way, sedimentary rocks become stratified.

A bedding plane, the line between layers, separates each rock layer, or bed. Bedding planes are usually horizontal, but cross-bedding can occur when a river deposits sediments at an angle on sandbars or when wind deposits beds at an angle on dunes.

Stratification occurs for a number of reasons. The river that brings sediment to an ocean or lake may break off and pick up new types of rock. A river in flood may carry larger amounts and different types of sediments. The river may carry the sediments farther out to sea than it normally does. Or it may drop its sediments closer to shore.



STRATIFICATION



FOSSIL

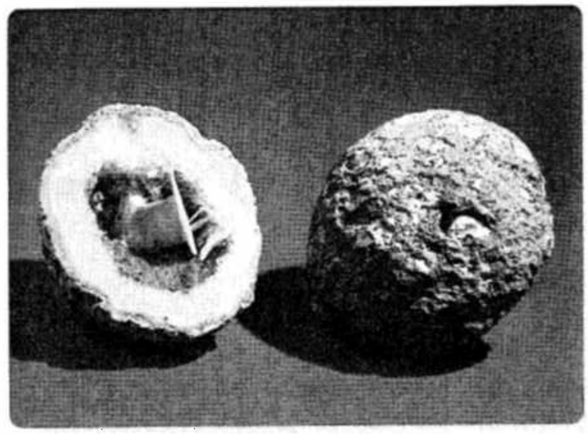
FOSSILS Sedimentary rock often contains fossils. A **fossil** is the remains, impression, or any other evidence of a plant or animal preserved in rock. Fossilization occurs when a dead plant or animal is buried by sediments that gradually turn to rock. The soft parts of the animals and plants usually decay, but the hard parts may become fossils. You will learn more about fossils in Chapter 29.

Splitting rock layers may reveal impressions in the rock, left when a shell or a skeleton was pressed into soft sediments. Plant impressions occur less frequently, but can be found in rocks formed from swamp sediments.

RIPPLE MARKS AND MUD CRACKS Two relatively common features of sedimentary rock are ripple marks and mud cracks. Ripple marks are sand patterns formed by the action of winds, streams, waves, or currents. You may have seen fresh ripple marks at a sandy beach or stream bed. Such ripple marks can be preserved when the sand becomes sandstone. Many sandstones show ripple marks on the surface of a bedding plane.

You may have seen fresh mud cracks where a muddy road or puddle of water has dried out after a rain. Mud cracks in sedimentary rock develop when deposits of wet clay dry and contract. The cracks are filled with different sediments and fossilize when the clay becomes shale rock.

RIPPLE MARKS



GEODE

NODULES, CONCRETIONS, AND GEODES Limestones and chalk often contain hard lumps of fine-grained silica called nodules. Whitish, brown, or gray nodules are called chert; darker varieties are sometimes called flint. Stone Age humans made many tools and weapons of chert and flint. The uniform fine grain and conchoidal fracture of these rocks made them easy to shape and to form sharp edges.

Round, solid masses of calcium carbonate called concretions often occur in layers of shale. Nodules and concretions probably form when minerals in a solution precipitate around a shell fragment or other impurity in the clay sediments.

Limestones sometimes contain spheres of silica rock called geodes (JEE-ohds). The interiors may be lined or completely filled with crystals—often quartz or calcite. Some geologists hypothesize that geodes form when groundwater creates cavities in limestone. Minerals in the groundwater then concentrate in the cavities, where they grow as crystals. Others propose that geodes form where older concretions have dissolved.

6.3 *Section Review*

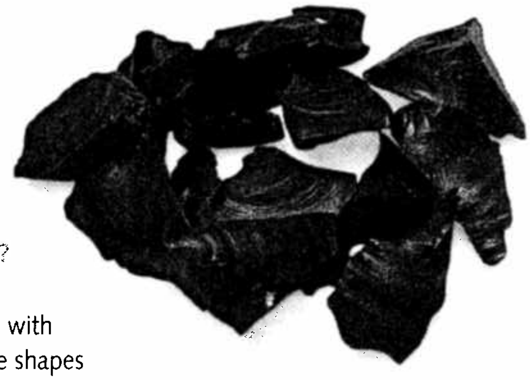
1. From where a stream runs into a lake and out to the middle of that lake, in what order would you most likely find the three basic types of clastic sedimentary rock?
2. Create a chart that shows the differences and similarities between sedimentary rocks of chemical origin and those of organic origin.
3. List and describe three features of sedimentary rocks. Which feature is common to nearly every type of sedimentary rock?
4. CRITICAL THINKING Why is it possible to find large, well-formed crystals inside geodes?
5. BIOLOGY What type of environmental change might stop the development of an organic sedimentary rock? Explain.

SCIENCE & Technology

What Good Is a Rock?

Rocks exist in an astonishing variety. Their origins, the way in which they form, their chemical composition—these and other factors lend rocks a wide range of physical properties.

Which physical properties of rocks have humans used to their benefit?



OBSIDIAN, an igneous rock that has sharp edges, is shown here in its natural form.

Imagine a surgeon telling you she will use stone-age technology to operate on your eye. You might be tempted to run until you learn that she is referring to obsidian, the sharpest material available for scalpels—nearly 500 times sharper than surgical steel. Obsidian, an igneous rock, has been valued for its sharp edges since prehistoric times.

Obsidian, flint, chert, and chalcedony—all quartz-based igneous rocks with extremely fine crystals—have been prized for thousands of years by flint knappers. Flint knapping is the process of creating chipped stone tools such as knife blades, scrapers, arrowheads, and spear points. A small group of flint knappers carries on the tradition today by striking these rocks with harder rocks to create precise shapes and edges.

Because it is so sharp, obsidian was a valuable commodity and was widely traded during the Stone Age, at least as far back as 10,000 years ago. Ancient obsidian tools have been discovered at distantly scattered sites, even though there are actually very few sources of obsidian in the world. Scientists have learned to analyze trace elements in obsidian artifacts to match them to source areas. They have found that obsidian artifacts in Israel originated in Greece and other sites thousands of kilometers away. Ancient obsidian tools found in Alberta, Canada, have been traced to sources in Wyoming.

The study of obsidian artifacts allows archaeologists to gain a real sense of sophisticated interactions between distant communities of prehistoric people.

Extension

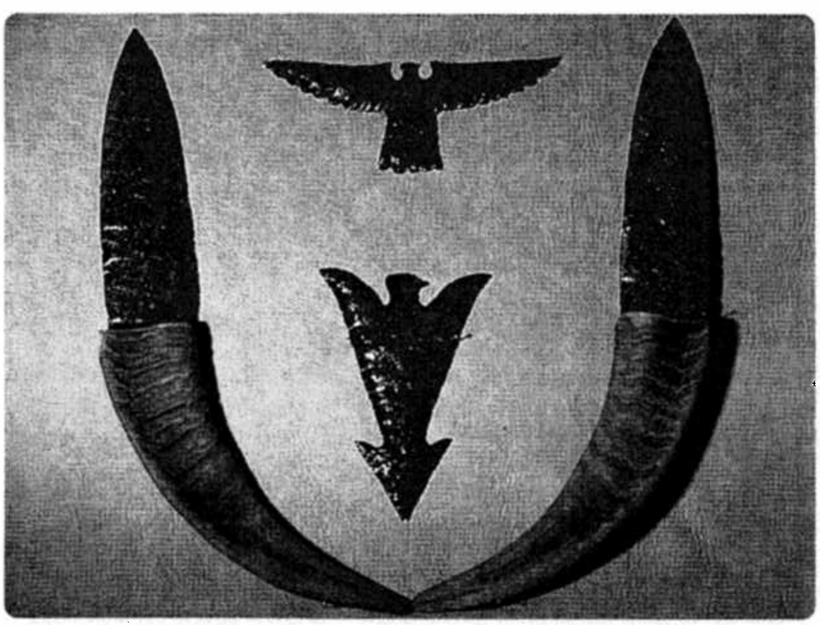
SCIENCE NOTEBOOK

Consider the ways in which sharp-edged stone tools might have been used in prehistoric times. Which materials seem to have replaced stone for these uses today? Write your answers in your science notebook.

DATA CENTER CLASSZONE.COM

Learn more about how people use rocks.

Keycode: ES0606



TOOLS AND WEAPONS, such as these knives and projectile-point artifacts, have been crafted from obsidian since prehistoric times.

Metamorphic Rocks

Metamorphic rocks are formed from preexisting rocks called **parent rocks.** As a result, a metamorphic rock often resembles its parent rock. Any differences between the two are a result of the metamorphic process the parent rock undergoes.

6.4

KEY IDEA

Metamorphic rocks form when natural forces, such as heat and pressure, alter existing rocks.

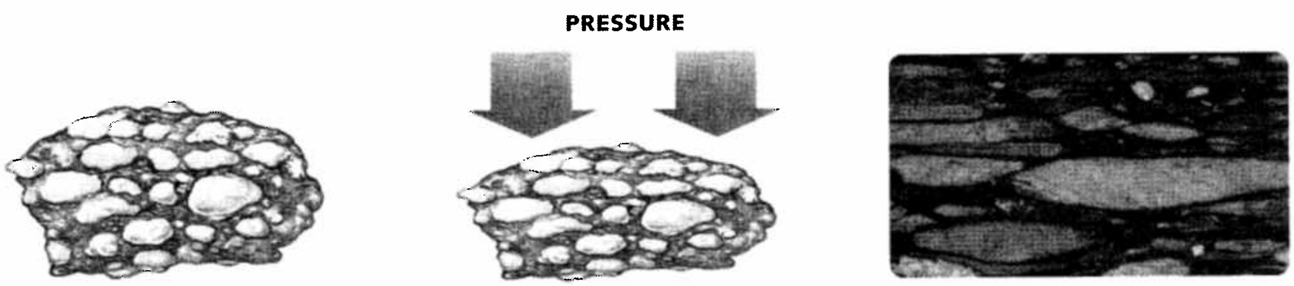
KEY VOCABULARY

- parent rock
- metamorphism
- deform

Metamorphic Processes

The process by which a rock's structure is changed by pressure, heat, and moisture is **metamorphism.** The pressure and heat can originate from Earth's internal heat, the weight of overlying rock, and the deformation of rock as mountains build. A metamorphosed, or changed, rock may have a chemical composition, texture, or internal structure that differs from that of the parent rock. Minerals may be enlarged or re-formed, or new minerals may appear. As shown below, pressure may force grains closer together, making the rock more dense and less porous.

Metamorphic Conglomerate



1. A conglomerate is a sedimentary rock consisting of pebbles and rounded rock fragments cemented together.
2. As the conglomerate undergoes metamorphism under high pressure, it flattens, stretches, and becomes more compact.
3. This is a photograph of a conglomerate that has undergone metamorphism. Note its compressed rock fragments and pebbles.

There are two basic types of metamorphism: regional and local. Regional metamorphism forms most of the metamorphic rock of Earth's crust; it occurs over very large areas. Local metamorphism occurs in much smaller, more distinct areas.

Regional Metamorphism

Regional metamorphism can occur during mountain-building movements of the crust, when large areas of rock change form after exposure to intense heat and pressure. As mountains form, deeply buried rocks are subjected to high heat and pressure. Due to Earth's internal heat, temperature increases with depth. The high pressure comes from the great weight of overlying rock. When the pressure is greater in one direction, minerals in the rock tend to align in layers. Hot liquids and gases in the deep rocks can help speed up the process.

VISUALIZATIONS
CLASSZONE.COM

Observe an animation of metamorphic rocks forming.
Keycode: ES0607

25-Minute **MiniLAB**

Metamorphic Molds

Materials
- object to make a mold
- modeling clay
- plaster of Paris
- water
- small cup
- stirring straw

Procedure
1. Press the object into a rectangular piece of clay and then remove it so that plaster can be poured in the depression.
2. Deform the mold, noting the steps you take and the order in which they are done.
3. Mix plaster and water together until a runny mixture is obtained.
4. Pour the mixture into the mold and wait 5–10 minutes for it to set.

Analysis

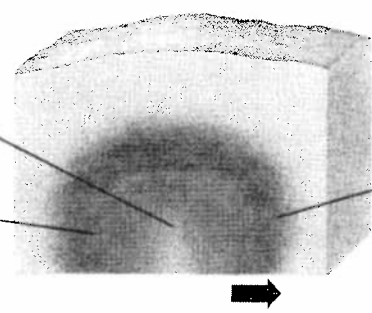
Can you recognize the original object from the resulting cast and detect the steps of the deformation? Trade casts with another person. Can you recognize this object? Can you determine individual steps of deformation? Describe how this exercise is similar to and different from metamorphic rock formation.

The degree of regional metamorphism is influenced by the amount of heat, pressure, and fluids or gases to which the rock is exposed. Extremely high temperature and pressure can produce extreme metamorphism. Little metamorphism occurs when temperature and pressure are very low. Metamorphism occurs slowly when the parent rock is dry, and as a result, fewer changes occur. These factors may occur in any combination. For example, a mass of rock may first experience moderate temperatures and high pressure and later be exposed to high temperature and low pressure.

Local Metamorphism

The two types of local metamorphism are contact metamorphism and deformational metamorphism. Contact metamorphism occurs when hot magma moves into rock, heating and changing it. Hot liquids and gases from the magma may also enter the intruded rock and react with its minerals.

Contact Metamorphism



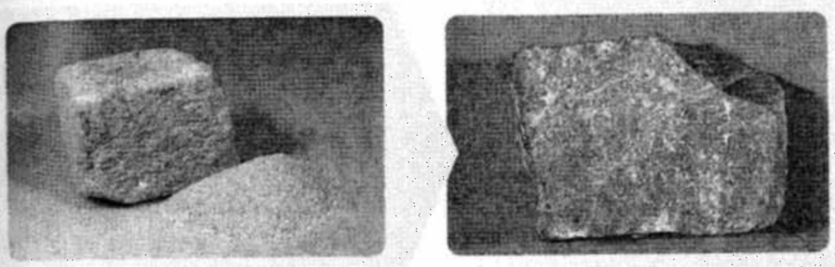
Compared to regional metamorphism, contact metamorphism causes fewer changes in the rock and affects much less rock. The size of the affected area depends on the temperature of the magma and whether gases and fluids are present, but the area is rarely wider than one hundred meters. Shale that undergoes contact metamorphism may become hornfels, a dense, hard, and fine-grained rock.

Deformational metamorphism occurs at relatively low temperatures and at high pressure caused by stress and friction, most often at faults where rock masses pass each other. As the masses move, heat from the friction, stress, and pressure cause the rock to **deform,** or change shape. The altered rocks usually have the same mineral composition of the rock around them but show changes in structure and texture.

Metamorphic Rock Descriptions

The descriptions and identifications of metamorphic rocks are often based on the parent rock, mineral content, and texture. Foliation, the tendency of a rock to form bands of minerals or split along parallel layers, can also help identify and classify metamorphic rocks.

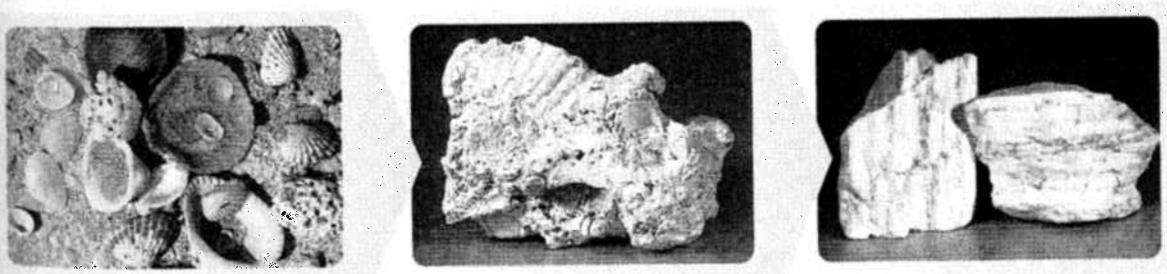
The properties of the metamorphic rock quartzite depend on the properties of its parent rock, sandstone. Some sandstones are made almost entirely of quartz sand grains. Quartzite consists largely of quartz crystal. Under heat and pressure, the spaces between the sandstone's grains are filled, and the rock recrystallizes into quartzite. Quartzite is a dense, nonfoliated, uniformly crystalline rock that is harder to break apart than the parent sandstone. An interesting type of quartzite called quartzite conglomerate is a metamorphosed conglomerate. Its parent rock was most likely a conglomerate composed largely of quartz fragments. Metamorphism changed the conglomerate into a "metaconglomerate."



Sandstone **Quartzite**

QUARTZITE Sandstone (left) is the parent rock of quartzite (right). The sandstone consists of cemented quartz particles, such as the sand shown to the right of the sandstone.

Marble is a metamorphosed limestone with a relatively simple mineral content. When parent limestones consist almost entirely of the mineral calcite, the resulting marbles are also almost entirely calcite. Impurities in marble tend to appear as wavy streaks and color changes. These impurities are often introduced by fluids and gases flowing through the metamorphosing parent rock. Marbles are usually non-foliated and even-grained with a sugarlike texture.

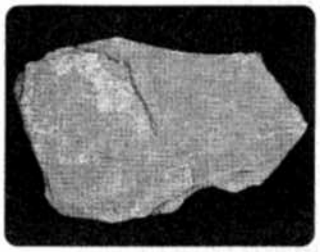


Shells **Limestone** **Marble**

SEASHELLS (left), formed by marine animals out of carbon and calcium ions in seawater, form the sedimentary rock limestone (center). When it undergoes metamorphosis, limestone becomes marble (right).

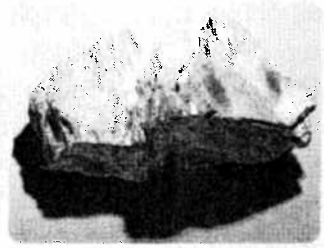
When shale undergoes regional metamorphism, many changes in physical properties can occur. The rock becomes denser, and its grain size may increase. The elements recombine to form new minerals not found in shale, such as mica; this can cause foliation. Foliation occurs when pressure squeezes the flakes of mica into parallel layers, sometimes causing the new rock to split easily along the layers into thin, leaflike flakes.

The lowest degree of regionally metamorphosed shale is slate. In slate, the foliation layers are thinly spaced. The rock is usually very fine-grained and composed mainly of clay and quartz with microscopic flakes of

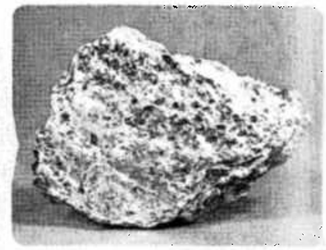


Shale

Slate



Phyllite



Schist

SHALE (left) is sedimentary rock. Through the process of metamorphism, it becomes slate (center left), phyllite (center right), and schist (right).

muscovite or chlorite. These micas form in layers that produce slate's characteristic cleavage. When compared with its parent rock, slate is slightly shinier and has a flatter, less irregular surface.

With more intense metamorphism, the rock phyllite forms. Phyllite has pronounced foliation and a shiny surface. This shine is due in part to the increase in size of the mica grains. The tiny grains of mica are now large enough to be detected with the unaided eye.

Further metamorphism, usually the high temperatures and pressures of regional metamorphism, produces schist. The parent rocks include shales and basalts, so there are several varieties of schist. Schists are usually named for their most conspicuous mineral. For example, mica schist, talc schist, and hornblende schist are named for their most

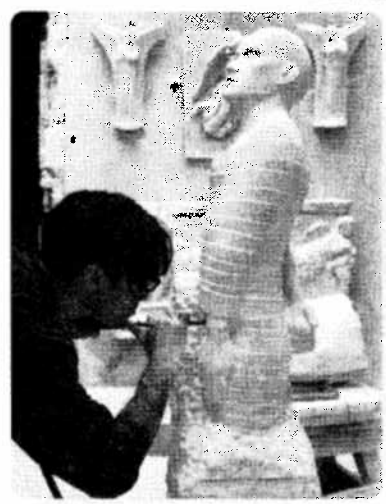
CAREER

Marble Sculptor

Some of history's most celebrated artists, such as Michelangelo, were marble sculptors. Today, marble sculptors carry on this respected art form, using power hand tools, slabs of marble, and their artistic creativity. Depending on their style, some sculptors focus on classic subjects, such as human figures or religious themes, while others create modern, abstract works. Once completed, the sculptures are then exhibited and sold in art galleries. Sculptures are sometimes commissioned by patrons such as the government, schools, private foundations, churches, or individuals.

Being a successful sculptor requires imagination, fine motor skills, a ready supply of marble, and, above all, patience. Because self-expression is so important to a marble sculptor, many artists are largely self-taught.

While a degree is not necessary, some find that a degree in fine arts is helpful in acquiring a sense of art history. Some sculptors also occasionally attend workshops, sculpting classes, and conferences to hone their skills and to share their work with colleagues. Part of a sculptor's training can come in the form of travel. As they visit cultural centers such as Carrara, Italy, which is famous for its sculpting tradition, sculptors gain a sense of what makes a true masterpiece. ■



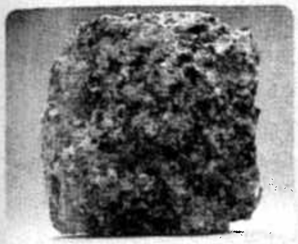
THIS MARBLE SCULPTOR in Tuscany, Italy, is creating a likeness of the human form.

CAREERS CLASSZONE.COM

Learn more about a career in sculpting.
Keycode: ES0608

observable minerals. Schists are flaky rocks in which the foliation layers are easily seen. These rocks tend to be very large-grained and often contain large crystals of minerals not found in the parent rock.

Gneiss is one of the most highly metamorphosed of the metamorphic rocks. The various forms of gneiss metamorphose from a number of parent rocks, including shale, granite, and conglomerate. It is often difficult to determine the parent rock of a gneiss, so its name usually reflects its chemical composition. For example, the gneiss shown below is called a granite gneiss. It contains many of the same minerals found in granite.



Granite

Gneiss

GRANITE (left) is one of the parent rocks that can become gneiss (right).

Gneiss has the coarsest foliation of all the metamorphic rocks. Its minerals are arranged in wavy parallel bands, usually no more than a few centimeters thick. Bands of light-colored minerals such as quartz and feldspar alternate with dark minerals such as hornblende or biotite.

6.4 *Section Review*

1. What factors cause metamorphism? Which of those factors is most important for each type of metamorphism (regional, contact, and deformational)?
2. Name two examples of nonfoliated metamorphic rocks. Explain why they do not exhibit foliation.
3. Describe the metamorphism of shale and the rock sequence involved in that metamorphism.
4. **CRITICAL THINKING** Compare the formation processes of igneous, sedimentary, and metamorphic rocks. In general, which process can be the most direct, requiring the fewest number of steps? Which can be the most complex? Explain.
5. **VISUAL ARTS** Marble is a very popular stone for artists to use when carving sculptures. What properties of marble might make it good for sculpting?

CHAPTER 6 LAB Activity

Studying Rocks in Thin Section

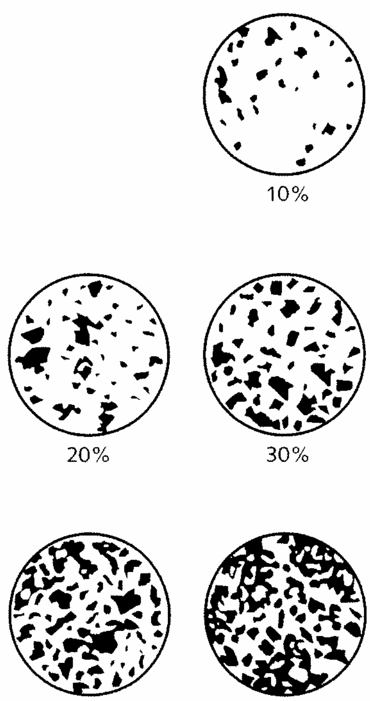
Skills and Objectives

- ***Observe*** and ***interpret*** several diagrams of rock thin sections.
- ***Classify*** and ***identify*** which minerals and rocks the diagrams represent.

Materials

- metric ruler

Mineral Percentage Chart



Have you ever tried to look through a rock? In addition to looking at hand-held rock samples, sometimes geologists need to see through the rock in order to study it. To do this, they make thin sections—slices of rock so thin that light actually passes through them! Geologists then use microscopes to analyze these sections. The magnified view allows scientists to see minerals that are not large enough to view in the hand-held sample, and to identify more easily the larger minerals that can be seen.

In this activity, you will look at some diagrams of thin sections. You will study minerals found in rocks and identify rocks containing such minerals.

Procedure

1. Look at the diagram of Rock A on the next page. Use the key to determine and list the name of each mineral found in Rock A.
2. Use the chart at left to estimate the percent of one mineral present in Rock A. Record the data on a separate sheet. Repeat for each of the minerals in Rock A. Your values should total 100%.
3. Repeat Steps 1 and 2 for Rock B.
4. Using the metric ruler, measure the diameter of the circular diagram for Rock C. Record your measurement.
5. Look at the mineral grains in Rock C. Measure the widths in any direction across five different mineral grains. Record your data. Calculate an average width for the grains.

Analysis and Conclusions

1. Grain or crystal size can provide clues to rock types. Typically, sedimentary grains are rounded and cemented together. Igneous grains fit together in a jigsaw-puzzle fashion. Metamorphic grains exhibit linear patterns and foliation. Which of Rocks A to E is sedimentary? Igneous? Metamorphic? Explain your answers.
2. Determine the actual size of an average grain of Rock C. The actual diameter of the rock sample shown in each diagram is 0.5 centimeters. Use the average grain diameter that you calculated and the magnified diameter you recorded. Show your work.

3. Using your answer to Question 2, determine the name of the average grain size in Rock C. The diameter of clay-size grains is less than 0.0004 cm, silt 0.0004 to 0.006 cm, sand 0.006 to 0.2 cm, and pebbles greater than 6.4 cm. Which kind of sedimentary rock is Rock C? Explain your answer.

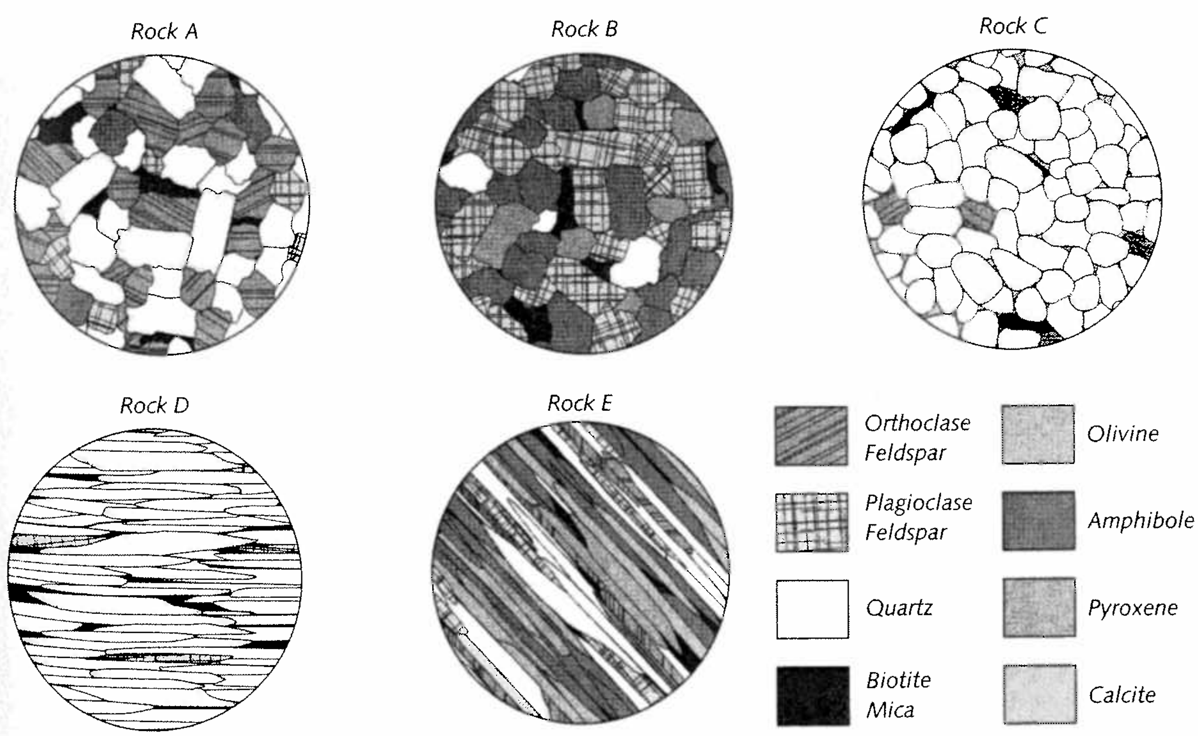
4. In Rock A, which two minerals did you estimate make up over 50% of the rock? Which minerals make up the remainder of the rock?

5. In Rock B, which two minerals did you estimate make up over 50% of the rock? Which minerals make up the remainder of the rock?

6. Igneous rocks are commonly grouped into mafic rocks and felsic rocks, based on their chemical composition. Mafic rocks are dark in color because they contain many dark minerals such as amphibole, pyroxene, olivine, and biotite. Felsic rocks are light in color and tend to contain minerals such as quartz and orthoclase feldspar. Based on these definitions, is Rock A mafic or felsic? Rock B? Explain your answers.

7. Compare the diagrams for Rock C and Rock D. Look at each rock's texture in its crystal size, shape, orientation, and contact points with other crystals. How do the textures differ?

DATA CENTER
CLASSZONE.COM
Discover more about thin sections of rocks.
Keycode: ES0611



CHAPTER 6 REVIEW

Summary of Key Ideas

6.1 Igneous, sedimentary, and metamorphic rocks are formed, broken down, and reformed in a recurring process called the rock cycle.

6.2 Igneous rocks form from magma deep in the crust or from lava at Earth's surface. Igneous rocks are grouped into families by mineral composition and texture. Igneous rock texture depends mainly on the rate at which magma cools. Felsic magmas form light-colored, silica-rich rocks. Mafic magmas form dark-colored, rocks rich in iron and magnesiums.

6.3 Sedimentary rocks often occur in layers formed when different sediments are deposited on top of each other. Sedimentary rocks are grouped by the type of sediment from which they form: clastic, chemical, or organic. Clastic sediments are often sorted by water action before pressure and mineral cements turn them into rock. Fossils, ripple marks, mud cracks, nodules, concretions, and geodes are sedimentary rock features.

6.4 Metamorphic rocks form when heat or pressure or both alter parent rocks. A metamorphic rock may be described and identified according to its parent rock, mineral composition, and texture.

Key Vocabulary

batholith (p. 126)
cementation (p. 128)
deform (p. 134)
felsic (p. 121)
fossil (p. 130)
igneous (p. 118)
mafic (p. 121)
magma (p. 118)
metamorphic (p. 118)
metamorphism (p. 133)
parent rock (p. 133)
pluton (p. 125)
rock (p. 118)
rock cycle (p. 119)
sediment (p. 118)
sedimentary (p. 118)
stratification (p. 130)

Vocabulary Review

Explain the difference between the terms in each pair.

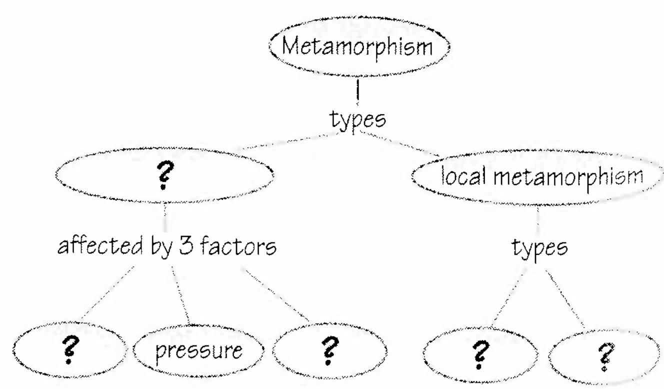
1. pluton, batholith
2. felsic magma, mafic magma
3. cementation, stratification

Write the term from the key vocabulary list that best completes the sentence.

4. Rocks classified as clastic, chemical, or organic are ___?___ rocks.
5. Evidence of an organism preserved in rock is called a ___?___.
6. If sedimentary or igneous rocks are subjected to heat and pressure, they become ___?___ rocks.
7. In the rock cycle, igneous rocks weather to form ___?___, which becomes sedimentary rocks.

Concept Review

8. Is it possible for rocks in the rock cycle to "skip" becoming sedimentary rock? Explain.
9. How does the cooling rate of magma affect the formation of igneous rock?
10. Why are fossils more likely to be formed in shale and sandstone than in conglomerate?
11. What characteristic might help you distinguish between a sandstone and a tuff?
12. **Graphic Organizer** Copy and complete the concept map below.



Critical Thinking

13. **Compare** Use the terms *felsic, mafic, plutonic,* and *volcanic* to compare each pair of igneous rocks: granite and gabbro, granite and rhyolite, gabbro and basalt, rhyolite and basalt.
14. **Apply** A newspaper reports that the fossil of an ancient plant has been found in a layer of gneiss. What can you conclude about the accuracy of the report, and why?
15. **Hypothesize** How might the locations of different types of sedimentary rocks help you map the boundary of an ancient inland sea?
16. **Infer** Prehistoric tools such as scrapers and knives were often made of chert and flint. What other type of rock has similar characteristics and might make similar tools?

Internet Extension

INVESTIGATIONS
CLASSZONE.COM

What Kind of Rock Is This? Use a key to help you determine the type of rock you have found.

Keycode: ES0610

Writing About the Earth System

SCIENCE NOTEBOOK Do research to find information about rocks in your region. Using the information, identify the types of rocks near you and explain how parts of the Earth system interacted to form the rocks. Describe what changes have helped shape the geologic features you see today.

Interpreting Graphs

The graph shows a classification system for sandstones made of varying amounts of three minerals: kaolin, feldspar, and quartz. Each corner shows a rock made up of 100% of the named mineral. The side opposite the same corner shows rocks with 0% of that mineral but 100% of the other two minerals. Determine the composition of a sandstone by finding the amount of each mineral in that sandstone. For example, to find the amount of feldspar in the sandstone associated with point *X*, start at the "0% Feldspar" side. Count the red lines from this side to point *X*. There are five lines. Each line is 10%; point *X* is on the 50% feldspar line. Likewise, point *X* is on the 30% kaolin line, and the 20% quartz line. It also falls within the graywacke area. Thus, point *X* shows a graywacke with 50% feldspar, 30% kaolin, and 20% quartz.

17. What is the composition and name of the sandstone at point *Y*?
18. What is the composition and name of the sandstone at point *Z*?
19. A sandstone contains 40% quartz, 30% feldspar, and 30% kaolin. What type of sandstone is it?
20. Suppose a particular sandstone contains 95% quartz and 5% other minerals. What type of sandstone is it?

Sandstone Classification