CHAPTER

3 Rocks

CONCEPTS in Action

Quick Lab
Observing Some of the Effects of Pressure on Mineral Grains

Exploration Lab
Rock Identification

Earth as a System
The Carbon Cycle

GEODe EARTH SCIENCE
Earth Materials
↳ Rock Cycle
Igneous Rocks
Sedimentary Rocks
Metamorphic Rocks

Discovery CHANNEL SCHOOL **Video Field Trip**

The Rock Cycle

Take a field trip through the rock cycle with Discovery Channel and learn about how rocks are constantly forming, changing, and eroding.

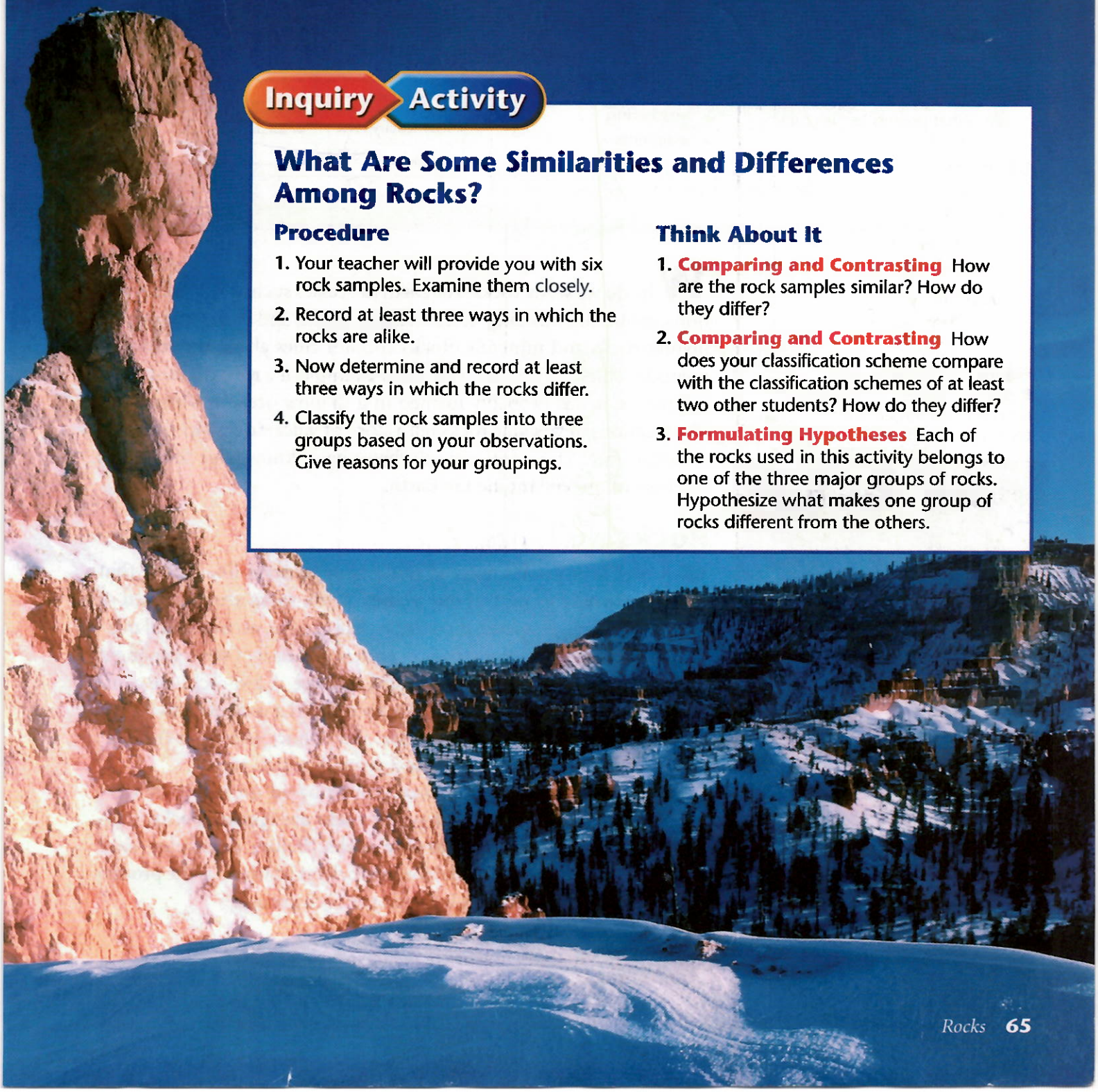
1. Name two natural forces that lead to rock erosion.
2. What can happen to rock that is buried beneath Earth's surface?

Go Online PHSchool.com

For: Chapter 3 Resources
Visit: PHSchool.com
Web Code: cjk-9999

Columns of rock called hoodoos dot ▶ Bryce Canyon National Park.

Chapter Preview



Inquiry Activity

What Are Some Similarities and Differences Among Rocks?

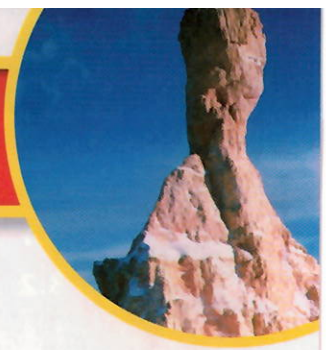
Procedure

1. Your teacher will provide you with six rock samples. Examine them closely.
2. Record at least three ways in which the rocks are alike.
3. Now determine and record at least three ways in which the rocks differ.
4. Classify the rock samples into three groups based on your observations. Give reasons for your groupings.

Think About It

1. **Comparing and Contrasting** How are the rock samples similar? How do they differ?
2. **Comparing and Contrasting** How does your classification scheme compare with the classification schemes of at least two other students? How do they differ?
3. **Formulating Hypotheses** Each of the rocks used in this activity belongs to one of the three major groups of rocks. Hypothesize what makes one group of rocks different from the others.

3.1 The Rock Cycle



Reading Focus

Key Concepts

- What is a rock?
- What are the three major types of rocks?
- How do igneous, sedimentary, and metamorphic rocks differ?
- What is the rock cycle?
- What powers Earth's rock cycle?

Vocabulary

- rock
- igneous rock
- sedimentary rock
- metamorphic rock
- rock cycle
- magma
- lava
- weathering
- sediments

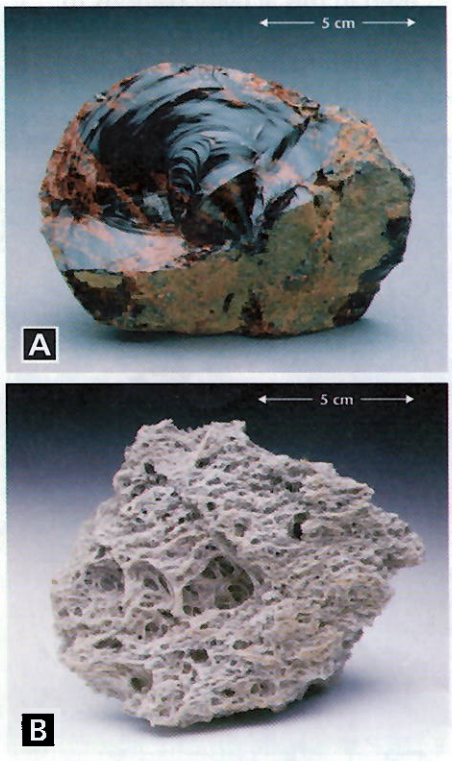
Reading Strategy

Building Vocabulary Copy and expand the table to include each vocabulary term. As you read, write down the definition for each term.

Term	Definition
rock	a. ?
igneous rock	b. ?
sedimentary rock	c. ?
sediments	d. ?

Why do we study rocks? All Earth processes such as volcanic eruptions, mountain building, weathering, erosion, and even earthquakes involve rocks and minerals. Rocks contain clues about the environments in which they were formed. For example, if a rock contains shell fragments, it was probably formed in a shallow ocean environment. The locations of volcanic rocks tell a story of volcanic activity on Earth through time. Thus, you can see that a basic knowledge of rocks is essential to understanding the Earth.

Figure 1 **A** Obsidian and **B** pumice are two examples of rocks that do not have a crystalline structure.



Rocks

A rock is any solid mass of mineral or mineral-like matter that occurs naturally as part of our planet. A few rocks are composed of just one mineral. However, most rocks, like granite, occur as solid mixtures of minerals. A characteristic of rock is that each of the component minerals retains their properties in the mixture. A few rocks are composed of nonmineral matter. Coal is considered a rock even though it consists of organic material. Obsidian and pumice, shown in Figure 1, are volcanic rocks that do not have a crystalline structure.

Rocks are classified into three groups based on how they were formed. **The three major types of rocks are igneous rocks, sedimentary rocks, and metamorphic rocks.** Before examining each group, you will look at a model for the rock cycle, which is the process that shows the relationships between the rock groups.

Reading Checkpoint *What are the three types of rocks?*

The Rock Cycle

Earth is a system. It consists of many interacting parts that form a complex whole. **Interactions among Earth's water, air, and land can cause rocks to change from one type to another. The continuous processes that cause rocks to change make up the rock cycle.** Most changes in the rock cycle take place over long periods of time.

Figure 2 shows some key events in the rock cycle. Refer to the figure throughout this section as you examine how rock might change over time. Look at Figures 2A and 2B. **Magma** is molten material that forms deep beneath Earth's surface. **When magma cools and hardens beneath the surface or as the result of a volcanic eruption, igneous rock forms.** Magma that reaches the surface is called **lava.**

Thank you Mrs. Miller

Rock Cycle

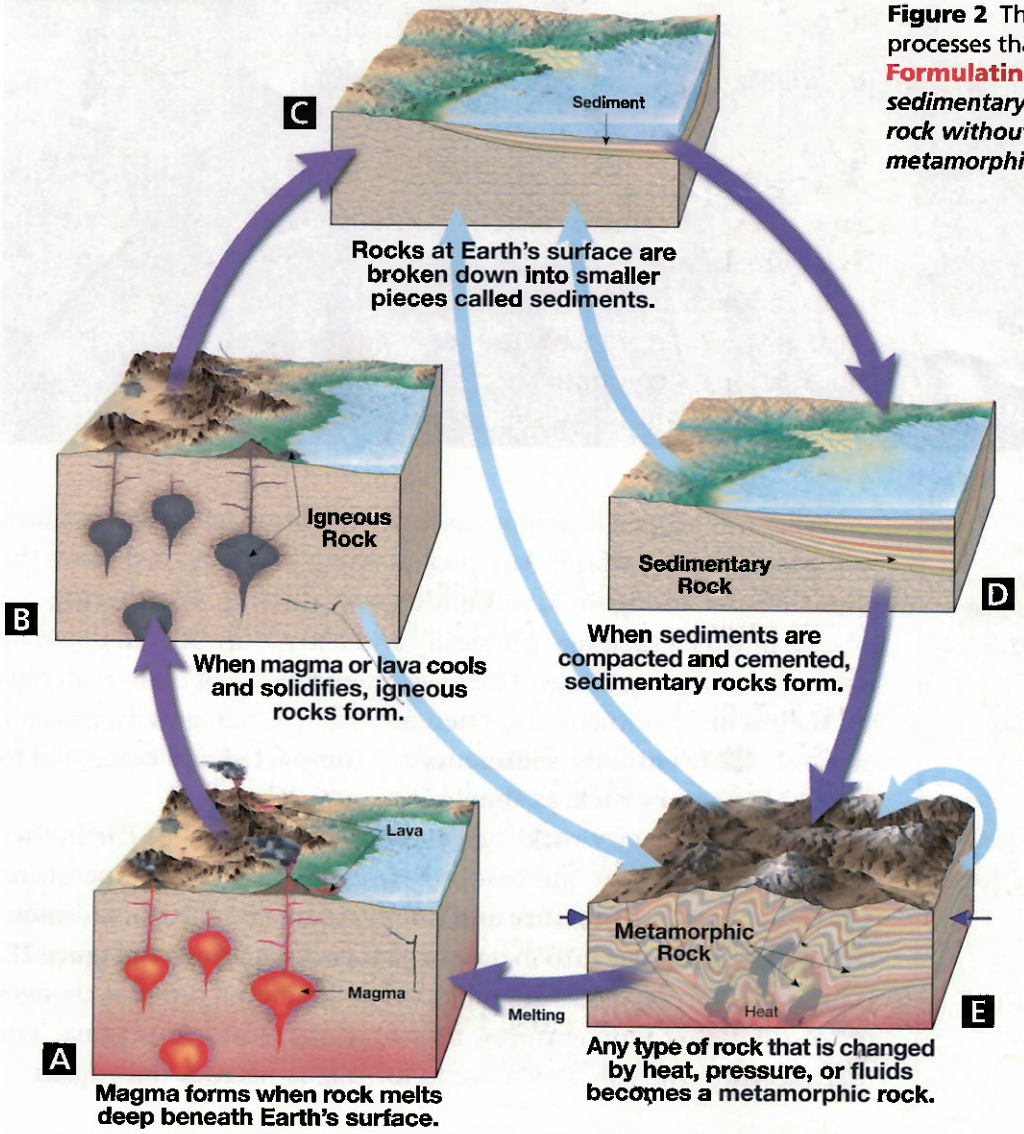


Figure 2 The rock cycle consists of many processes that change Earth's rocks. **Formulating Hypotheses** ***Can a sedimentary rock become an igneous rock without changing first to a metamorphic rock? Explain.***

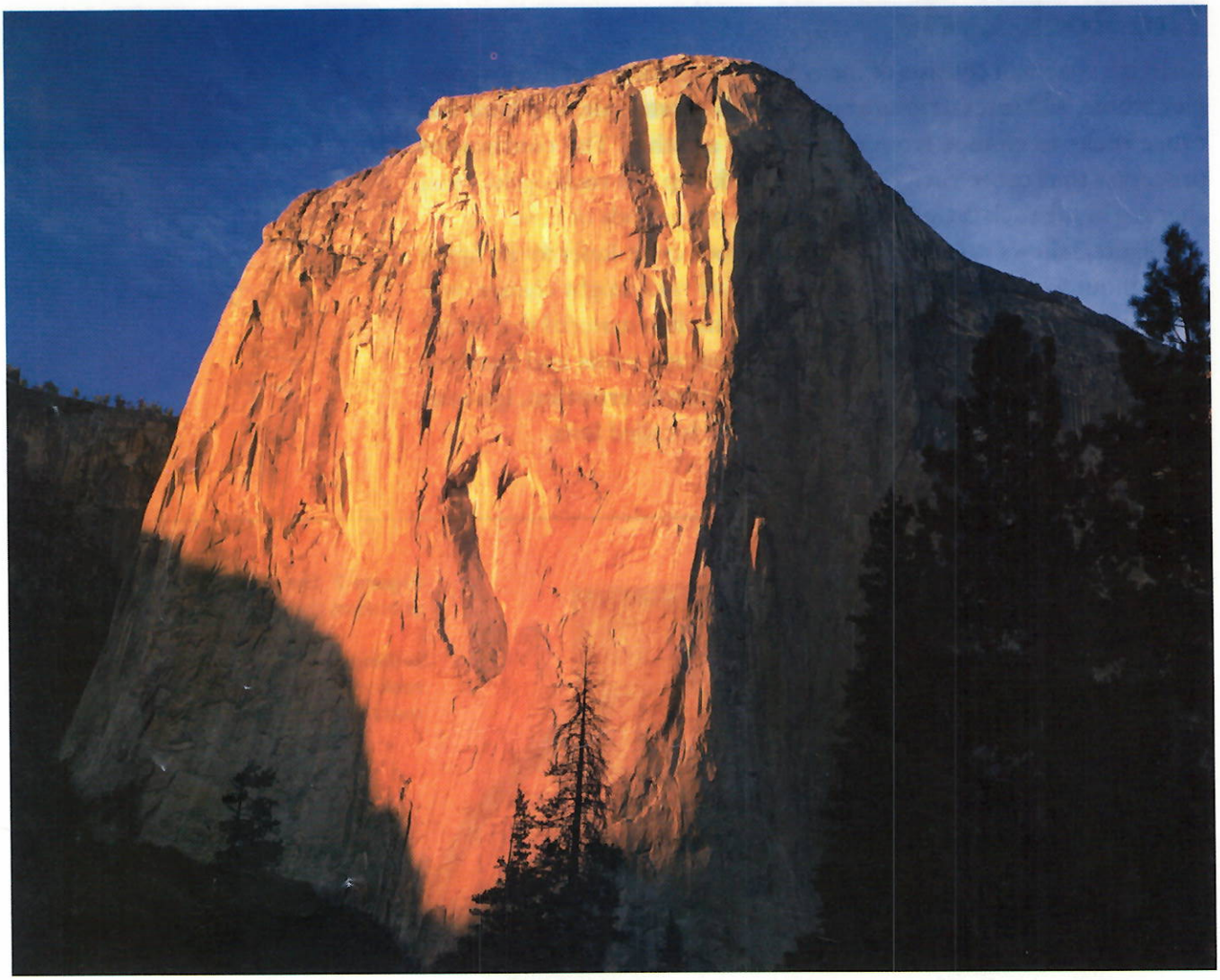


Figure 3 El Capitan in Yosemite National Park This granite was once buried deep beneath Earth's surface. Now that it is exposed, it will eventually weather and form sediments.

What will happen if an igneous rock that formed deep within Earth is exposed at the surface? Any rock at Earth's surface, including the granite shown in Figure 3, will undergo weathering. **Weathering** is a process in which rocks are physically and chemically broken down by water, air, and living things. These weathered pieces of earth materials are **sediments.** Sediments are often moved by water, gravity, glaciers, or wind. **Eventually, sediments are compacted and cemented to form sedimentary rock, as shown in Figure 2C and 2D.**

If the sedimentary rocks become buried deep within Earth, they will be subjected to increases in pressure and/or temperature. **Under extreme pressure and temperature conditions, sedimentary rock will change into metamorphic rock, as shown in Figure 2E.** If the metamorphic rocks are subjected to additional pressure changes or to still higher temperatures, they may melt to form magma. The magma will eventually crystallize to form igneous rock once again.

Alternate Paths

The purple arrows in Figure 2 show only one way in which an igneous rock might form and change. Other paths are just as likely to be taken as an igneous rock goes through the rock cycle. The blue arrows show a few of these alternate paths.

Suppose, for example, that an igneous rock remained deeply buried. Eventually, the rock could be subjected to strong forces and high temperatures such as those associated with mountain building. Then, the igneous rock could change into one or more kinds of metamorphic rock. If the temperatures and pressures were high enough, the igneous rock could melt and recrystallize to form new igneous rock.

Metamorphic and sedimentary rocks, as well as sediment, do not always remain buried. Often, overlying rocks are stripped away, exposing the rock that was once buried. When this happens, the rocks weather to form sediments that eventually become sedimentary rocks. However, if the sedimentary rocks become buried again, metamorphic rocks, like those used for the roof tiles in Figure 4, will form.

Where does the energy that drives Earth's rock cycle come from?

Processes driven by heat from Earth's interior are responsible for forming both igneous and metamorphic rocks. Weathering and the movement of weathered materials are external processes powered by energy from the sun. External processes produce sedimentary rocks.

Figure 4 The roof on this house is made of slate. Slate is a metamorphic rock that forms from the sedimentary rock shale. **Explaining** ***How can shale become slate?***

Section 3.1 Assessment

Reviewing Concepts

1. What is a rock?
2. What are the three major types of rocks?
3. How do igneous, sedimentary, and metamorphic rocks differ?
4. What is the rock cycle?
5. What powers Earth's rock cycle?

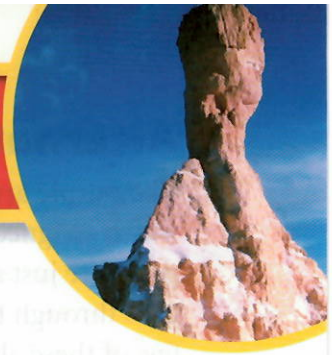
Critical Thinking

6. **Comparing and Contrasting** Compare and contrast igneous and metamorphic rocks.
7. **Applying Concepts** How might a sedimentary rock become an igneous rock?
8. **Applying Concepts** List in order the processes that could change one sedimentary rock into another sedimentary rock.

Writing in Science

Writing to Persuade Coral reefs are made of calcite that is secreted by the corals and algae that make up the reefs. Over time, this calcite accumulates to form limestone. Use what you know about minerals and rocks to write a paragraph explaining whether or not you think that this limestone is a rock.

3.2 Igneous Rocks



Reading Focus

Key Concepts

- How are intrusive and extrusive igneous rocks alike and different?
- How does the rate of cooling affect an igneous rock's texture?
- How are igneous rocks classified according to composition?

Vocabulary

- intrusive igneous rock
- extrusive igneous rock
- porphyritic texture
- granitic composition
- basaltic composition
- andesitic composition
- ultramafic

Reading Strategy

Outlining Copy the outline and complete it as you read. Include points about how each of these rocks form, some of the characteristics of each rock type, and some examples of each.

I. Igneous Rocks
  A. Intrusive Rocks
    1. ____?____
    2. ____?____
  B. Extrusive Rocks
    1. ____?____
    2. ____?____

Recall from the discussion of the rock cycle that igneous rocks form when magma or lava cools and hardens. When the red hot lava shown in Figure 5 cools, a dark-colored igneous rock called basalt will form. If this melted material had stayed deep beneath Earth's surface, a very different kind of igneous rock would have been produced as the material cooled. Different kinds of igneous rocks form when magma and lava cool and harden.

Figure 5 Basaltic Lava Lava from this Hawaiian volcano flows easily over Earth's surface. When this lava cools and hardens, the igneous rock called basalt will form.

Formation of Igneous Rocks

The word *igneous* comes from the Latin word *ignis*, which means "fire." Perhaps that is why people often associate igneous rock with fiery volcanic eruptions like the one shown in Figure 5. Igneous rock also forms deep beneath Earth's surface.

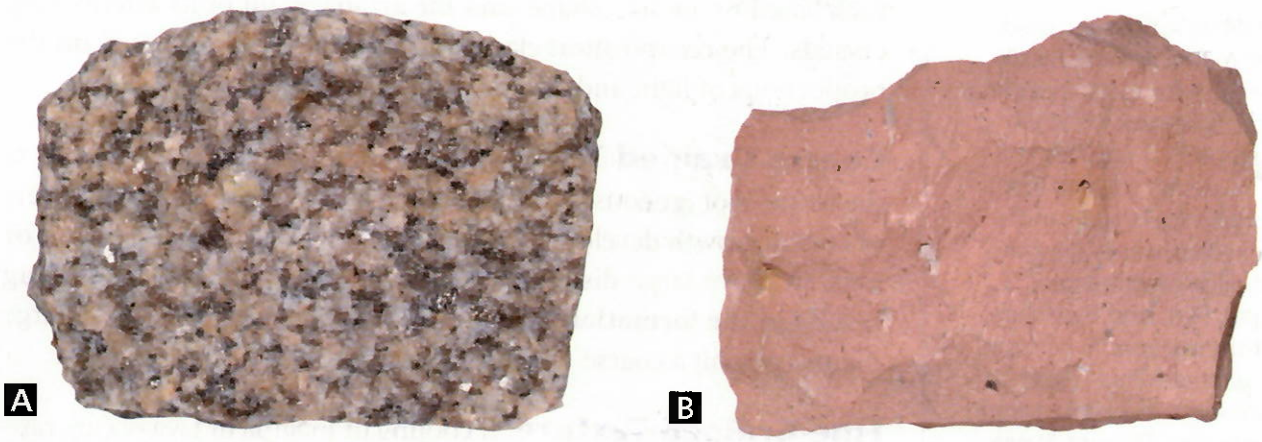


Figure 6 **A** Granite is an intrusive igneous rock that forms when magma cools slowly beneath Earth's surface. **B** Rhyolite is an extrusive igneous rock that forms when lava cools quickly at Earth's surface.

Intrusive Igneous Rocks

Rocks that form when magma hardens beneath Earth's surface are called intrusive igneous rocks. That is because they *intrude* into the existing rocks. We would never see these deep rocks were it not for erosion stripping away the overlying rock.

Magma consists mainly of the elements silicon and oxygen, plus aluminum, iron, calcium, sodium, potassium, and magnesium. Magma also contains some gases, including water vapor. These gases are kept within the magma by the pressure of the surrounding rocks. Because magma is less dense than the surrounding rocks, it slowly works its way toward the surface. As magma rises, it cools, allowing elements to combine and form minerals. Gradually, the minerals grow in size, forming a solid mass of interlocking crystals. Granite, shown in Figure 6A, is a common intrusive igneous rock.

Extrusive Igneous Rocks

You know that when magma reaches Earth's surface, it is called lava. Lava is similar to magma, except that in lava, most of the gases have escaped. **When lava hardens, the rocks that form are called extrusive igneous rocks.** That is because they are *extruded* onto the surface. The rhyolite shown in Figure 6B is an extrusive igneous rock.

Q *How are magma and lava the same, and how are they different?*

A Magma and lava are both terms used to describe melted rock. The composition of magma and lava can be the same. However, magma is melted material beneath Earth's surface. Lava is melted material at Earth's surface.

Q *Native Americans used obsidian for making arrowheads and cutting tools. Is this the only material they used?*

A No. Native Americans used whatever materials were locally available to make tools, including any hard dense rock material that could be shaped. This includes materials such as the metamorphic rocks slate and quartzite, sedimentary deposits made of silica called jasper, chert, opal, flint, and even jade. Some of these deposits occur in only a few areas. That helps anthropologists reconstruct trade routes between different Native Americans groups.

Figure 7 This sample of andesite displays igneous rock with a porphyritic texture.
Describing ***Describe how this rock probably formed.***

Classification of Igneous Rocks

A quick glance at the two rocks in Figure 6 tells you that they are different. The granite contains large mineral grains. Only a few of the mineral grains in the sample of rhyolite can be seen with the unaided eye. Texture **and composition are two characteristics used to classify igneous rocks.** Texture describes the appearance of an igneous rock based on its size, shape, and the arrangement of its interlocking crystals. The composition classes of igneous rocks are based on the proportions of light and dark minerals in the rock.

Coarse-Grained Texture The rate of cooling strongly affects the textures of igneous rocks. If magma cools very slowly, few centers of crystal growth develop. Slow cooling also allows charged atoms, or ions, to move large distances within the magma. **Slow cooling results in the formation of large crystals.** Igneous rocks with large crystals exhibit a coarse-grained texture.

Fine-Grained Texture If cooling of magma or lava occurs rapidly, the ions in the melted material lose their motion and quickly combine. This results in a large number of tiny crystals that all compete for the available ions. **Rapid cooling of magma or lava results in rocks with small, interconnected mineral grains.** Igneous rocks with small grains are said to have a fine-grained texture.

Glassy Texture When lava spews onto Earth's surface, there may not be enough time for the ions in the lava to arrange themselves into a network of crystals. So the solids produced this way are made of randomly distributed ions. Such rocks have a glassy texture. The obsidian and pumice shown in Figure 1 on page 66 are igneous rocks with glassy textures.

Porphyritic Texture A large body of magma located deep within Earth may take tens of thousands of years to harden. Minerals that crystallize from the magma do not form at the same rate or at the same time. It is possible for some crystals to become quite large before others even start to form. The resulting rock can have large crystals, called phenocrysts, surrounded by fine-grained minerals. Rocks with very different-size minerals experience different rates of cooling. These rocks have a **porphyritic texture.** The igneous rock shown in Figure 7 has a porphyritic texture.

Reading Checkpoint ***How does the rate of cooling of magma or lava affect the texture of igneous rocks?***

Granitic Composition One group of igneous rocks includes those that are made almost entirely of the light-colored silicate minerals quartz and feldspar. Igneous rocks in which these are the main minerals are said to have a **granitic composition.** In addition to quartz and feldspar, most granitic rocks contain about 10 percent dark silicate minerals. These dark minerals are often biotite mica and amphibole. Granitic rocks contain about 70 percent silica and are the major rocks of the continental crust. Rhyolite is an extrusive granitic rock. Compare granite and rhyolite again in Figure 6 on page 71.

Go Online
NSTA SCILINKS™
For: Links on igneous rocks
Visit: www.SciLinks.org
Web Code: cjn-1032

Basaltic Composition Rocks that contain many dark silicate minerals and plagioclase feldspar have a **basaltic composition.** Basaltic rocks are rich in the elements magnesium and iron. Because of their iron content, basaltic rocks are typically darker and denser than granitic rocks. The most common basaltic rock is basalt, shown in Figure 8. Gabbro is an intrusive igneous rock with a basaltic composition.

Figure 8 Basalt is an igneous rock made mostly of dark-colored silicate minerals.
Describing ***Describe the texture of this igneous rock.***

Other Compositional Groups Rocks with a composition between granitic and basaltic rocks have an **andesitic composition.** This group of igneous rocks is named after the common volcanic rock andesite. Andesitic rocks contain at least 25 percent dark silicate minerals—mainly amphibole, pyroxene, and biotite mica. The other dominant mineral in andesitic rocks is plagioclase feldspar.

Another important igneous rock is peridotite. This rock contains mostly the minerals olivine and pyroxene. Because peridotite is composed almost entirely of dark silicate minerals, its chemical composition is referred to as **ultramafic.** Although ultramafic rocks are rare at Earth's surface, much of the upper mantle is thought to be made of peridotite.

Reading Checkpoint ***Describe the main differences between granitic and basaltic rocks.***

To summarize, igneous rocks form when magma or lava cools and hardens. Intrusive rocks form when magma cools and hardens deep within Earth. Extrusive rocks form when lava cools and hardens on Earth's surface. Igneous rocks can be classified according to texture and composition. A general classification scheme based on texture and mineral composition is shown in Table 1.

Table 1 Classification of Major Igneous Rocks

			Granitic	Andesitic	Basaltic	Ultramafic
Chemical Composition						
Dominant Minerals			Quartz Potassium feldspar Sodium-rich plagioclase feldspar	Amphibole Sodium- and calcium-rich plagioclase feldspar	Pyroxene Calcium-rich plagioclase feldspar	Olivine Pyroxene
TEXTURE	Coarse-grained		**Granite**	**Diorite**	**Gabbro**	**Peridotite**
	Fine-grained		**Rhyolite**	**Andesite**	**Basalt**	**Komatiite** (rare)
	Porphyritic		"Porphyritic" precedes any of the above names whenever there are appreciable phenocrysts.			Uncommon
	Glassy		**Obsidian** (compact glass) **Pumice** (frothy glass)			
Rock Color (based on % of dark minerals)			0% to 25%	25% to 45%	45% to 85%	85% to 100%

Section 3.2 Assessment

Reviewing Concepts

1. Compare and contrast the formation of intrusive and extrusive igneous rocks.
2. How do coarse-grained igneous rocks form?
3. How are igneous rocks classified according to composition?
4. How do fine-grained igneous rocks form?
5. How do igneous rocks with glassy textures form?

Critical Thinking

6. **Contrasting** Contrast basalt and granite in terms of how each forms, the texture of each rock, the color of each rock, and each rock's composition.
7. **Formulating Hypotheses** The extrusive igneous rock pumice contains many small holes. Hypothesize how these holes might form.

Writing in Science

Explanatory Paragraph Write a paragraph to explain how one of the igneous rocks pictured in this chapter may have formed.

Formation of Sedimentary Rocks

The word *sedimentary* comes from the Latin word *sedimentum*, which means "settling." Sedimentary rocks form when solids settle out of a fluid such as water or air. The rocks shown in Figure 10 formed when sediments were dropped by moving water. The sediments eventually became cemented to form rocks. Several major processes contribute to the formation of sedimentary rocks.

Weathering, Erosion, and Deposition Recall that weathering is any process that breaks rocks into sediments. Weathering is often the first step in the formation of sedimentary rocks. Chemical weathering takes place when the minerals in rocks change into new substances. Weathering also takes place when physical forces break rocks into smaller pieces. Living things, too, can cause chemical and physical weathering.

Weathered sediments don't usually remain in place. Instead, water, wind, ice, or gravity carries them away. **Erosion involves weathering and the removal of rock. When an agent of erosion—water, wind, ice, or gravity—loses energy, it drops the sediments. This process is called deposition.** Sediments are deposited according to size. The largest sediments, such as the rounded pebbles in the conglomerate in Figure 10A, are deposited first. Smaller sediments, like the pieces of sand that make up the sandstone in Figure 10B, are dropped later. Some sediments are so small that they are carried great distances before being deposited.

A

B

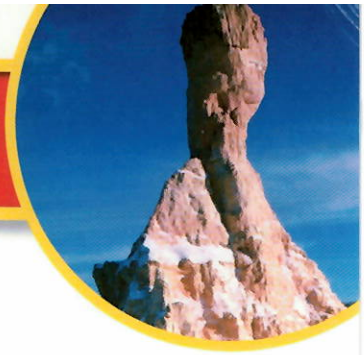
Figure 10 Although these two rocks appear quite different, both formed when sediments were dropped by moving water. **A** Conglomerate is made of rounded pebbles cemented together. **B** Sandstone is made of sand grains cemented together.

Compaction and Cementation After sediments are deposited, they often become lithified, or turned to rock. **Compaction** and **cementation** change sediments into sedimentary rock. **Compaction is a process that squeezes, or compacts, sediments.** Compaction is caused by the weight of sediments. During compaction, much of the water in the sediments is driven out.

Cementation takes place when dissolved minerals are deposited in the tiny spaces among the sediments. Much of the cement in the conglomerate shown in Figure 10A can be seen with the unaided eye. The cement holding the sand grains together in the sandstone in Figure 10B, however, is microscopic.

Reading Checkpoint ***Briefly describe the five major processes involved in the formation of sedimentary rocks.***

3.3 Sedimentary Rocks



Reading Focus

Key Concepts

- Describe the major processes involved in the formation of sedimentary rocks.
- What are clastic sedimentary rocks?
- What are chemical sedimentary rocks?
- What features are unique to some sedimentary rocks?

Vocabulary

- erosion
- deposition
- compaction
- cementation
- clastic sedimentary rock
- chemical sedimentary rock

Reading Strategy

Outlining Copy this outline beneath the outline you made for Section 3.2. Complete this outline as you read. Include points about how each of these rocks form, some of the characteristics of each rock type, and some examples of each.

II. Sedimentary Rocks
  A. Clastic Rocks
    1. ___?___
    2. ___?___
  B. Chemical Rocks
    1. ___?___
    2. ___?___

All sedimentary rocks begin to form when existing rocks are broken down into sediments. Sediments, which consist mainly of weathered rock debris, are often transported to other places. When sediments are dropped, they eventually become compacted and cemented to form sedimentary rocks. The structures shown in Figure 9 are made of the sedimentary rock called sandstone. It is only one of many types of sedimentary rocks.

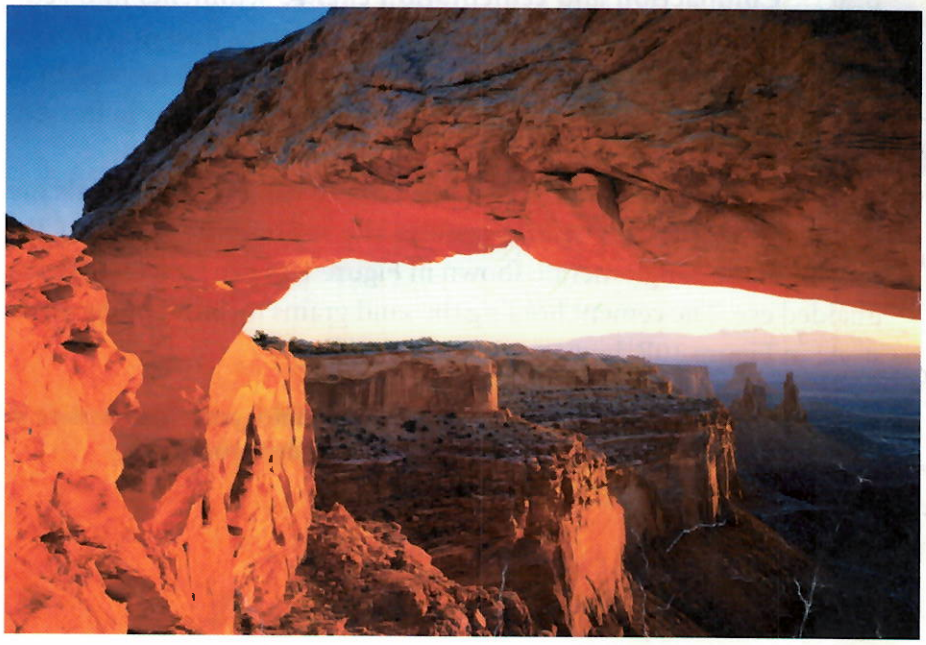


Figure 9 Sedimentary Rocks in Canyonlands National Park, Utah The rocks shown here formed when sand and other sediments were deposited and cemented. Weathering processes created this arch.

Figure 12 This biochemical rock, called coquina, is a type of limestone that is made of hundreds of shell fragments.

About 90 percent of limestones are formed from biochemical sediments. Such sediments are the shells and skeletal remains of organisms that settle to the ocean floor. The coquina in Figure 12 is one obvious example. You can actually see the shells cemented together. Another biochemical rock is chalk, the material used to write on a chalkboard.

Features of Some Sedimentary Rocks

Sedimentary rocks, like other types of rocks, are used to unravel what may have happened in Earth's long history. **The many unique features of sedimentary rocks are clues to how, when, and where the rocks formed.** Each layer of a sedimentary rock, for example, records a period of sediment deposition. In undisturbed rocks, the oldest layers are found at the bottom. The youngest layers are found at the top of the rocks. Ripple marks like the ones shown in Figure 13A may indicate that the rock formed along a beach or stream bed. The mud cracks in Figure 13B formed when wet mud or clay dried and shrank, leaving a rock record of a dry environment.

Fossils, which are the traces or remains of ancient life, are unique to some sedimentary rocks. Fossils can be used to help answer many questions about the rocks that contain them. For example, did the rock form on land or in the ocean? Was the climate hot or cold, rainy or dry? Did the rock form hundreds, thousands, millions, or billions of years ago? Fossils also play a key role in matching up rocks from different places that are the same age.

To summarize, sedimentary rocks are rocks that form as the result of four major processes. *Weathering* produces particles called sediments. Wind, water, ice, and gravity *erode* and *deposit* these sediments. Over time, the sediments are *compacted and cemented* to form rocks. Sedimentary rocks can be classified according to how they form. A general classification scheme based on a rock's formation, texture, and composition is shown in Table 2.

Figure 13 **A** Ripple marks and **B** mud cracks are features of sedimentary rocks that can be used to learn about the environments in which the rocks formed.

Classification of Sedimentary Rocks

Just like igneous rocks, sedimentary rocks can be classified into two main groups according to the way they form. The first group includes rocks that are made of weathered bits of rocks and minerals. These rocks are called **clastic sedimentary rocks.** The second group forms when dissolved minerals precipitate from water solutions. These rocks are called **chemical sedimentary rocks.**

Figure 11 **A** Shale and **B** breccia are common clastic sedimentary rocks. This sample of shale contains plant fossils.
Formulating Hypotheses ***How do you think this breccia might have formed?***

Clastic Sedimentary Rocks

Many different minerals are found in clastic rocks. The most common are the clay minerals and quartz. This is because clay minerals, like those that make up much of the shale in Figure 11A, are the most abundant products of chemical weathering. Quartz, which is a major mineral in the breccia shown in Figure 11B, is a common sedimentary mineral for a different reason. It is very durable and resistant to chemical weathering.

Clastic sedimentary rocks can be grouped according to the size of the sediments in the rocks. When rounded, gravel-size or larger particles make up most of the rock, the rock is called conglomerate. If the particles are angular, the rock is called breccia. Sandstone is the name given to rocks when most of the sediments are sand-size grains. Shale, the most common sedimentary rock, is made of very fine-grained sediment. Siltstone is another fine-grained rock.

Reading Checkpoint ***Describe the major types of clastic sedimentary rocks.***

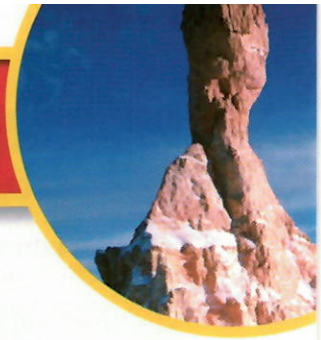
Chemical and Biochemical Sedimentary Rocks

Chemical sedimentary rocks form when dissolved substances precipitate, or separate, from water solution. This precipitation generally occurs when the water evaporates or boils off leaving a solid product. Examples of this type of chemical rock are some limestones, rock salt, chert, flint, and rock gypsum.

Go Online NSTA SCILINKS

For: Links on sedimentary rocks
Visit: www.SciLinks.org
Web Code: cjn-1034

3.4 Metamorphic Rocks



Reading Focus

Key Concepts

- Where does most metamorphism take place?
- How is contact metamorphism different from regional metamorphism?
- What are three agents of metamorphism, and what kinds of changes does each cause?
- What are foliated metamorphic rocks, and how do they form?
- How are metamorphic rocks classified?

Vocabulary

- metamorphism
- contact metamorphism
- regional metamorphism
- hydrothermal solution
- foliated metamorphic rock
- nonfoliated metamorphic rock

Reading Strategy

Outlining Copy this outline beneath the outline you made for Section 3.3. Complete it as you read. Include points about how each of these rocks form, some of the characteristics of each rock type, and some examples of each.

III. Metamorphic Rocks
  A. Foliated Rocks
    1. ___?___
    2. ___?___
  B. Nonfoliated Rocks
    1. ___?___
    2. ___?___

Figure 14 Deformed Rock Intense pressures metamorphosed these rocks by causing them to fold as well as change composition.

Recall that metamorphic rocks form when existing rocks are changed by heat and pressure. **Metamorphism** is a very appropriate name for this process because it means *to change form*. Rocks produced during metamorphism often look much different from the original rocks, or parent rocks. The folds in the rocks shown in Figure 14 formed when the parent rocks were subjected to intense forces. These highly folded metamorphic rocks may also develop a different composition than the parent rocks had.

Formation of Metamorphic Rocks

Most metamorphic changes occur at elevated temperatures and pressures. These conditions are found a few kilometers below Earth's surface and extend into the upper mantle. Most metamorphism occurs in one of two settings—contact metamorphism or regional metamorphism.

Table 2 Classification of Major Sedimentary Rocks

Clastic Sedimentary Rocks

Texture (grain size)		Sediment Name	Rock Name
Coarse (over 2 mm)		Gravel (rounded fragments)	**Conglomerate**
		Gravel (angular fragments)	**Breccia**
Medium (1/16 to 2 mm)		Sand	**Sandstone**
Fine (1/16 to 1/256 mm)		Mud	**Siltstone**
Very fine (less than 1/256 mm)		Mud	**Shale**

Chemical Sedimentary Rocks

Composition	Texture (grain size)	Rock Name	
Calcite, $CaCO_3$	Fine to coarse crystalline	**Crystalline Limestone**	
		Travertine	
	Visible shells and shell fragments loosely cemented	**Coquina**	**Biochemical Limestone**
	Various size shells and shell fragments cemented with calcite cement	**Fossiliferous Limestone**	
	Microscopic shells and clay	**Chalk**	
Quartz, SiO_2	Very fine crystalline	**Chert (light colored) Flint (dark colored)**	
Gypsum $CaSO_4 \cdot 2H_2O$	Fine to coarse crystalline	**Rock Gypsum**	
Halite, NaCl	Fine to coarse crystalline	**Rock Salt**	
Altered plant fragments	Fine-grained organic matter	**Bituminous Coal**	

Section 3.3 Assessment

Reviewing Concepts

1. Contrast weathering, erosion, and deposition.
2. Name four clastic sedimentary rocks and explain how these rocks form.
3. Name four chemical sedimentary rocks and explain how these rocks form.
4. Explain how three different features of sedimentary rocks can be used to determine how, where, or when the rocks formed.
5. What is compaction?
6. Where do the cements that hold sediments together come from?

Critical Thinking

7. **Applying Concepts** Briefly describe how the rock shown in Figure 12 may have formed.
8. **Predicting** Which type of sediments do you think would undergo more compaction—grains of sand or grains of clay? Explain your choice.
9. **Formulating Conclusions** Suppose you found a sedimentary rock in which ripple marks were pointing toward the ground. What could you conclude about the rock?

Connecting Concepts

Sedimentary Rocks Choose one of the sedimentary rocks pictured in this section. Find out how the rock is useful to people.

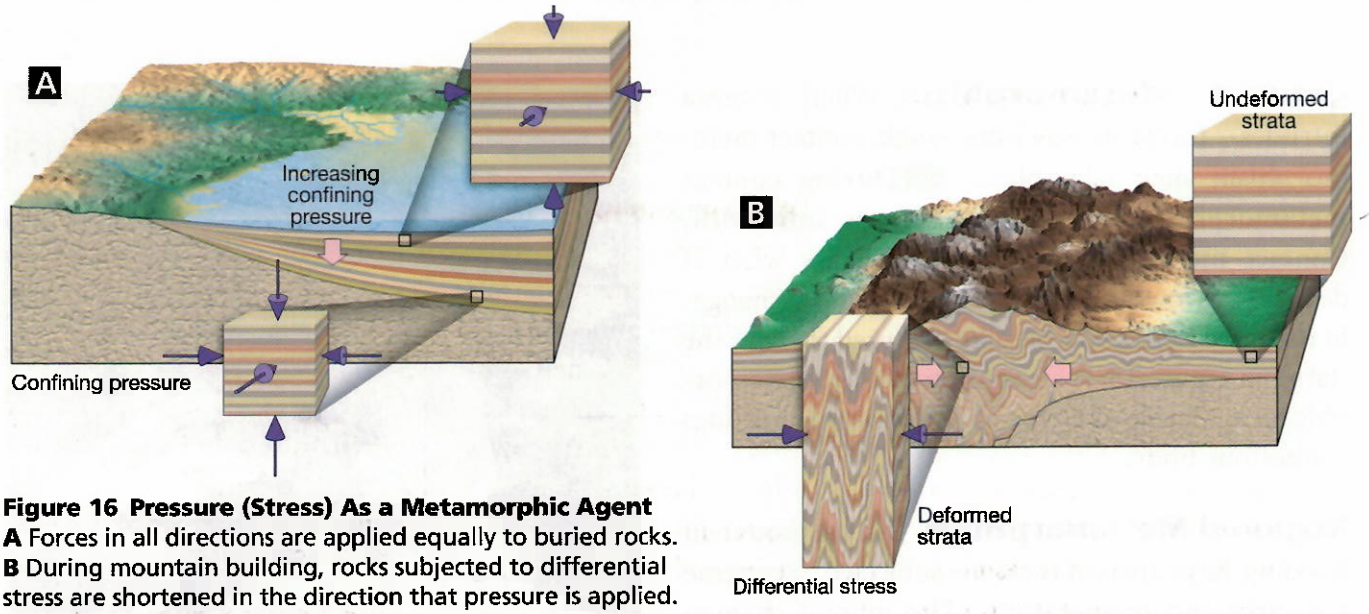


Figure 16 Pressure (Stress) As a Metamorphic Agent
A Forces in all directions are applied equally to buried rocks. **B** During mountain building, rocks subjected to differential stress are shortened in the direction that pressure is applied.

Figure 17 Imagine the tremendous amounts of pressure that caused these rocks to fold.

Pressure (Stress) Pressure, like temperature, also increases with depth. Like the water pressure you might have experienced at the bottom of a swimming pool, pressure on rocks within Earth is applied in all directions. See Figure 16. Pressure on rocks causes the spaces between mineral grains to close. The result is a more compact rock with a greater density. This pressure also may cause minerals to recrystallize into new minerals.

Increases in temperature and pressure cause rocks to flow rather than fracture. Under these conditions, mineral grains tend to flatten and elongate.

Quick Lab

Observing Some of the Effects of Pressure on Mineral Grains

Materials

soft modeling clay; 2 pieces of waxed paper (each 20 cm × 20 cm); 20–30 small, round, elongated plastic beads; small plastic knife

Procedure

1. Use the clay to form a ball about the size of a golf ball. Randomly place all of the beads into this model rock.
2. Make a sketch of the rock. Label the sketch *Before*.
3. Sandwich the model rock between the two pieces of waxed paper. Use your weight to apply pressure to the model rock.
4. Remove the waxed paper and observe your "metamorphosed" rock.
5. Draw a top view of your rock and label it *After*. Include arrows to show the directions from which you applied pressure.
6. Make a cut through your model rock. Sketch this view of the rock.

Analyze and Conclude

1. **Comparing and Contrasting** How did the *Before* sketch compare with the *After* sketch of your model rock?
2. **Drawing Conclusions** How does pressure affect the mineral grains in a rock?
3. **Inferring** Was pressure the only agent of change that affected your rock? Explain.

Contact Metamorphism When magma intrudes—forces its way into—rock, contact metamorphism may take place. **During contact metamorphism, hot magma moves into rock.** Contact metamorphism often produces what is described as low-grade metamorphism. Such changes in rocks are minor. Marble, like that used to make the statue in Figure 15, is a common contact metamorphic rock. Marble often forms when magma intrudes a limestone body.

Regional Metamorphism During mountain building, large areas of rocks are subjected to extreme pressures and temperatures. The intense changes produced during this process are described as high-grade metamorphism. **Regional metamorphism results in large-scale deformation and high-grade metamorphism.** The rocks shown in Figure 14 on page 80 were changed as the result of regional metamorphism.

Figure 15 Statue Carved from Marble Marble is a common metamorphic rock that forms as the result of contact metamorphism of limestone.

Agents of Metamorphism

The agents of metamorphism are heat, pressure, and hydrothermal solutions. During metamorphism, rocks are usually subjected to all three of these agents at the same time. However, the effect of each agent varies greatly from one situation to another.

Heat The most important agent of metamorphism is heat. Heat provides the energy needed to drive chemical reactions. Some of these reactions cause existing minerals to recrystallize. Other reactions cause new minerals to form. The heat for metamorphism comes mainly from two sources—magma and the change in temperature with depth. Magma essentially "bakes" any rocks that are in contact with it. Heat also comes from the gradual increase in temperature with depth. In the upper crust, this increase averages between 20°C and 30°C per kilometer.

When buried to a depth of about 8 kilometers, clay minerals are exposed to temperatures of 150°C to 200°C. These minerals become unstable and recrystallize to form new minerals that are stable at these temperatures, such as chlorite and muscovite. In contrast, silicate minerals are stable at these temperatures. Therefore, it takes higher temperatures to change silicate minerals.

Reading Checkpoint *Compare and contrast contact and regional metamorphism.*

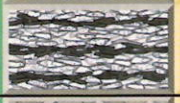
Q & A

Q *How hot is it deep in the crust?*

A The deeper a person goes beneath Earth's surface, the hotter it gets. The deepest mine in the world is the Western Deep Levels mine in South Africa, which is about 4 kilometers deep. Here, the temperature of the surrounding rock is so hot that it can scorch human skin. In fact, miners in this mine often work in groups of two. One miner mines the rock, and the other operates a large fan that keeps the worker cool.

To summarize, metamorphic rocks form when existing rocks are changed by heat, pressure, or hydrothermal solution. Contact metamorphism is often caused when hot magma intrudes a body of rock. Changes during this type of metamorphism are minor. Regional metamorphism is associated with mountain building. Such metamorphic changes can be extreme. Metamorphic rocks can be classified by texture as foliated or nonfoliated, as shown in Table 3.

Table 3 Classification of Major Metamorphic Rocks

Rock Name		Texture		Grain Size	Comments	Parent Rock
Slate	Increasing Metamorphism	Foliated		Very fine	Smooth dull surfaces	Shale, mudstone, or siltstone
Phyllite				Fine	Breaks along wavy surfaces, glossy sheen	Slate
Schist				Medium to Coarse	Micaceous minerals dominate	Phyllite
Gneiss				Medium to Coarse	Banding of minerals	Schist, granite, or volcanic rocks
Marble		Nonfoliated		Medium to coarse	Interlocking calcite or dolomite grains	Limestone, dolostone
Quartzite				Medium to coarse	Fused quartz grains, massive, very hard	Quartz sandstone
Anthracite				Fine	Shiny black organic rock that fractures	Bituminous coal

Section 3.4 Assessment

Reviewing Concepts

1. Where does most metamorphism take place?
2. Compare and contrast contact metamorphism and regional metamorphism.
3. Name the agents of metamorphism and explain how each changes a rock.
4. What are foliated rocks, and how do they form?
5. How are metamorphic rocks classified?

Critical Thinking

6. **Applying Concepts** What is the major difference between igneous and metamorphic rocks?
7. **Predicting** What type of metamorphism—contact or regional—would result in a schist? Explain your choice.
8. **Formulating Conclusions** Why can the composition of gneiss vary but overall texture cannot?

Writing in Science

Explanatory Paragraph Write a short paragraph that explains the major differences and similarities among the three major rock groups.

During mountain building, horizontal forces metamorphose large segments of Earth's crust. This often produces intricately folded rocks like those shown in Figure 17.

Reactions in Solution Water solutions containing other substances that readily change to gases at the surface play an important role in some types of metamorphism. Solutions that surround mineral grains aid in recrystallization by making it easier for ions to move. When solutions increase in temperature reactions among substances can occur at a faster rate. When these hot, water-based solutions escape from a mass of magma, they are called **hydrothermal solutions.** These hot fluids also promote recrystallization by dissolving original minerals and then depositing new ones. As a result of contact with hydrothermal solutions, a change in a rock's overall composition may occur.

Classification of Metamorphic Rocks

Like igneous rocks, metamorphic rocks can be classified by texture and composition. **The texture of metamorphic rocks can be foliated or nonfoliated.**

Foliated Metamorphic Rocks When rocks undergo contact metamorphism, they become more compact and thus more dense. A common example is the metamorphic rock slate. Slate forms when shale is subjected to temperatures and pressures only slightly greater than those at which the shale formed. The pressure on the shale causes the microscopic clay minerals to become more compact. The increase in pressure also causes the clay minerals to align in a similar direction.

Under more extreme conditions, certain minerals will recrystallize. Some minerals recrystallize with a preferred orientation, which is at right angles to the direction of the force. The resulting alignment usually gives the rock a layered or banded appearance. This rock is called a **foliated metamorphic rock.** Gneiss, the metamorphic rock shown in Figure 18, is a foliated rock. Another foliated metamorphic rock is schist.

Nonfoliated Metamorphic Rocks A metamorphic rock that does not have a banded texture is called a **nonfoliated metamorphic rock.** Most nonfoliated rocks contain only one mineral. Marble, for example, is a nonfoliated rock made of calcite. When its parent rock, limestone, is metamorphosed, the calcite crystals combine to form the larger interlocking crystals seen in marble. A sample of marble is shown in Figure 19. Quartzite and anthracite are other nonfoliated metamorphic rocks.

Reading Checkpoint *Contrast foliated and nonfoliated metamorphic rocks.*

Figure 18 Gneiss is a foliated metamorphic rock.
Inferring ***In which directions was pressure exerted on this rock?***

Go Online NSTA SCILINKS

For: Links on metamorphic rocks
Visit: www.SciLinks.org
Web Code: cjn-1033

Figure 19 Marble is a nonfoliated metamorphic rock.

Exploration Lab

Rock Identification

Most rocks can be easily identified by texture and composition. In this lab, you will use what you have learned about rocks as well as the information on minerals from Chapter 2 to identify some common rocks.

Problem How can you use composition and texture to identify common rocks?

Materials

- rock samples
- hand lens
- pocket knife
- dilute hydrochloric acid
- colored pencils
- Chapter 2, Table 4 and Chapter 3, Tables 1, 2, 3

Skills Observing, Comparing and Contrasting, Measuring

Procedure

1. On a separate sheet of paper, make a copy of the data table shown below. Add any other columns that you think might be useful.
2. Examine each rock specimen with and without the hand lens. Determine and record the overall color of each rock.
3. Try to identify all of the minerals in each rock, using the information in Chapter 2 Table 4. Record your observations.

Data Table

Rock	Overall Color	Composition	Texture	Sketch	Rock Type	Rock Name
1.						
2.						
3.						
4.						
5.						

earth as a SYSTEM

The Carbon Cycle

To illustrate the movement of material and energy in the Earth system, we can take a brief look at the carbon cycle, shown in Figure 20. Pure carbon is rare in nature. It is found mainly as two minerals—diamond and graphite. Most carbon is bonded to other elements to form compounds. Carbon dioxide (CO_2), for example, is an important gas in Earth's atmosphere. Calcite ($CaCO_3$) is a mineral found in many sedimentary and metamorphic rocks. Hydrocarbons, such as coal, oil, and natural gas, are compounds made of carbon and hydrogen. Carbon also combines with hydrogen and oxygen to form the basic compounds that make up living things. This important element moves continually among Earth's major spheres by way of the carbon cycle.

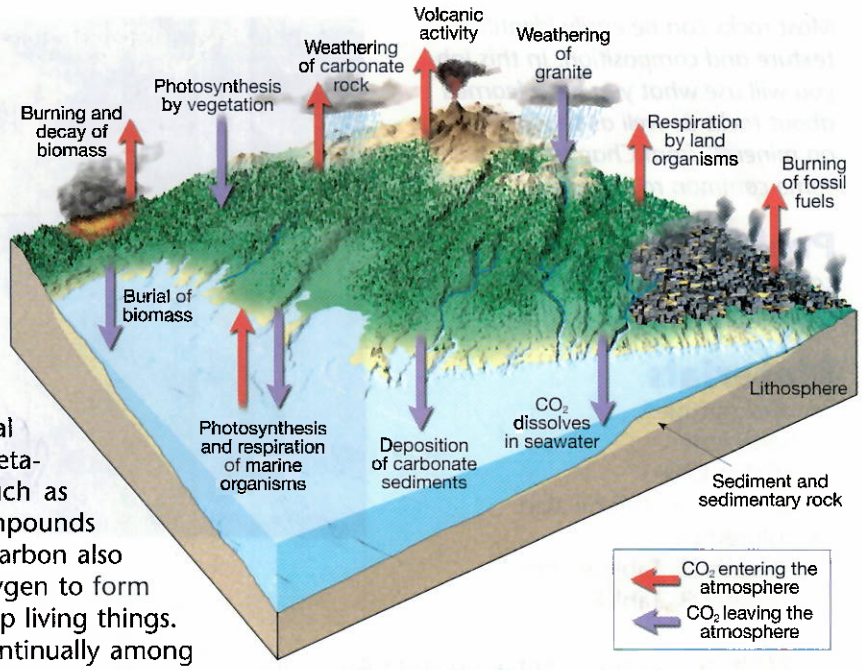


Figure 20 The Carbon Cycle

Carbon Dioxide on the Move

In the atmosphere, carbon is found mainly as carbon dioxide. This gas absorbs much of the energy given off by Earth. Therefore, carbon dioxide influences the heating of the atmosphere. Carbon dioxide constantly moves into and out of the atmosphere by way of four major processes: photosynthesis, respiration, organic decay, and combustion of organic material.

Carbon and Fossil Fuels

Some carbon from decayed organic matter is deposited as sediment. Over long periods of time, this carbon becomes buried. Under the right conditions, some of these carbon-rich deposits are changed to fossil fuels, such as coal. When fossil fuels are burned, huge quantities of carbon dioxide enter into the air.

The Role of Marine Animals

Chemical weathering of certain rocks produce bicarbonate ions that dissolve water. Groundwater, rivers, and streams carry these ions to the ocean. Here, some organisms extract this substance to produce body parts—shells, skeletons, and spines—made of calcite. When the organisms die, these hard parts settle to the ocean floor and become the sedimentary rock called limestone.

The Complete Cycle

The source of most CO_2 in the atmosphere is thought to be from volcanic activity early in Earth's history. When CO_2 combines with water, it forms carbonic acid. This substance reacts with rock through chemical weathering to form bicarbonate ions that are carried by groundwater and streams to the ocean. Here, marine organisms take over and sedimentary rock is eventually produced. If this rock is then exposed at the surface and subjected to chemical weathering, CO_2 is also produced. Use Figure 20 to trace the path of carbon from the atmosphere to the hydrosphere, the geosphere, the biosphere, and back to the atmosphere.

CHAPTER 3

Study Guide

3.1 The Rock Cycle

Key Concepts

- A rock is any solid mass of mineral or mineral-like matter that occurs naturally.
- The three major types of rocks are igneous, sedimentary, and metamorphic.
- Interactions among Earth's water, air, and land can cause rocks to change from one type to another. The continuous processes that cause rocks to change make up the rock cycle.
- When magma cools and hardens beneath the surface or as the result of a volcanic eruption, igneous rock forms.
- Eventually sediments are compacted and cemented to form sedimentary rocks.
- Under extreme pressure and temperature conditions, sedimentary rock will change into metamorphic rock.
- Heat from Earth's interior and energy from the sun power the rock cycle.

Vocabulary

rock, *p. 66;* igneous rock, *p. 66;* sedimentary rock, *p. 66;* metamorphic rock, *p. 66;* rock cycle, *p. 67;* magma, *p. 67;* lava, *p. 67;* weathering, *p. 68;* sediments, *p. 68*

3.2 Igneous Rocks

Key Concepts

- Rocks that form when magma hardens beneath Earth's surface are called intrusive igneous rocks.
- When lava hardens, the rocks that form are called extrusive igneous rocks.
- Texture and composition are two characteristics used to classify igneous rocks.
- Slow cooling results in the formation of large crystals.
- Rapid cooling of magma or lava results in rocks with small, interconnected mineral grains.

Vocabulary

intrusive igneous rock, *p. 71;* extrusive igneous rock, *p. 71;* porphyritic texture, *p. 72;* granitic composition, *p. 73;* basaltic composition, *p. 73;* andesitic composition, *p. 73;* ultramafic, *p. 73*

3.3 Sedimentary Rocks

Key Concepts

- Erosion involves weathering and the removal of rock. When an agent of erosion—water, wind, ice, or gravity—loses energy, it drops the sediments. This process is called deposition.
- Compaction is a process that squeezes, or compacts, sediments.
- Cementation takes place when dissolved minerals are deposited in the tiny spaces among the sediments.
- Just like igneous rocks, sedimentary rocks can be classified into two main groups according to the way they form.
- The many unique features of sedimentary rocks are clues to how, when, and where the rocks formed.

Vocabulary

erosion, *p. 76;* deposition, *p. 76;* compaction, *p. 76;* cementation, *p. 76;* clastic sedimentary rock, *p. 77;* chemical sedimentary rock, *p. 77*

3.4 Metamorphic Rocks

Key Concepts

- Most metamorphic changes occur at elevated temperatures and pressures. These conditions are found a few kilometers below Earth's surface and extend into the upper mantle.
- During contact metamorphism, hot magma moves into rock.
- Regional metamorphism results in large-scale deformation and high-grade metamorphism.
- The agents of metamorphism are heat, pressure, and hydrothermal solutions.
- Metamorphic rocks can be classified by texture as foliated or nonfoliated.

Vocabulary

metamorphism, *p. 80;* contact metamorphism, *p. 81;* regional metamorphism, *p. 81;* hydrothermal solution, *p. 83;* foliated metamorphic rock, *p. 83;* nonfoliated metamorphic rock, *p. 83*

4. Determine and record the presence of any organic matter in any of the samples.
5. Observe the relationships among the minerals in each rock to determine texture. Refer to Chapter 3 Tables 1, 2, and 3 if necessary. Record your observations.
6. Note and record any other unique observations of the samples.
7. In your data table, make and color a detailed sketch of each sample.
8. Identify each sample as being an igneous rock, a sedimentary rock, or a metamorphic rock.
9. Name each sample. Use the photographs in this chapter and Tables 1, 2, and 3 if necessary.

Analyze and Conclude

1. **Evaluating** Which of the rock identification characteristics did you find most useful? Which of the characteristics did you find least useful? Give reasons for your answers.
2. **Comparing and Contrasting** How did identifying rocks compare with the mineral identification lab you did in Chapter 2? How is identifying rocks different from identifying the minerals that compose the rocks?

3. **Applying Concepts** Match the metamorphic rocks with their probable parent rocks.
4. **Applying Concepts** Choose two pairs of rocks used in this investigation. Write a brief description for each pair that explains how one rock can be changed into the other. Refer to the diagram of the rock cycle on page 67.

Go Further Obtain permission to collect some local rock samples from a park or nearby road. Use what you have learned about rocks and minerals to identify the rocks. Then write a brief history of each sample to explain how it formed and how it has changed since being formed.

Assessment *continued*

Critical Thinking

23. **Synthesizing** Is it possible for two different types of igneous rocks to have the same composition and the same texture? Explain.

24. **Comparing and Contrasting** Compare and contrast the two types of sedimentary rocks and give at least two examples of each type.

25. **Formulating Hypotheses** Think about the sediments that compose both conglomerate and breccia. What one sedimentary process makes these two rocks different? Explain.

26. **Comparing and Contrasting** Compare and contrast the effects of heat and pressure in the formation of metamorphic rocks.

27. **Explaining** Explain all of the processes that might change a sandstone into a quartzite.

28. **Synthesizing** In what ways do metamorphic rocks differ from the sedimentary and igneous rocks from which they form?

Use the photograph to answer Questions 29–33.

29. **Observing** Describe the texture of the rock.

30. **Identifying** To which of the three major groups of rocks does the rock belong?

31. **Classifying** Classify the rock as specifically as possible.

32. **Formulating Hypotheses** Briefly describe how this rock formed.

33. **Applying Concepts** Explain how this rock might become an igneous rock.

Concepts in Action

34. **Applying Concepts** Your friend shows you a rock with distinct layers. How can you and your friend determine if the rock is a sedimentary rock or a metamorphic rock?

35. **Applying Concepts** Name two rocks discussed in this chapter that might be used as flooring, countertops, or facades on museums and government buildings. Name two rocks that might be used for monuments and statues.

36. **Calculating** Each year, roughly 9100 kilograms of rock, sand, and gravel are mined for each person in the United States. Calculate how many kilograms of rock, sand, and gravel have been mined for you thus far in your life. Then calculate how much will be mined when you are 75 years old.

37. **Writing in Science** Suppose you're a writer for the school newspaper. You have been asked to do a story on one of the rocks described in this chapter. Pick a rock and write a short, newspaper-type story. Include facts about the rock—its texture, mineral composition, and how it formed. Also describe how the rock might change into a rock in each of the other two categories of rocks. Be creative, but scientifically accurate.

Performance-Based Assessment

Applying Concepts Go on field trip around your house, neighborhood, and community to find at least 10 items that are made from rocks or show ways in which rocks are used. Make a poster that shows what you found and display it for the class.

CHAPTER 3

Assessment

Interactive textbook with assessment at PHSchool.com

Reviewing Content

Choose the letter that best answers the question or completes the statement.

1. Which of the following is NOT one of the three major types of rocks?
   a. anthracite b. igneous
   c. metamorphic d. sedimentary

2. Which of the following forms partly as the result of surface processes?
   a. metamorphic slate
   b. igneous basalt
   c. magma
   d. intrusive granite

3. Which of the following would NOT be a major process in the formation of sedimentary rocks?
   a. erosion b. melting
   c. deposition d. compaction

4. The formation of igneous rocks is powered by
   a. internal heat. b. the rock cycle.
   c. erosion. d. the sun.

5. A fine-grained igneous rock forms
   a. deep within Earth.
   b. from magma.
   c. as the result of slow cooling.
   d. as the result of quick cooling.

6. Cementation often occurs after Earth materials are
   a. eroded. b. weathered.
   c. intruded. d. deposited.

7. Ripple marks indicate that the rock formed
   a. underground. b. under a glacier.
   c. in water. d. from lava.

8. A major process in the formation of clastic sedimentary rocks is
   a. contact with magma.
   b. cementation.
   c. hardening.
   d. foliation.

9. Metamorphic rocks that have a banded appearance due to the alignment of minerals are called
   a. foliated. b. nonfoliated.
   c. clastic. d. glassy.

10. Which rock is made of the smallest sediments?
    a. shale b. conglomerate
    c. breccia d. sandstone

Understanding Concepts

11. Use what you have learned about the rock cycle to explain the following statement: One rock is the raw material for another rock.

12. Which igneous rock forms when basaltic lava hardens? When basaltic magma hardens?

13. A rock has a porphyritic texture. What can you conclude about the rock?

14. How are granite and rhyolite the same, and how do they differ?

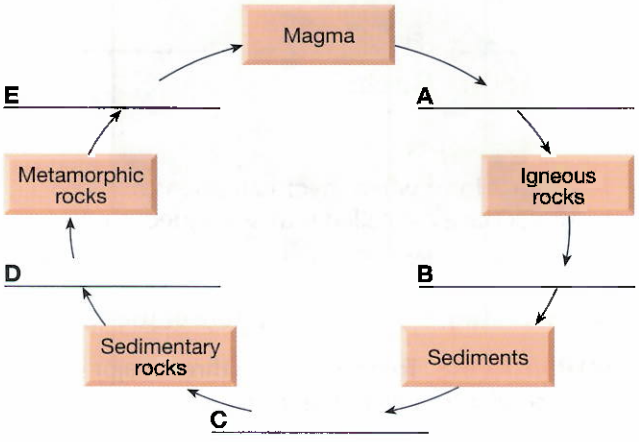
15. Explain three types of weathering.

16. What are the most common minerals in clastic rocks? Why?

17. Distinguish between regional and contact metamorphism.

18. How could you easily distinguish a black and white gneiss from a similar-colored granite?

Use the following diagram to answer Questions 19–22.



19. What process occurs at point A?

20. What three processes can occur at point B?

21. Name two processes that occur at point C.

22. What two processes occur at points D and E?

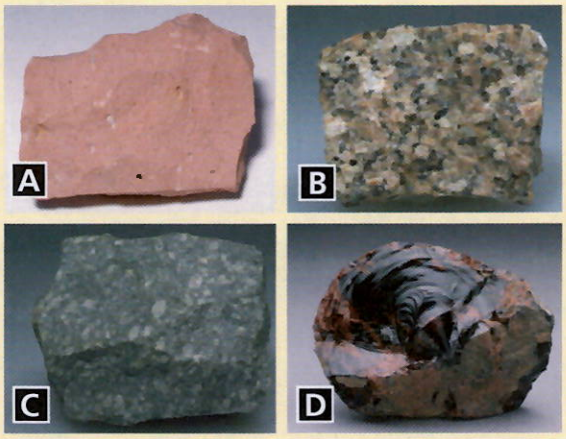
Standardized Test Prep

Test-Taking Tip

Using Visuals

Sometimes an answer to a test question requires that you interpret a drawing, a table, or a photograph. When this occurs, carefully study the visual before you read the questions pertaining to it. Refer to the visual again as you read each of the questions to which it pertains.

Use the photographs to answer Questions 1–9.



Choose the letter that best answers the question or completes the statement.

1. Which of the rocks has a fine-grained texture?
   (A) A
   (B) B
   (C) C
   (D) D

2. Which rock cooled the fastest?
   (A) A
   (B) B
   (C) C
   (D) D

3. Which of the rocks formed deep beneath the surface?
   (A) only A
   (B) only B
   (C) both A and D
   (D) both B and C

4. Which of the following best describes the texture of the rock labeled D?
   (A) porphyritic
   (B) glassy
   (C) fine-grained
   (D) coarse-grained

Write one or two complete sentences to answer each of the following questions.

5. What kinds of conditions produced the rock labeled A?

6. How and where did the rock labeled B form?

7. Compare and contrast the rocks labeled A and D.

8. How is the rock labeled C different from the other rocks shown?

9. Describe the conditions that led to the formation of the rock labeled D.

10. Use what you have learned about rocks to describe the color and texture of the rock below. What type of rock is this? How did it form?