Section 2.2

1 FOCUS

Section Objectives

2.6 **List** five characteristics of minerals.

2.7 **Describe** the processes that result in mineral formation.

2.8 **Explain** how minerals can be classified.

2.9 **List** some of the major groups of minerals.

Reading Focus

Build Vocabulary L2

Word Parts Help students understand the meaning of the word *tetrahedron* by breaking the word down into parts. The part *tetra* comes from the Greek word for "four." The part *hedron* comes from the Greek word for "face." So a tetrahedron is a shape that has four faces.

Reading Strategy L2

Silicates: made of tetrahedra; quartz; feldspar
Carbonates: contain carbon, oxygen, and one or more other metallic elements; calcite; dolomite
Oxides: contain oxygen, and one or more other elements; rutile; corundum
Sulfate and sulfides: contain sulfur; gypsum; galena
Halides: contain a halogen ion plus one or more other elements; halite; fluorite
Native elements: substances that exist as free elements; gold; silver

2 INSTRUCT

Address Misconceptions L2

Students may think that the minerals discussed in this chapter are the same as the minerals found in vitamin pills. They are related, but not the same. Remind students of the Q&A on p. 38. In earth science, a mineral is a naturally occurring inorganic crystalline solid. In contrast, minerals found in vitamin pills are inorganic compounds made in the laboratory that contain elements needed by the body. Many elements needed by the body are metals such as calcium, potassium, phosphorus, magnesium, and iron.
Logical

2.2 Minerals

Reading Focus

Key Concepts

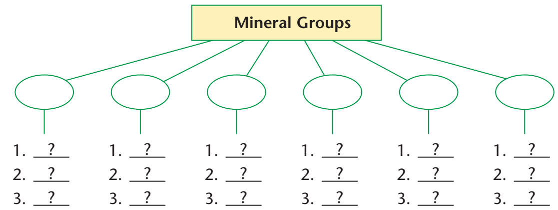
- What are five characteristics of a mineral?
- What processes result in the formation of minerals?
- How can minerals be classified?
- What are some of the major groups of minerals?

Vocabulary

- mineral
- silicate
- silicon-oxygen tetrahedron

Reading Strategy

Previewing Copy the organizer below. Skim the material on mineral groups on pages 47 to 49. Place each group name into one of the ovals in the organizer. As you read this section, complete the organizer with characteristics and examples of each major mineral group.



Look at the salt shaker in Figure 9B. This system is made up of the metal cap, glass container, and salt grains. Each component is made of elements or compounds that either are minerals or that are obtained from minerals. In fact, practically every manufactured product that you might use in a typical day contains materials obtained from minerals. What other minerals do you probably use regularly? The lead in your pencils actually contains a soft black mineral called graphite. Most body powders and many kinds of make-up contain finely ground bits of the mineral talc. Your dentist's drill bits contain tiny pieces of the mineral diamond. It is hard enough to drill through your tooth enamel. The mineral quartz is the main ingredient in the windows in your school and the drinking glasses in your family's kitchen. What do all of these minerals have in common? How do they differ?

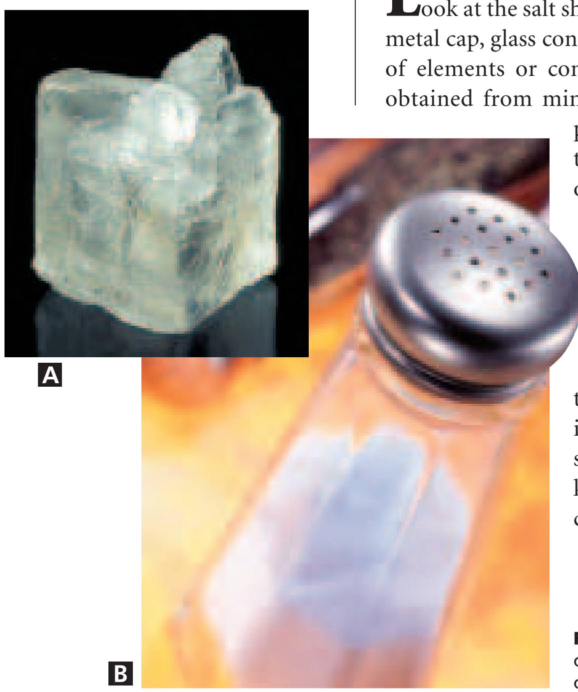


Figure 9 **A** Table salt is the mineral halite. **B** The glass container is made from the mineral quartz. Bauxite contains minerals that provide aluminum for the cap.

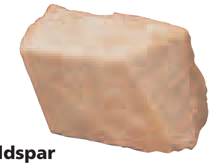
Minerals

A mineral in Earth science is different from the minerals in foods. **A mineral is a naturally occurring, inorganic solid with an orderly crystalline structure and a definite chemical composition.** For an Earth material to be considered a mineral, it must have the following characteristics:

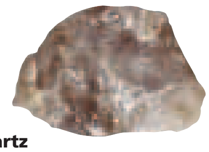
1. **Naturally occurring** A mineral forms by natural geologic processes. Therefore, synthetic gems, such as synthetic diamonds and rubies, are not considered minerals.
2. **Solid substance** Minerals are solids within the temperature ranges that are normal for Earth's surface.
3. **Orderly crystalline structure** Minerals are crystalline substances which means that their atoms or ions are arranged in an orderly and repetitive manner. You saw this orderly type of packing in Figure 5 for halite (NaCl). The gemstone opal is not a mineral even though it contains the same elements as quartz. Opal does not have an orderly internal structure.
4. **Definite chemical composition** Most minerals are chemical compounds made of two or more elements. A few, such as gold and silver, consist of only a single element (native form). The common mineral quartz consists of two oxygen atoms for every silicon atom. Thus the chemical formula for quartz would be SiO_2.
5. **Generally considered inorganic** Most minerals are inorganic crystalline solids found in nature. Table salt (halite) is one such mineral. However, sugar, another crystalline solid is not considered a mineral because it is classified as an organic compound. Sugar comes from sugar beets or sugar cane. We say "generally inorganic" because many marine animals secrete inorganic compounds, such as calcium carbonate (calcite). This compound is found in their shells and in coral reefs. Most geologists consider this form of calcium carbonate a mineral.

How Minerals Form

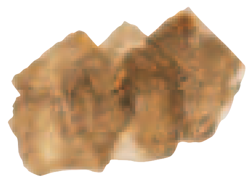
Minerals form nearly everywhere on Earth under different conditions. For example, minerals called silicates often form deep in the crust or mantle where temperatures and pressures are very high. Most of the minerals known as carbonates form in warm, shallow ocean waters. Most clay minerals form at or near Earth's surface when existing minerals are exposed to weathering. Still other minerals form when rocks are subjected to changes in pressure or temperature. **There are four major processes by which minerals form: crystallization from magma, precipitation, changes in pressure and temperature, and formation from hydrothermal solutions.**



Feldspar



Quartz



Muscovite

Hornblende

Figure 10 These minerals often form as the result of crystallization from magma.

Go Online PLANETDIARY

For: Links on Minerals
Visit: PHSchool.com
Web Code: (czd-1022)

Minerals

Build Reading Literacy L1

Refer to **p. 334D** in **Chapter 12**, which provides guidelines for this strategy.

Outline Have students read the text on pp. 45–49 about how minerals form and mineral groups. Encourage students to use the headings as major divisions in an outline. Have students refer to their outlines when answering the questions in the Section 2.2 Assessment.
Verbal, Logical

How Minerals Form

Teacher Demo

Crystallization of Sulfur L2

Purpose Students observe how the rate of cooling of a mineral affects crystal size.

Materials two crucibles, 50-mL beaker, water, teaspoon, sulfur powder, tongs, Bunsen burner, magnifying glass

Procedure Put a teaspoon of powdered sulfur into one of the crucibles. Using tongs, hold the crucible near the burner flame until the sulfur melts. Set the crucible aside to cool. Put a teaspoon of powdered sulfur into the second crucible. Put about 200 mL of water in the beaker. Melt the sulfur in the second crucible and carefully pour the molten sulfur into the beaker. Pour off the water. When the first crucible has cooled, allow students to look at the crystals using the magnifying glass.

Safety Wear goggles, apron, and heat-resistant mitts while melting the sulfur. Make sure students are at a safe distance from the crucible and flame and that the room is well ventilated.

Expected Outcome The sulfur in the first crucible, which cooled slowly, will have bigger crystals than the sulfur that cooled quickly.
Visual, Logical

Go Online PLANETDIARY

Find links to additional activities and have students monitor phenomena that affect Earth and its residents.

Customize for English Language Learners

To help students learn and understand the names of the different mineral groups, have them focus on the roots of the names and ignore the endings. The beginning of *silicates*, for example, is *silic-*. This is similar to *silicon* and indicates that silicates contain silicon. Have students go though all the other names, isolate the beginnings of the names, and figure out what the name indicates about what elements the minerals contain *(carbonates: carbon-, carbon; oxides: ox-, oxygen; sulfates and sulfides: sulf-, sulfur; halides: hal-, halogens).*

Teacher Demo

Precipitation of a Mineral L2

Purpose Students observe how a mineral can form by precipitation.

Materials rock salt, spoon warm water, 400-mL beaker, shallow pan or tray

Procedure Out of view of students, add rock salt spoon by spoon to a beaker of warm water, stirring as you go. Stop when no more salt will dissolve. Show the beaker to students and ask them if there is a mineral in it. Most will say no. Then pour the liquid into the pan and leave it in a warm and/or sunny spot. (If you don't have a suitable warm and/or sunny spot or want to save time, pour some of the solution into an evaporation dish and heat it on a hot plate.) When the water has evaporated, show the pan to students and ask them to identify the substance in it *(halite crystals).*

Expected Outcome As the water evaporates, the salt will precipitate out of the solution and form crystals.
Visual, Logical

Build Science Skills L2

Inferring Sometimes rocks are buried deep under Earth's surface. When they reach the surface again they are often changed into a different type of rock. Ask students why this happens. *(The rocks are subjected to great heat and pressure deep below Earth's surface. The heat and pressure cause reactions that change the minerals and thus produces new types of rocks.)*
Logical

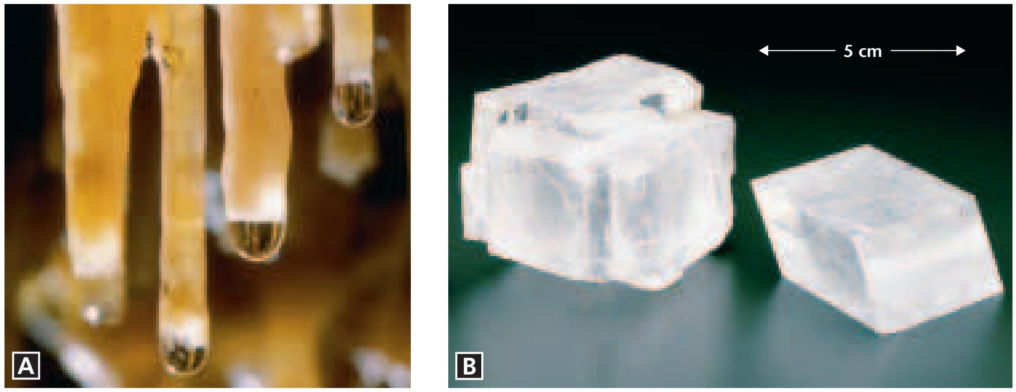


Figure 11 A This limestone cave formation is an obvious example of precipitation. **B** Halite and calcite are also formed by precipitation.

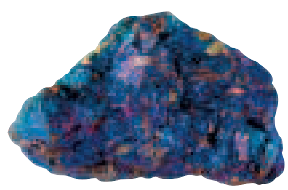
Crystallization from Magma Magma is molten rock. It forms deep within Earth. As magma cools, elements combine to form minerals such as those shown in Figure 10 on page 45. The first minerals to crystallize from magma are usually those rich in iron, calcium, and magnesium. As minerals continue to form, the composition of the magma changes. Minerals rich in sodium, potassium, and aluminum then form.

Precipitation The water in Earth's lakes, rivers, ponds, oceans, and beneath its surface contains many dissolved substances. If this water evaporates, some of the dissolved substances can react to form minerals. Changes in water temperature may also cause dissolved material to precipitate out of a body of water. The minerals are left behind, or precipitated, out of the water. Two common minerals that form in this way are shown in Figure 11.

Pressure and Temperature Some minerals, including talc and muscovite, form when existing minerals are subjected to changes in pressure and temperature. An increase in pressure can cause a mineral to recrystallize while still solid. The atoms are simply rearranged to form more compact minerals. Changes in temperature can also cause certain minerals to become unstable. Under these conditions, new minerals form, which are stable at the new temperature.

Hydrothermal Solutions A hydrothermal solution is a very hot mixture of water and dissolved substances. Hydrothermal solutions have temperatures between about 100°C and 300°C. When these solutions come into contact with existing minerals, chemical reactions take place to form new minerals. Also, when such solutions cool, some of the elements in them combine to form minerals such as quartz and pyrite. The sulfur minerals in the sample shown in Figure 12 formed from thermal solutions.

Figure 12 Bornite (blue and purple) and chalcopyrite (gold) are sulfur minerals that form from thermal solutions.



Reading Checkpoint *Describe what happens when a mineral is subjected to changes in pressure or temperature.*

Mineral Groups

Over 3800 minerals have been named, and several new ones are identified each year. You will be studying only the most abundant minerals. **Common minerals, together with the thousands of others that form on Earth, can be classified into groups based on their composition.** Some of the more common mineral groups include the silicates, the carbonates, the oxides, the sulfates and sulfides, the halides, and the native elements. First, you will learn about the most common groups of minerals on Earth—the **silicates.**

Silicates If you look again at Table 1, you can see that the two most abundant elements in Earth's crust are silicon and oxygen. **Silicon and oxygen combine to form a structure called the silicon-oxygen tetrahedron.** This structure is shown in Figure 13. The tetrahedron, which consists of one silicon atom and four oxygen atoms, provides the framework of every silicate mineral. Except for a few silicate minerals, such as pure quartz (SiO_2), most silicates also contain one or more other elements.

Silicon-oxygen tetrahedra can join in a variety of ways, as you can see in Figure 14 on the next page. The silicon-oxygen bonds are very strong. Some minerals, such as olivine, are made of millions of single tetrahedra. In minerals such as augite, the tetrahedra join to form single chains. Double chains are formed in minerals such as hornblende. Micas are silicates in which the tetrahedra join to form sheets. Three-dimensional network structures are found in silicates such as quartz and feldspar. As you will see, the internal structure of a mineral affects its properties.

Reading Checkpoint *What is the silicon-oxygen tetrahedron, and in how many ways can it combine?*

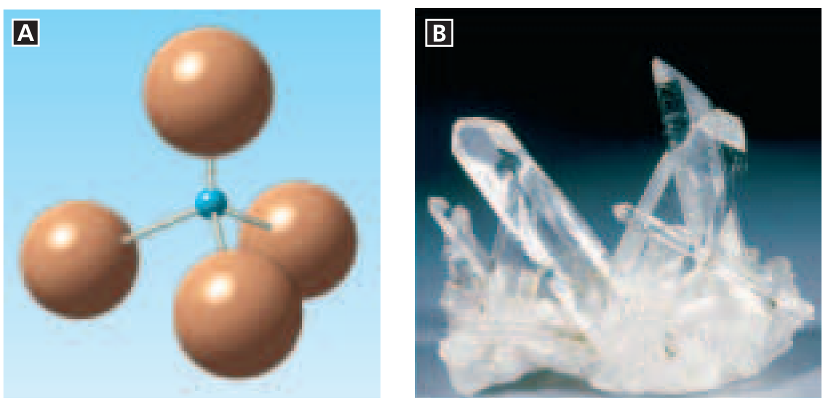


Figure 13 **A** The silicon-oxygen tetrahedron is made of one silicon atom and four oxygen atoms. The rods represent chemical bonds between silicon and the oxygen atoms. **B** Quartz is the most common silicate mineral. A typical piece of quartz like this contains millions of silicon-oxygen tetrahedra.

Mineral Groups

Address Misconceptions L2

Students may think that the silicates described in this section are the same materials as those in silicon computer chips or silicone sealant. They are different materials, although all three contain silicon. Silicon chips are made from pure silicon, which does not contain the oxygen found in silicates. Silicone is an artificially-made silicon-oxygen polymer gel that feels rubbery and is water repellent, chemically inert, and stable at extreme temperatures.
Verbal

Use Visuals L1

Figure 13 Use this diagram to explain the basic structure of silicates. Ask: **What is the atom at the center of the tetrahedron?** *(a silicon atom)* **What are the four atoms at the corners of the tetrahedron?** *(oxygen atoms)* **What do the rods represent?** *(chemical bonds between the atoms)* **Why is this structure called a tetrahedron?** *(it has four sides, or faces)*
Visual

Facts and Figures

Judging from the enormous number of known minerals, one might think that a large number of elements are needed to make them. Surprisingly, the bulk of these minerals are made up of only eight elements. These elements, in order of abundance, are oxygen (O), silicon (Si), aluminum (Al), iron (Fe), calcium (Ca), sodium (Na), potassium (K), and magnesium (Mg). These eight elements represent over 98 percent by weight of the continental crust. The two most abundant elements, oxygen and silicon, comprise nearly three-fourths of Earth's continental crust. These elements are the main building blocks of silicates. The most common group of silicates, the feldspars, compose over 50 percent of Earth's crust. Quartz is the second most abundant mineral in the continental crust. It is a silicate made mostly of oxygen and silicon.

Answer to . . .

Reading Checkpoint *The mineral often becomes unstable, and its atoms react to form a new mineral.*

Reading Checkpoint *The silicon-oxygen tetrahedron consists of one silicon atom and four oxygen atoms and provides the framework of every silicate mineral. These tetrahedra can join to form single chains, double chains, sheets, and three-dimensional networks. In these arrangements the corner oxygen atoms are shared between silicon atoms so the ratio is not necessarily 1 to 4.*

Build Science Skills

L2

Using Models Have students use Figures 13 and 14 to build models of the various silicate structures. They can use balls of modeling clay or gumdrops to represent silicon and oxygen atoms and toothpicks to represent chemical bonds. First have each student build several silicon-oxygen tetrahedra as shown in Figure 13. Then have students work in groups to combine their tetrahedra into chains and other structures as shown in Figure 14.
Kinesthetic, Visual, Logical

Use Visuals

L1

Figure 14 Use this diagram to explain the different structures that silicate tetrahedra can form. Ask: **How does a single chain form?** *(A series of tetrahedra are joined together end-to-end.)* **How are double chains formed?** *(Two single chains are joined together side-by-side.)* **How are sheets formed?** *(Many single chains are joined together side-by-side.)*
Visual

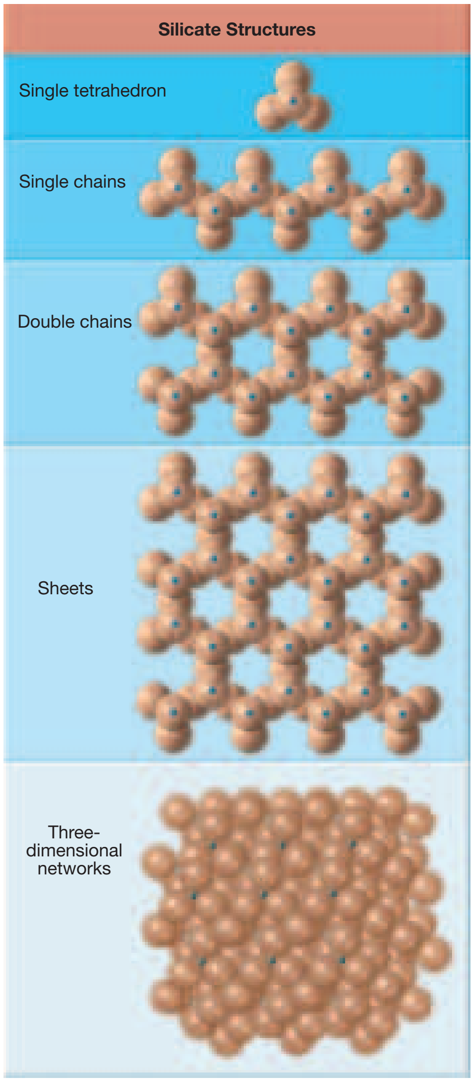


Figure 14 Silicon-oxygen tetrahedra can form chains, sheets, and three-dimensional networks.
Formulating Hypotheses ***What type of chemical bond is formed by silicon atoms in an SiO_4 tetrahedron?***

Recall that most silicate minerals crystallize from magma as it cools. This cooling can occur at or near Earth's surface, where temperatures and pressures are relatively low. The formation of silicates can also occur at great depths, where temperatures and pressures are high. The place of formation and the chemical composition of the magma determine which silicate minerals will form. For example, the silicate olivine crystallizes at temperatures of about 1200°C. Quartz crystallizes at about 700°C.

Some silicate minerals form at Earth's surface when existing minerals are exposed to weathering. Clay minerals, which are silicates, form this way. Other silicate minerals form under the extreme pressures that occur with mountain building. Therefore, silicate minerals can often provide scientists with clues about the conditions in which the minerals formed.

Carbonates Carbonates are the second most common mineral group. **Carbonates are minerals that contain the elements carbon, oxygen, and one or more other metallic elements.** Calcite ($CaCO_3$) is the most common carbonate mineral. Dolomite is another carbonate mineral that contains magnesium and calcium. Both limestone and marble are rocks composed of carbonate minerals. Both types of rock are used in building and construction.

Oxides **Oxides are minerals that contain oxygen and one or more other elements, which are usually metals.** Some oxides, including the mineral called rutile (TiO_2), form as magma cools deep beneath Earth's surface. Rutile is titanium oxide. Other oxides, such as corundum (Al_2O_3), form when existing minerals are subjected to changes in temperature and pressure. Corundum is aluminum oxide. Still other oxides, such as hematite (Fe_2O_3), form when existing minerals are exposed to liquid water or to moisture in the air. Hematite is one form of iron oxide.

Sulfates and Sulfides **Sulfates and sulfides are minerals that contain the element sulfur.** Sulfates, including anhydrite ($CaSO_4$) and gypsum ($CaSO_4 \cdot 2H_2O$), form when mineral-rich waters evaporate. Sulfides, which include the minerals galena (PbS), sphalerite (ZnS), and pyrite (FeS_2), often form from thermal, or hot-water, solutions. Figure 15 shows two of these sulfides.

Halides **Halides are minerals that contain a halogen ion plus one or more other elements.** Halogens are elements from Group 7A of the periodic table. This group includes the elements fluorine (F) and chlorine (Cl). The mineral halite (NaCl), table salt, is a common halide. Fluorite (CaF_2) is also a common halide and is used in making steel. It forms when salt water evaporates.

Native Elements **Native elements are minerals that only contain one element or type of atom.** You are probably familiar with many native elements, such as gold (Au), silver (Ag), copper (Cu), sulfur (S), and carbon (C). Native forms of carbon are diamond and graphite. Some native elements form from hydrothermal solutions.

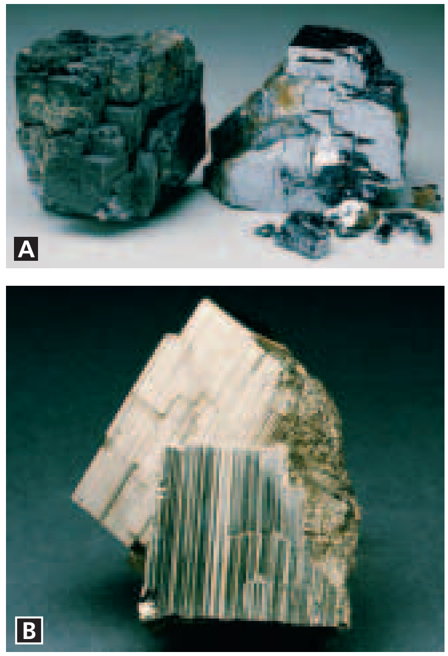


Figure 15 Sulfides A Galena is a sulfide mineral that can be mined for its lead. **B** Pyrite, another sulfide, is often called fool's gold.
Inferring ***What element do you think pyrite is generally mined for?***

Section 2.2 Assessment

Reviewing Concepts

1. What are five characteristics of a mineral?
2. Describe four processes that result in the formation of minerals.
3. How can minerals be classified?
4. Name the major groups of minerals, and give at least two examples of minerals in each group.

Critical Thinking

5. **Comparing and Contrasting** Compare and contrast sulfates and sulfides.
6. **Formulating Conclusions** When hit with a hammer, quartz shows an uneven breakage pattern. Using Figure 14, what can you suggest about its structure?
7. **Applying Concepts** To which mineral group does each of the following minerals belong: bornite (Cu_5FeS_4), cuprite (Cu_2O), magnesite ($MgCO_3$), and barite ($BaSO_4$)?

Writing in Science

Explanatory Paragraph Coal forms from ancient plant matter that has been compressed over time. Do you think coal is a mineral? Write a paragraph that explains your reasoning.

Use Community Resources L2

Invite a geologist from a local college or company to visit the classroom and discuss different groups of minerals with students. Ask the geologist to bring in samples from each group of minerals to show to students.
Visual, Interpersonal

3 ASSESS

Evaluate Understanding L2

Have students describe the four major processes by which minerals can form.

Reteach L1

Review the five characteristics that a material must have to be considered a mineral. Have students list and define all of the science terms used in the description of the five characteristics. Then review each of the five points again to be sure students understand them.

Writing in Science

Students should explain that because coal is formed from once-living things, it is not considered a mineral. Also, coal is a carbon-based material that falls into the class of organic compounds.

Answer to . . .

Figure 14 *covalent*

Figure 15 *Iron (Fe)*

Section 2.2 Assessment

1. A mineral is a natural, inorganic solid with an orderly internal structure and a definite chemical composition.
2. Crystallization occurs when minerals form as magma cools. Precipitation is a process whereby minerals form as waters rich in dissolved substances evaporate. Changes in pressure and temperature can cause the atoms in a mineral to change places to form a new mineral. Precipitation from hydrothermal solutions is another way in which minerals form.
3. Minerals can be classified according to their compositions.
4. silicates (quartz, feldspar, olivine, and mica); carbonates (calcite, dolomite); oxides (rutile, corundum, hematite); sulfates (anhydrite, gypsum); sulfides (galena, pyrite, sphalerite); halides (fluorite, halite); native elements (gold, silver, copper, iron, sulfur, diamond)
5. Both contain the element sulfur. Sulfates also contain oxygen and a metallic element. Sulfides contain only sulfur and one or more other metallic elements.
6. The tetrahedra that combine to form quartz share very strong bonds, resulting in an uneven breakage.
7. Bornite is a sulfide mineral, cuprite is an oxide, magnesite is a carbonate mineral, and barite is a sulfate.