SECTION 4

Metamorphic Rock

Have you ever watched a caterpillar change into a butterfly? Some caterpillars go through a biological process called metamorphosis in which they completely change their shape.

Rocks can also go through a process called *metamorphism*. The word *metamorphism* comes from the Greek words *meta*, which means "changed," and *morphos*, which means "shape." Metamorphic rocks are rocks in which the structure, texture, or composition of the rock have changed. All three types of rock can be changed by heat, pressure, or a combination of both.

What You Will Learn

- Describe two ways a rock can undergo metamorphism.
- Explain how the mineral composition of rocks changes as the rocks undergo metamorphism.
- Describe the difference between foliated and nonfoliated metamorphic rock.
- Explain how metamorphic rock structures are related to deformation.

Vocabulary

foliated
nonfoliated

READING STRATEGY

Discussion Read this section silently. Write down questions that you have about this section. Discuss your questions in a small group.

Origins of Metamorphic Rock

The texture or mineral composition of a rock can change when its surroundings change. If the temperature or pressure of the new environment is different from the one in which the rock formed, the rock will undergo metamorphism.

The temperature at which most metamorphism occurs ranges from 50°C to 1,000°C. However, the metamorphism of some rocks takes place at temperatures above 1,000°C. It seems that at these temperatures the rock would melt, but this is not true of metamorphic rock. It is the depth and pressure at which metamorphic rocks form that allows the rock to heat to this temperature and maintain its solid nature. Most metamorphic change takes place at depths greater than 2 km. But at depths greater than 16 km, the pressure can be 4,000 times greater than the pressure of the atmosphere at Earth's surface.

Large movements within the crust of the Earth cause additional pressure to be exerted on a rock during metamorphism. This pressure can cause the mineral grains in rock to align themselves in certain directions. The alignment of mineral grains into parallel bands is shown in the metamorphic rock in **Figure 1.**

Figure 1 *This metamorphic rock is an example of how mineral grains were aligned into distinct bands when the rock underwent metamorphism.*

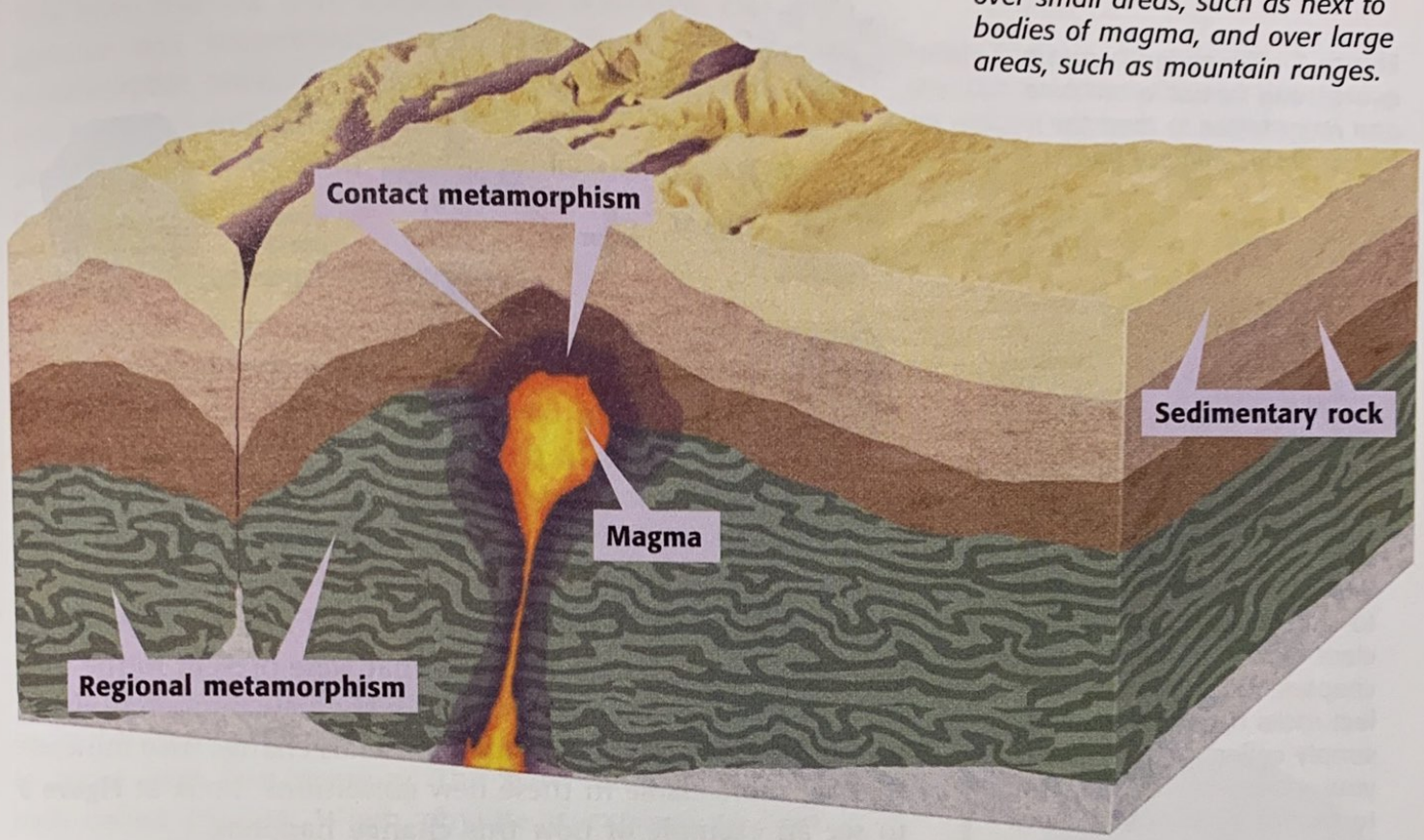

Figure 2 *Metamorphism occurs over small areas, such as next to bodies of magma, and over large areas, such as mountain ranges.*

Contact Metamorphism

One way rock can undergo metamorphism is by being heated by nearby magma. When magma moves through the crust, the magma heats the surrounding rock and changes it. Some minerals in the surrounding rock are changed into other minerals by this increase in temperature. The greatest change takes place where magma comes into direct contact with the surrounding rock. The effect of heat on rock gradually decreases as the rock's distance from the magma increases and as temperature decreases. *Contact metamorphism* occurs near igneous intrusions, as shown in **Figure 2.**

Regional Metamorphism

When pressure builds up in rock that is buried deep below other rock formations or when large pieces of the Earth's crust collide with each other, *regional metamorphism* occurs. The increased pressure and temperature causes rock to become deformed and chemically changed. Unlike contact metamorphism, which happens near bodies of magma, regional metamorphism occurs over thousands of cubic kilometers deep within Earth's crust. Rocks that have undergone regional metamorphism are found beneath most continental rock formations.

Reading Check **Explain how and where regional metamorphism takes place.** (*See the Appendix for answers to Reading Checks.*)

Stretching Out

1. Sketch the crystals in granite rock on a **piece of paper** with a **black-ink pen.** Be sure to include the outline of the rock, and fill it in with different crystal shapes.
2. Flatten some **plastic play putty** over your drawing, and slowly peel it off.
3. After making sure that the outline of your granite has been transferred to the putty, squeeze and stretch the putty. What happened to the crystals in the granite? What happened to the granite?

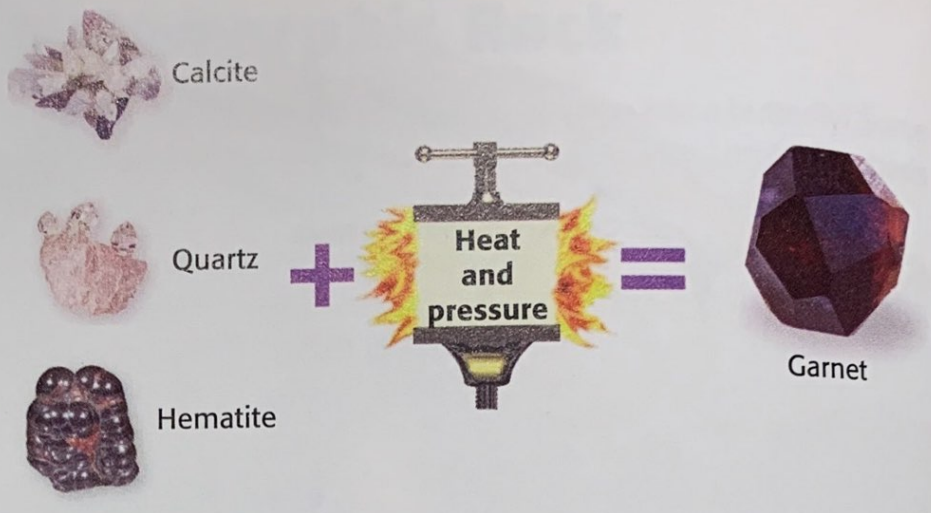

Figure 3 *The minerals calcite, quartz, and hematite combine and recrystallize to form the metamorphic mineral garnet.*

SCHOOL to HOME

Making a Rock Collection

With a parent or guardian, try to collect a sample of each class of rock described in this chapter. You may wish to collect rocks from road cuts or simply collect pebbles from your garden or driveway. Try to collect samples that show the composition and texture of each rock. Classify the rocks in your collection, and bring it to class. With other members of the class, discuss your rock samples and see if they are accurately identified.

ACTIVITY

Composition of Metamorphic Rock

Metamorphism occurs when temperature and pressure inside the Earth's crust change. Minerals that were present in the rock when it formed may not be stable in the new temperature and pressure conditions. The original minerals change into minerals that are more stable in these new conditions. Look at **Figure 3** to see an example of how this change happens.

Many of these new minerals form only in metamorphic rock. As shown in **Figure 4,** some metamorphic minerals form only at certain temperatures and pressures. These minerals, known as *index minerals,* are used to estimate the temperature, depth, and pressure at which a rock undergoes metamorphism. Index minerals include biotite mica, chlorite, garnet, kyanite, muscovite mica, sillimanite, and staurolite.

Reading Check **What is an index mineral?**

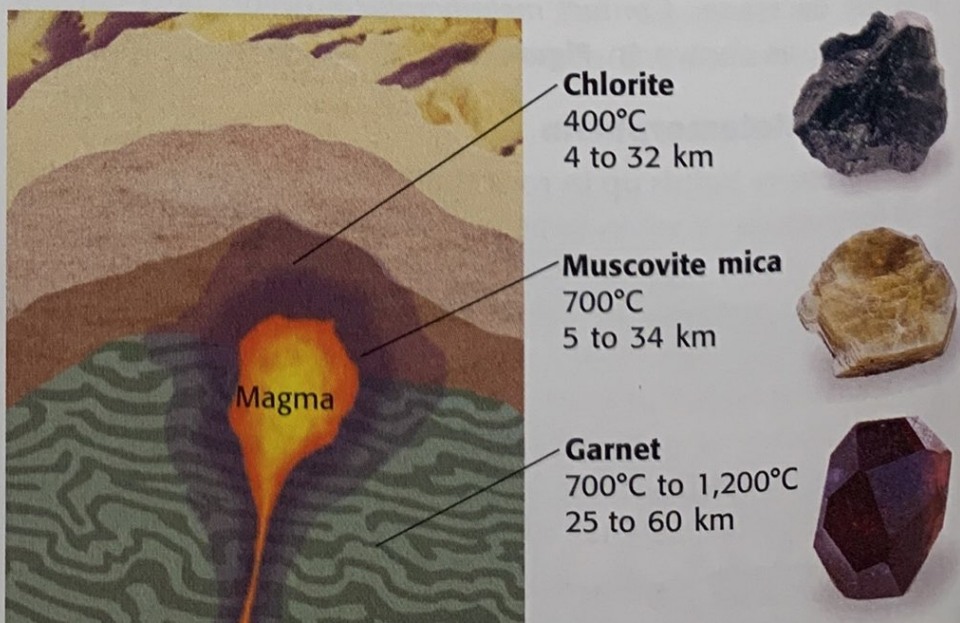

Figure 4 *Scientists can understand a metamorphic rock's history by observing the minerals the rock contains. For example, a metamorphic rock that contains garnet formed at a greater depth and under greater heat and pressure than a rock that contains only chlorite.*

Textures of Metamorphic Rock

You have learned that texture helps scientists classify igneous and sedimentary rock. The same is true of metamorphic rock. All metamorphic rock has one of two textures—foliated or nonfoliated. Take a closer look at each of these types of metamorphic rock to find out how each type forms.

foliated the texture of metamorphic rock in which the mineral grains are arranged in planes or bands

Foliated Metamorphic Rock

The texture of metamorphic rock in which the mineral grains are arranged in planes or bands is called **foliated.** Foliated metamorphic rock usually contains aligned grains of flat minerals, such as biotite mica or chlorite. Look at **Figure 5.** Shale is a sedimentary rock made of layers of clay minerals. When shale is exposed to slight heat and pressure, the clay minerals change into mica minerals. The shale becomes a foliated metamorphic rock called *slate*.

Metamorphic rocks can become other metamorphic rocks if the environment changes again. If slate is exposed to more heat and pressure, the slate can change into rock called *phyllite*. When phyllite is exposed to heat and pressure, it can change into *schist*.

If metamorphism continues, the arrangement of minerals in the rock changes. More heat and pressure cause minerals to separate into distinct bands in a metamorphic rock called *gneiss* (NIES).

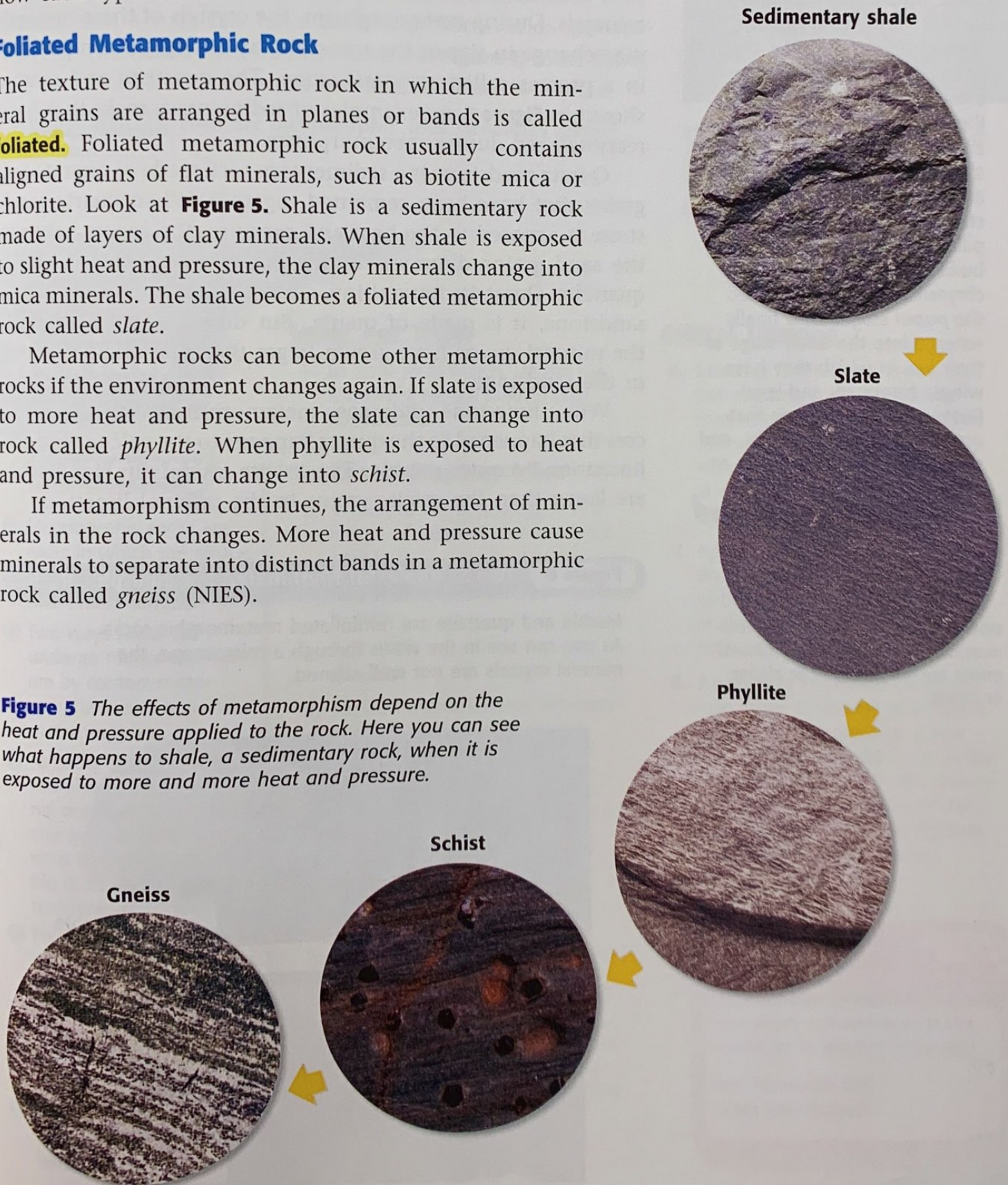

Figure 5 *The effects of metamorphism depend on the heat and pressure applied to the rock. Here you can see what happens to shale, a sedimentary rock, when it is exposed to more and more heat and pressure.*

Nonfoliated Metamorphic Rock

The texture of metamorphic rock in which the mineral grains are not arranged in planes or bands is called **nonfoliated.** Notice that the rocks shown in **Figure 6** do not have mineral grains that are aligned. This lack of aligned mineral grains is the reason these rocks are called *nonfoliated rocks*.

Nonfoliated rocks are commonly made of one or only a few minerals. During metamorphism, the crystals of these minerals may change in size or the mineral may change in composition in a process called *recrystallization*. The quartzite and marble shown in **Figure 6** are examples of sedimentary rocks that have recrystallized during metamorphism.

Quartz sandstone is a sedimentary rock made of quartz sand grains that have been cemented together. When quartz sandstone is exposed to the heat and pressure, the spaces between the sand grains disappear as the grains recrystallize to form quartzite. Quartzite has a shiny, glittery appearance. Like quartz sandstone, it is made of quartz. But during recrystallization, the mineral grains have grown larger than the original grains in the sandstone.

When limestone undergoes metamorphism, the same process that happened to the quartz happens to the calcite, and the limestone becomes marble. The calcite crystals in the marble are larger than the calcite grains in the original limestone.

nonfoliated the texture of metamorphic rock in which the mineral grains are not arranged in planes or bands

Figure 6 Two Examples of Nonfoliated Metamorphic Rock

Marble and quartzite are nonfoliated metamorphic rocks. As you can see in the views through a microscope, the mineral crystals are not well aligned.

Marble

Quartzite

CONNECTION TO Biology

WRITING SKILL

Metamorphosis The term *metamorphosis* means "change in form." When some animals undergo a dramatic change in the shape of their body, they are said to have undergone a metamorphosis. As part of their natural life cycle, moths and butterflies go through four stages. After they hatch from an egg, they are in the larval stage in the form of a caterpillar. In the next stage, they build a cocoon or become a chrysalis. This stage is called the *pupal stage*. They finally emerge into the adult stage of their life, in which they have wings, antennae, and legs! Research other animals that undergo a metamorphosis, and summarize your findings in a short essay.

Metamorphic Rock Structures

Like igneous and sedimentary rock, metamorphic rock also has features that tell you about its history. In metamorphic rocks, these features are caused by deformation. *Deformation* is a change in the shape of a rock caused by a force placed on it. These forces may cause a rock to be squeezed or stretched.

Folds, or bends, in metamorphic rock are structures that indicate that a rock has been deformed. Some folds are not visible to the naked eye. But, as shown in **Figure 7,** some folds may be kilometers or even hundreds of kilometers in size.

Reading Check How are metamorphic rock structures related to deformation?

Figure 7 *These large folds occur in metamorphosed sedimentary rock along Saglet Fiord in Labrador, Canada.*

SECTION Review

Summary

- Metamorphic rocks are rocks in which the structure, texture, or composition has changed.
- Two ways rocks can undergo metamorphism are by contact metamorphism and regional metamorphism.
- As rocks undergo metamorphism, the original minerals in a rock change into new minerals that are more stable in new pressure and temperature conditions.
- Foliated metamorphic rock has mineral crystals aligned in planes or bands, whereas nonfoliated rocks have unaligned mineral crystals.
- Metamorphic rock structures are caused by deformation.

Using Key Terms

1. In your own words, define the following terms: *foliated* and *nonfoliated.*

Understanding Key Ideas

2. Which of the following is not a type of foliated metamorphic rock?
   - **a.** gneiss
   - **b.** slate
   - **c.** marble
   - **d.** schist
3. Explain the difference between contact metamorphism and regional metamorphism.
4. Explain how index minerals allow a scientist to understand the history of a metamorphic rock.

Math Skills

5. For every 3.3 km a rock is buried, the pressure placed upon it increases 0.1 gigapascal (100 million pascals). If rock undergoing metamorphosis is buried at 16 km, what is the pressure placed on that rock? (Hint: The pressure at Earth's surface is .101 gigapascal.)

Critical Thinking

6. **Making Inferences** If you had two metamorphic rocks, one that has garnet crystals and the other that has chlorite crystals, which one could have formed at a deeper level in the Earth's crust? Explain your answer.
7. **Applying Concepts** Which do you think would be easier to break, a foliated rock, such as slate, or a nonfoliated rock, such as quartzite? Explain.
8. **Analyzing Processes** A mountain range is located at a boundary where two tectonic plates are colliding. Would most of the metamorphic rock in the mountain range be a product of contact metamorphism or regional metamorphism? Explain.