Section 4 Metamorphic Rocks and the Geologic History of Your Community

What Do You See?

Learning Outcomes

In this section, you will

- **Identify** and **classify** several metamorphic rocks using a rock chart.
- **Describe** two agents of metamorphism.
- **Use** a geologic map to search for evidence of past metamorphism in your community.
- **Recognize** that properties of materials can change over time.

Think About It

Metamorphism is the amazing process that transforms a rock into a new kind of rock.

- **What factors are responsible for changing a rock from one kind to another?**
- **Where does metamorphism occur?**
- **What are some of the distinguishing features of metamorphic rocks?**

Record your ideas about these questions in your *Geo* log. Provide a sketch. Be prepared to discuss your responses with your small group and the class.

Investigate

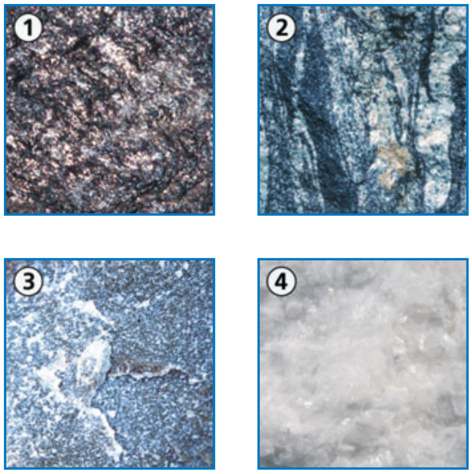
In this *Investigate*, you will examine the properties of *metamorphic rocks*. You will then make and use a model of how rocks change their shape, or deform, during metamorphosis. Finally, you will use a geologic map to locate metamorphic rocks in your local area and wider region.

Part A: Classifying Metamorphic Rocks

1. Examine the photographs of the metamorphic rocks shown, or a set of metamorphic rock samples that you are provided, and the following Classification of Metamorphic Rocks table.

   a) What properties do geologists use to classify metamorphic rocks?

   b) Use the Classification of Metamorphic Rocks table to identify your rock samples (or the pictured rocks).

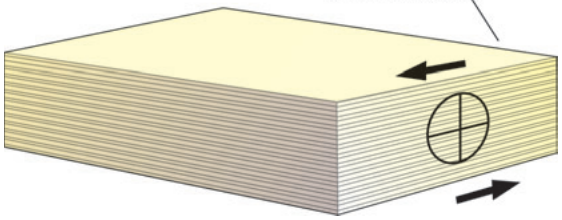


Classification of Metamorphic Rocks

Texture	Rock Name	Description	Rock Before Metamorphism
Strongly foliated: rocks in which platy minerals are arranged to be approximately parallel, causing the rock to split easily along parallel planes, or where mineral bands develop in which individual grains show common alignment.	Slate	Very fine grained, usually dark, splits easily along parallel planes.	Mudstone, claystone, shale
	Phyllite	Fine grained, usually dark, splits easily along parallel planes: often crinkled or folded; not as fine grained as slate.	Mudstone, claystone, shale
	Schist	Medium grained to coarse grained, with parallel alignment of platy mineral grains like micas.	Mudstone, claystone, shale, some volcanic rocks
	Gneiss	Medium grained to coarse grained, often with alternating layers of light and dark minerals.	Granite, rhyolite, some sandstones, some volcanic rocks
Weakly foliated or nonfoliated: rocks without abundant platy mineral; the rocks do not split easily along parallel planes.	Marble	Usually light colored, composed of calcite crystals.	Limestone
	Quartzite	Usually light colored, composed of quartz crystals.	Quartz sandstone
	Greenstone	Dark green, fine grained, made of various minerals rich in iron and magnesium.	Basalt
	Amphibolite	Dark colored, medium grained to coarse grained, with abundant amphibole minerals.	Basalt

Part B: Modeling Deformation During Metamorphosis

1. Obtain a ream (500 sheets) of paper, or an old, very thick (at least 3 cm) telephone book or catalog.
2. On the side of the stack of sheets, draw a large circle. Then draw a straight line through the center of the circle parallel to the sheets, and another straight line perpendicular to the sheets. See the diagram below.



3. Change the shape of the stack of sheets by sliding them parallel to one another so that the stack "leans sideways." Change in the shape of an object is called deformation. The kind of deformation you are producing here is called shear. If you use a ream of paper rather than a book or catalog, you will be able to make the stack lean farther (in other words, you will be able to make it deform more).
   a) How does the shape of the circle change when you deform the stack?
   b) How does the line parallel to the sheets change when you deform the stack?
   c) How does the line perpendicular to the sheets change when you deform the stack? Record your observations in your log along with a sketch of the stack before and after deformation.
4. What do you think would happen to a rock if it is sheared in the same way as the ream of paper or the book?
   a) Record your conclusions in your log. Compare your conclusions with those of the other groups, and discuss any differences in your conclusions.

Part C: Evidence of Metamorphic Rocks in Your Community

1. Examine the geologic map of your community or region.
   a) Are any metamorphic rocks described in the legend? If so, make a list of the rock type, locations, and ages (in millions of years). Record your observations in a data table. If there are numerous metamorphic rocks in your community, limit your data table to about five different examples. Be sure to include any evidence found in the area that you have selected for your *Chapter Challenge*.
   b) What are the most common metamorphic rocks in your area?

Digging Deeper

METAMORPHIC ROCKS

Formation of Metamorphic Rocks

In the *Investigate*, you looked at what properties geologists use to classify metamorphic rocks. You then classified several samples. You also simulated how rocks change their shape, or deform, during metamorphosis. Finally, you used a geologic map to locate metamorphic rocks in your local area and region. Sedimentary and igneous rocks can be turned into **metamorphic rocks**. To do so, they need to be subjected to high temperatures and/or pressures. The process is called metamorphism. The changes occur while the rock is still solid. The temperature of the rock is not so high that part of the rock melts. If the temperature becomes too high, part of the rock melts to form magma. The magma later cools to form an igneous rock.

Crystals of a mineral can grow only in a certain range of temperature and pressure. Suppose a mineral crystal in a rock is subjected to the high temperatures and pressures outside of this range. Metamorphosis occurs. The mineral crystal is changed into crystals of one or more different minerals. This is why the minerals in a metamorphic rock are usually very different from the minerals in the original rock. However, a few common minerals, such as quartz and calcite, do not change form. When a limestone is metamorphosed, the calcite continues to exist. However, the crystals grow to be much larger. All evidence of the original features of the limestone is destroyed. For example, there is no more evidence of fossils.

Geologists have learned a lot about metamorphic rocks in labs. They use special furnaces. These furnaces can be heated to extremely high temperatures. They are also under tremendous pressure. These are the temperatures and pressures under which metamorphic rocks can form. Using these studies, the geologist can infer the temperatures and pressures in Earth when the rocks were formed. Recall that every rock “tells a story.” Metamorphic rocks have their own story to tell.

The temperature of a rock can be increased in two ways. Rocks can be buried deeper and deeper in Earth. This can happen by deposition of a very thick layer of sediment on top of the rock. It can also happen by movement along **faults**. Very thick masses of rock are shoved on top of the rock. As the rock is buried, its temperature gradually increases. This is because the temperature in Earth increases with depth. Enormous volumes of rock can be metamorphosed in this way by deep burial. This is the most important kind of metamorphism. It is called **regional metamorphism**, because large regions of Earth’s crust can be affected in this way.

Geo Words

metamorphic rock: rock that has been changed (metamorphosed) into a different rock type, without actually melting, by an increase in temperature and/or pressure, and/or the action of chemical fluids.

fault: a fracture or fracture zone in rock, along which rock masses have moved relative to one another parallel to the fracture.

regional metamorphism: a general term for metamorphism affecting an extensive region.

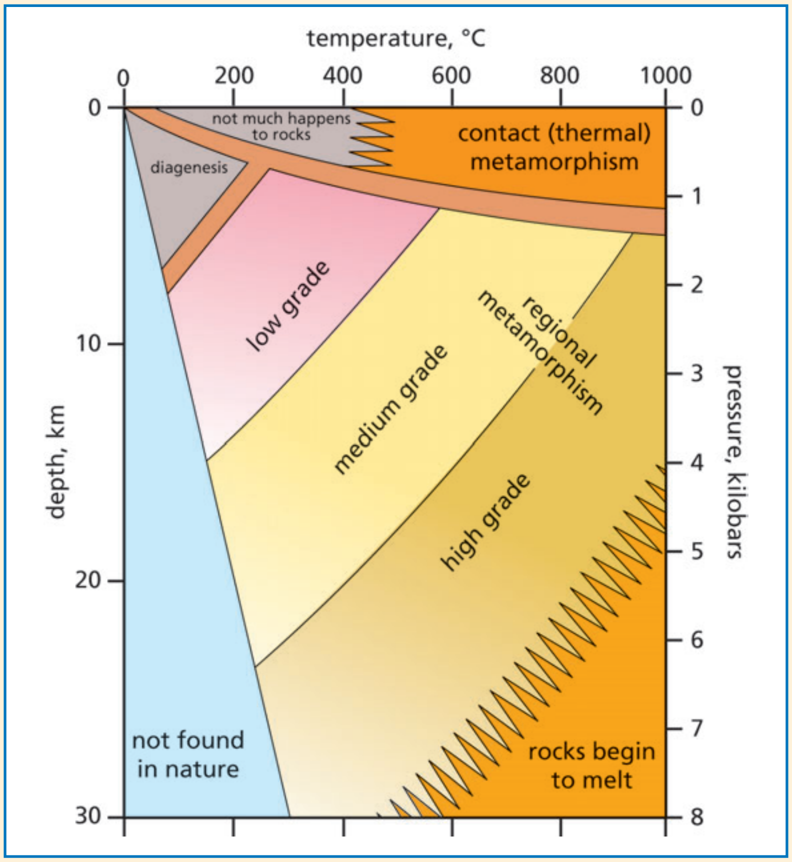


Figure 1 Diagram explaining regional metamorphism.

The temperature of a rock can also be increased if a body of magma passes near the rock. As the magma cools, the surrounding rock is heated. This can metamorphose the rock. See *Figure 2*. If the intrusion is small, only a thin layer of the surrounding rock is metamorphosed. However, very large intrusions can metamorphose a large amount of rock. Surrounding rock for thousands of meters away from the intrusion can be changed. The further away from the intrusion, the less the degree of metamorphism.

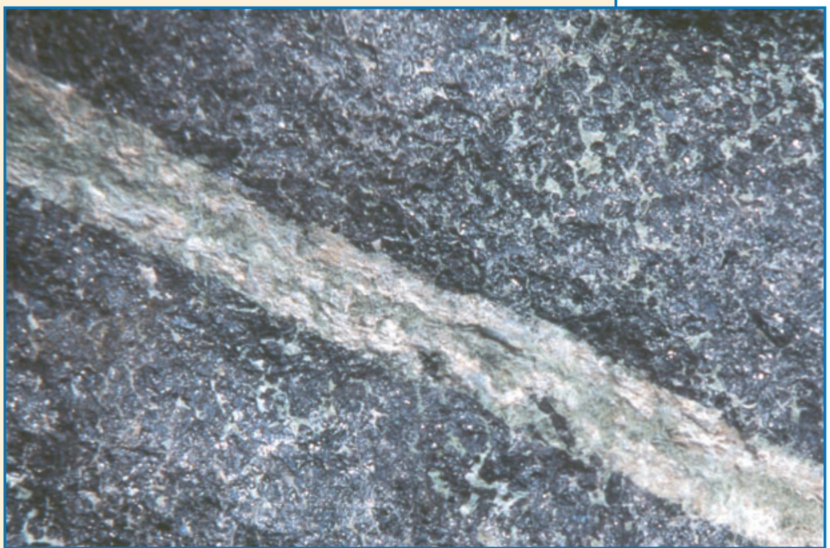


Figure 2 When an igneous rock intrudes another rock, the intense heat of the intrusion can result in metamorphism of the surrounding rock. This is known as contact metamorphism.

Geo Words

transposition: the process by which lines or planes within a material become more parallel when they are sheared.

foliation: the tendency for a metamorphic rock to split along parallel planes.

Deformation in Metamorphism

Extreme deformation is common during regional metamorphism. In *Part B* of the *Investigate,* you modeled the deformation of a rock by shearing. The same thing happens, usually even more so, when rock is sheared by forces within Earth. This is especially common where one lithospheric plate slides down beneath another. You saw in the *Investigate* that when a material is sheared, lines or planes within it become more parallel. This is called **transposition**. In many metamorphic rocks, all kinds of features and structures are "smeared out" by transposition to become nearly parallel planes. The layering you see in a metamorphic rock may not have anything to do with layering in the original rock. Forces within Earth can also stretch or compress the rock. In some metamorphosed conglomerates, the pebbles are stretched into a shape similar to a test tube.

Foliation in Metamorphic Rocks

Some sedimentary rocks contain a high percentage of very fine flakes of mica minerals. These include claystone, mudstone, and shale. These rocks become metamorphosed first to slate. Then they become phyllite, and then schist. It depends on the intensity of metamorphism. You looked at the classification table in the *Investigate*. You noticed that all of these rocks tend to split easily along parallel planes. This is because the mica minerals in the rock have grown to be parallel to one another. This causes weakness in the direction parallel to the planes of the mineral grains. The parallel growth develops for two reasons. First, the mica minerals grow with their planes perpendicular to the direction of greatest force on the rock. Second, when the rock is sheared, the mica grains tend to become parallel, as you read earlier. The tendency for a metamorphic rock to split along parallel planes is called **foliation**. Foliation, as shown in the photograph in *Figure 3*, is a major feature of many metamorphic rocks.

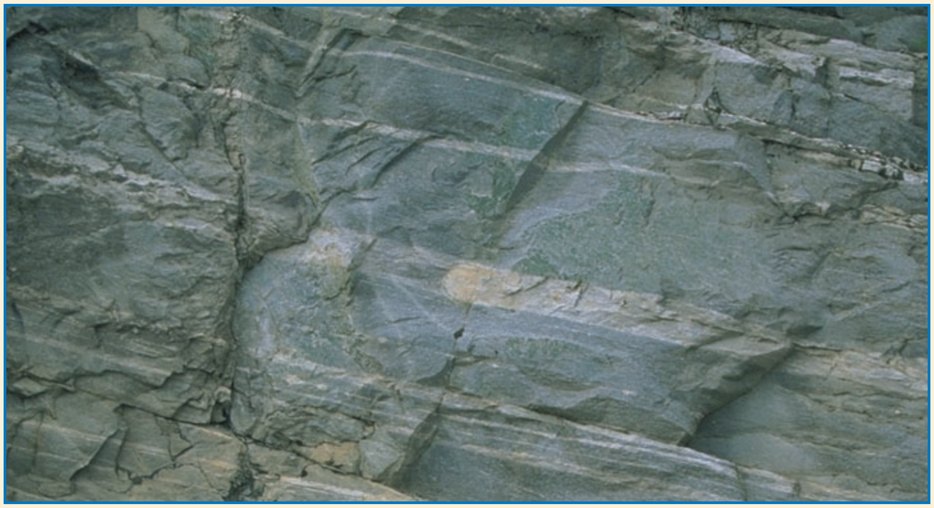


Figure 3 This gneiss is an example of a strongly foliated metamorphic rock.

The Protoliths of Metamorphic Rocks

The rock from which a metamorphic rock was formed is called the **protolith**. Both sedimentary and igneous rocks are protoliths of metamorphic rocks. The protolith can also be older metamorphic rock. Geologists are always interested in trying to figure out what the protolith of a rock was. Sometimes this is easy. For example, a quartzite probably started out as a quartz sandstone. Marble probably started out as a limestone. However, it is sometimes very difficult to guess the protolith of a metamorphic rock.

Figure 4a Quartz sandstone.

Figure 4b Quartzite.

Geo Words

protolith: the rock from which a metamorphic rock was formed.

Checking Up

1. In your own words, describe two sources of heat that lead to metamorphism.
2. Why do temperature and pressure increase with depth in Earth?
3. Why is the mineral composition of a metamorphic rock usually different from the mineral composition of the protolith (the original rock)?

Think About It Again

At the beginning of this section, you were asked the following:

- **What factors are responsible for changing a rock from one kind to another?**
- **Where does metamorphism occur?**
- **What are some of the distinguishing features of metamorphic rocks?**

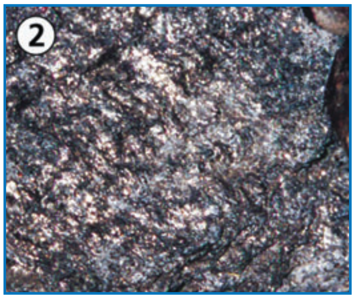
Record your ideas about these questions now. Include the role of pressure and temperature in your answer.

Reflecting on the Section and the Challenge

Your exhibit will need to show visitors how metamorphic rocks in your region were formed by tectonic processes. You might want to show images similar to what you saw in the *Investigate* about how materials can be deformed by shear forces. You can also include samples of metamorphic rocks and geologic maps showing metamorphic rocks in your community. It will be important to communicate to visitors that sometimes you have to look deep in the crust to find the old metamorphic roots of a continent. Discuss with your group how you can best show the connections between metamorphic rocks far below the surface in your region and how they were formed.

Understanding and Applying

1. Why is foliation more likely to occur during mountain building than through the contact of rock with magma?
2. Why are some metamorphic rocks foliated while others lack foliation?
3. Calculate the mass (in kg) of a column of rock that covers an area of one square meter (m^2) and is 100 m deep. Assume that the density of the rock is 2700 kg/m^3. Repeat this for a depth of 500 m, 1 km, 2 km, 4 km, 8 km, and 16 km. Graph your results. Use your results to describe the relationship between pressure and depth in Earth. (Remember that 1 km = 1000 m.)
4. Look at the photographs of the metamorphic rocks, or the samples of metamorphic rocks provided by your teacher.



   a) Are the rocks foliated or nonfoliated?
   b) What are the names of these metamorphic rocks?
   c) How did these rocks form?
5. Examine the geologic map of your state and a sketch of a deep rock core. Look at the ages of the metamorphic rocks in your area. Did you find evidence of more than one period of metamorphism? Discuss reasons why you might see more than one time period of metamorphism.
6. In your own words, describe how metamorphic rocks demonstrate the principle that the properties of materials can change over time. Discuss crystal size, foliation, and hardness.
7. ***Preparing for the Chapter Challenge***

   You have read about how metamorphic rocks are formed. You have also read that looking at the features in a rock can provide clues about the history of the rock. In addition, you have gathered information about metamorphic rocks from a geologic map. You can add this information to your museum exhibit about the geologic history of your local area and region. In preparation for making the explanatory part of your exhibit, write a one- or two-paragraph description about the events and evidence for metamorphism in your local area and region. Make sure that your description is easy for a general audience of museum visitors to read.

Inquiring Further

1. **Metamorphism in the United States**

   Research the history of the formation of metamorphic rocks in the Appalachian Mountains. Discuss how you determined the reliability of the sources you used in your research.

2. **Metamorphism and mineral resources**

   A third major type of metamorphism is caused by the movement of heated solutions of mineral-rich groundwater. The groundwater is heated by bodies of hot magma. Investigate how hydrothermal alteration leads to the formation of deposits of valuable minerals, such as gold, silver, and copper.