Chapter 3 Rocks

Section 1 The Rock Cycle

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

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.

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.

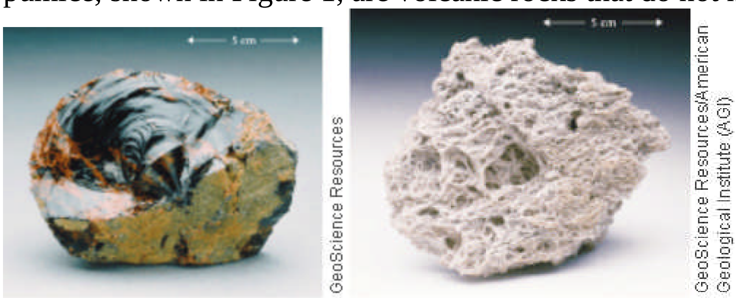

Figure 1 A Obsidian and B pumice are two examples of rocks that do not have a crystalline structure.

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.

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.

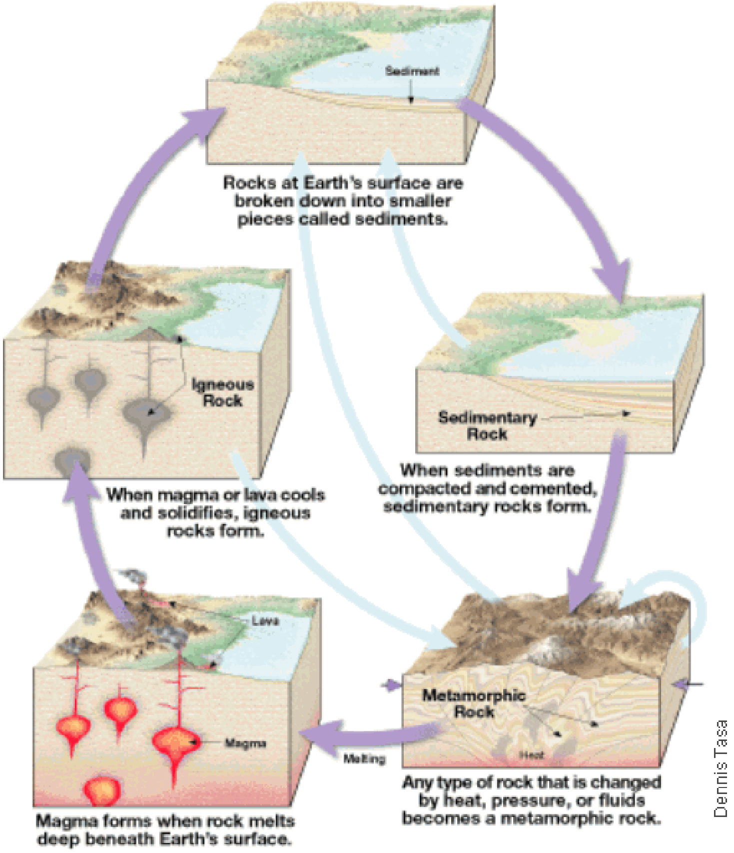

Figure 2 The rock cycle consists of many processes that change Earth's rocks. Formulating Hypotheses Can a sedimentary rock become an igneous rock without changing first to a metamorphic rock? Explain.

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.

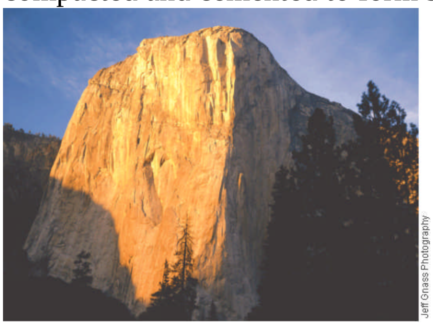

Figure 3 El Capitan in Yosemite National Park This granite was once buried deep beneath Earth's surface. Now that it is exposed, it will eventually weather and form sediments.

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.

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?

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.

Section 2 Igneous Rock

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

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.

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.

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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.

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.

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.

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

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.

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.

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

	Chemical Composition	Granitic	Andesitic	Basaltic	Ultramafic
	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%

Dennis Tasa

Section 3 Sedimentary Rocks

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

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.

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.

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.

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.

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.

Edward J. Tarbuck

Edward J. Tarbuck

- 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 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.

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.

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.

Edward J. Tarbuck

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

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.

Stephen Trimble

Gary Yeowell/Getty Images

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.

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.

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
Coarse (over 2 mm)	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	

Dennis Tasa

Section 4 Metamorphic Rocks

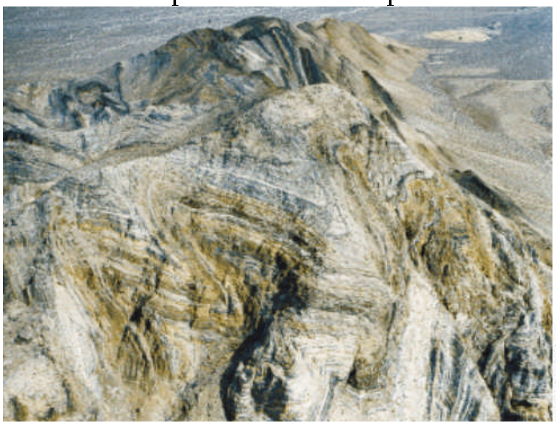
Key Concepts

- 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

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.



Michael Collier

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

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.

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.

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

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 highgrade 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.

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.

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.

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.

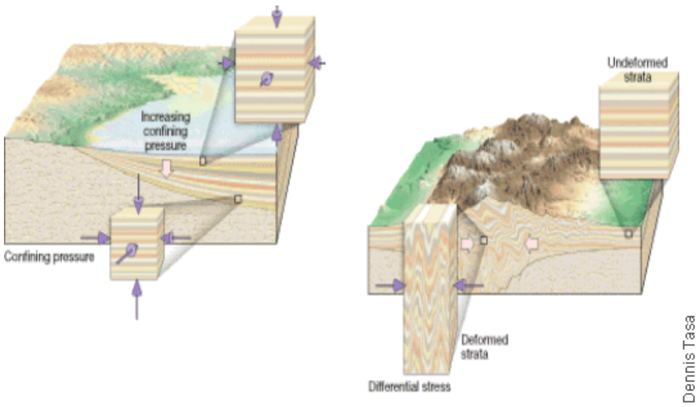


Figure 16 Pressure (Stress) As a Metamorphic Agent A Forces in all directions are applied equally to buried rocks. B During mountain building, rocks subjected to differential stress are shortened in the direction that pressure is applied.

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

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

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

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.

Edward J. Tarbuck

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

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.

Breck P. Kent

Figure 19 Marble is a nonfoliated metamorphic rock.

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

Increasing Metamorphism (Slate → Gneiss)

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