How did it get there?

The giant rocky peak of El Capitan towers majestically in Yosemite National Park. Surrounded by flat landscape, it seems out of place. How did this expanse of granite rock come to be?

**Science Journal** Are you a rock collector? If so, write two sentences about your favorite rock. If not, describe the rocks you see in the photo in enough detail that a nonsighted person could visualize them.

### chapter preview

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<td>Lab</td>
<td>Igneous Rock Clues</td>
<td></td>
<td></td>
<td></td>
<td>How are rocks classified?</td>
</tr>
</tbody>
</table>
Observe and Describe Rocks

Some rocks are made of small mineral grains that lock together, like pieces of a puzzle. Others are grains of sand tightly held together or solidified lava that once flowed from a volcano. If you examine rocks closely, you sometimes can tell what they are made of.

1. Collect three different rock samples near your home or school.
2. Draw a picture of the details you see in each rock.
3. Use a magnifying lens to look for different types of materials within the same rock.
4. Describe the characteristics of each rock. Compare your drawings and descriptions with photos, drawings, and descriptions in a rocks and minerals field guide.
5. Use the field guide to try to identify each rock.
6. **Think Critically** Decide whether you think your rocks are mixtures. If so, infer or suggest what these mixtures might contain. Write your explanations in your Science Journal.

Make an Organizational Study Fold

As you read the chapter, write and illustrate what you learn about the three main types of rocks in your study fold.

**STEP 1** Fold a sheet of paper in half lengthwise. Make the back edge about 5 cm longer than the front edge.

**STEP 2** Turn the paper so the fold is on the bottom. Then fold it into thirds.

**STEP 3** Unfold and cut only the top layer along both folds to make three tabs.

**STEP 4** Label the Foldable as shown.
What is a rock?

Imagine you and some friends are exploring a creek. Your eye catches a glint from a piece of rock at the edge of the water. As you wander over to pick up the rock, you notice that it is made of different-colored materials. Some of the colors reflect light, while others are dull. You put the rock in your pocket for closer inspection in science lab.

Common Rocks  The next time you walk past a large building or monument, stop and take a close look at it. Chances are that it is made out of common rock. In fact, most rock used for building stone contains one or more common minerals, called rock-forming minerals, such as quartz, feldspar, mica, or calcite. When you look closely, the sparkles you see are individual crystals of minerals. A rock is a mixture of such minerals, rock fragments, volcanic glass, organic matter, or other natural materials. Figure 1 shows minerals mixed together to form the rock granite. You might even find granite near your home.

Figure 1  Mount Rushmore, in South Dakota, is made of granite. Granite is a mixture of feldspar, quartz, mica, hornblende, and other minerals.
The Rock Cycle

To show how rocks slowly change through time, scientists have created a model called the rock cycle, shown in Figure 2. It illustrates the processes that create and change rocks. The rock cycle shows the three types of rock—igneous, metamorphic, and sedimentary—and the processes that form them.

Look at the rock cycle and notice that rocks change by many processes. For example, a sedimentary rock can change by heat and pressure to form a metamorphic rock. The metamorphic rock then can melt and later cool to form an igneous rock. The igneous rock then could be broken into fragments by weathering and erode away. The fragments might later compact and cement together to form another sedimentary rock. Any given rock can change into any of the three major rock types. A rock even can transform into another rock of the same type.

What is illustrated by the rock cycle?

Modeling Rock

Procedure
1. Mix about 10 mL of white glue with about 7 g of dirt or sand in a small paper cup.
2. Stir the mixture and then allow it to harden overnight.
3. Tear away the paper cup carefully from your mixture.

Analysis
1. Which rock type is similar to your hardened mixture?
2. Which part of the rock cycle did you model?
Rocks continuously form and transform in a process that geologists call the rock cycle. For example, molten rock—from volcanoes such as Washington’s Mount Rainier, background—cools and solidifies to form igneous rock. It slowly breaks down when exposed to air and water to form sediments. These sediments are compacted or cemented into sedimentary rock. Heat and pressure might transform sedimentary rock into metamorphic rock. When metamorphic rock melts and hardens, igneous rock forms again. There is no distinct beginning, nor is there an end, to the rock cycle.
Matter and the Rock Cycle
The rock cycle, illustrated in Figure 3, shows how rock can be weathered to small rock and mineral grains. This material then can be eroded and carried away by wind, water, or ice. When you think of erosion, it might seem that the material is somehow destroyed and lost from the cycle. This is not the case. The chemical elements that make up minerals and rocks are not destroyed. This fact illustrates the principle of conservation of matter. The changes that take place in the rock cycle never destroy or create matter. The elements are just redistributed in other forms.

**Reading Check**
What is the principle of conservation of matter?

Discovering the Rock Cycle
James Hutton, a Scottish physician and naturalist, first recognized in 1788 that rocks undergo profound changes. Hutton noticed, among other things, that some layers of solid rock in Siccar Point, shown in Figure 4, had been altered since they formed. Instead of showing a continuous pattern of horizontal layering, some of the rock layers at Siccar Point are tilted and partly eroded. However, the younger rocks above them are nearly horizontal.

Hutton published these and other observations, which proved that rocks are subject to constant change. Hutton’s early recognition of the rock cycle continues to influence geologists.

**Summary**

What is a rock?
- Rocks are mixtures of minerals, rock fragments, organic matter, volcanic glass, and other materials found in nature.

The Rock Cycle
- The three major types of rock are igneous, metamorphic, and sedimentary.
- Rock cycle processes do not create or destroy matter.
- Processes that are part of the rock cycle change rocks slowly over time.
- In the late eighteenth century, James Hutton recognized some rock cycle processes by observing rocks in the field.
- Some of Hutton’s ideas continue to influence geologic thinking today.

**Self Check**
1. Explain how rocks differ from minerals.
2. Compare and contrast igneous and metamorphic rock formation.
3. Describe the major processes of the rock cycle.
4. Explain one way that the rock cycle can illustrate the principle of conservation of matter.
5. Think Critically How would you define magma based on the illustration in Figure 2? How would you define sediment and sedimentary rock?

**Applying Skills**
6. Communicate Review the model of the rock cycle in Figure 2. In your Science Journal, write a story or poem that explains what can happen to a sedimentary rock as it changes throughout the rock cycle.
Chapter 3
Rocks

Igneous Rocks

Formation of Igneous Rocks

Perhaps you’ve heard of recent volcanic eruptions in the news. When some volcanoes erupt, they eject a flow of molten rock material, as shown in Figure 5. Molten rock material, called magma, flows when it is hot and becomes solid when it cools. When hot magma cools and hardens, it forms igneous (IHG nee us) rock. Why do volcanoes erupt, and where does the molten material come from?

Magma In certain places within Earth, the temperature and pressure are just right for rocks to melt and form magma. Most magmas come from deep below Earth’s surface. Magma is located at depths ranging from near the surface to about 150 km below the surface. Temperatures of magmas range from about 650°C to 1,200°C, depending on their chemical compositions and pressures exerted on them.

The heat that melts rocks comes from sources within Earth’s interior. One source is the decay of radioactive elements within Earth. Some heat is left over from the formation of the planet, which originally was molten. Radioactive decay of elements contained in rocks balances some heat loss as Earth continues to cool.

Because magma is less dense than surrounding solid rock, it is forced upward toward the surface, as shown in Figure 6. When magma reaches Earth’s surface and flows from volcanoes, it is called lava.

Figure 5 Some lava is highly fluid and free-flowing, as shown by this spectacular lava fall in Volcano National Park, East Rift, Kilauea, Hawaii.
**Intrusive Rocks**  Magma is melted rock material composed of common elements and fluids. As magma cools, atoms and compounds in the liquid rearrange themselves into new crystals called mineral grains. Rocks form as these mineral grains grow together. Rocks that form from magma below the surface, as illustrated in Figure 6, are called **intrusive** igneous rocks. Intrusive rocks are found at the surface only after the layers of rock and soil that once covered them have been removed by erosion. Erosion occurs when the rocks are pushed up by forces within Earth. Because intrusive rocks form at depth and they are surrounded by other rocks, it takes a long time for them to cool. Slowly cooled magma produces individual mineral grains that are large enough to be observed with the unaided eye.

**Extrusive Rocks**  Extrusive igneous rocks are formed as lava cools on the surface of Earth. When lava flows on the surface, as illustrated in Figure 6, it is exposed to air and water. Lava, such as the basaltic lava shown in Figure 5, cools quickly under these conditions. The quick cooling rate keeps mineral grains from growing large, because the atoms in the liquid don’t have the time to arrange into large crystals. Therefore, extrusive igneous rocks are fine grained.

---

| Reading Check | **What controls the grain size of an igneous rock?** |

---

**Figure 6**  Intrusive rocks form from magma trapped below Earth’s surface. Extrusive rocks form from lava flowing at the surface.
Volcanic Glass  Pumice, obsidian, and scoria are examples of volcanic glass. These rocks cooled so quickly that few or no mineral grains formed. Most of the atoms in these rocks are not arranged in orderly patterns, and few crystals are present.

In the case of pumice and scoria, gases become trapped in the gooey molten material as it cools. Some of these gases eventually escape, but holes are left behind where the rock formed around the pockets of gas.

### Classifying Igneous Rocks

Igneous rocks are intrusive or extrusive depending on how they are formed. A way to further classify these rocks is by the magma from which they form. As shown in Table 1, an igneous rock can form from basaltic, andesitic, or granitic magma. The type of magma that cools to form an igneous rock determines important chemical and physical properties of that rock. These include mineral composition, density, color, and melting temperature.

### Table 1  Common Igneous Rocks

<table>
<thead>
<tr>
<th>Magma Type</th>
<th>Basaltic</th>
<th>Andesitic</th>
<th>Granitic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrusive</td>
<td>Gabbro</td>
<td>Diorite</td>
<td>Granite</td>
</tr>
<tr>
<td>Extrusive</td>
<td>Basalt</td>
<td>Rhyolite</td>
<td>Obsidian</td>
</tr>
<tr>
<td></td>
<td>Scoria</td>
<td>Andesite</td>
<td>Pumice</td>
</tr>
</tbody>
</table>

### ScienceOnline

**Topic: Rock Formation**

Visit green.msscience.com for Web links to information about intrusive and extrusive rocks.

**Activity**  List several geographic settings where intrusive or extrusive rocks are found. Select one setting for intrusive rocks, and one for extrusive rocks. Describe how igneous rocks form in the two settings, and locate an example of each on a map.

**Reading Check**  Name two ways igneous rocks are classified.
**Basaltic Rocks** Basaltic (buh SAWL tihk) igneous rocks are dense, dark-colored rocks. They form from magma that is rich in iron and magnesium and poor in silica, which is the compound SiO₂. The presence of iron and magnesium in minerals in basalt gives basalt its dark color. Basaltic lava is fluid and flows freely from volcanoes in Hawaii, such as Kilauea. How does this explain the black beach sand common in Hawaii?

**Granitic Rocks** Granitic igneous rocks are light-colored rocks of a lower density than basaltic rocks. Granitic magma is thick and stiff and contains lots of silica but lesser amounts of iron and magnesium. Because granitic magma is stiff, it can build up a great deal of gas pressure, which is released explosively during violent volcanic eruptions.

**Andesitic Rocks** Andesitic igneous rocks have mineral compositions between those of basaltic and granitic rocks. Many volcanoes around the rim of the Pacific Ocean formed from andesitic magmas. Like volcanoes that erupt granitic magma, these volcanoes also can erupt violently.

Take another look at Table 1. Basalt forms at the surface of Earth because it is an extrusive rock. Granite forms below Earth’s surface from magma with a high concentration of silica. When you identify an igneous rock, you can infer how it formed and the type of magma that it formed from.

**Summary**

**Formation of Igneous Rocks**
- When molten rock material, called magma, cools and hardens, igneous rock forms.
- Intrusive igneous rocks form as magma cools and hardens slowly, beneath Earth’s surface.
- Extrusive igneous rocks form as lava cools and hardens rapidly, at or above Earth’s surface.

**Classifying Igneous Rocks**
- Igneous rocks are further classified according to their mineral compositions.
- The violent nature of some volcanic eruptions is partly explained by the composition of the magma that feeds them.

**Self Check**

1. Explain why some types of magma form igneous rocks that are dark colored and dense.
2. Identify the property of magma that causes it to be forced upward toward Earth’s surface.
3. Explain The texture of obsidian is best described as glassy. Why does obsidian contain few or no mineral grains?
4. Think Critically Study the photos in Table 1. How are granite and rhyolite similar? How are they different?
5. Make and Use Graphs Four elements make up most of the rocks in Earth’s crust. They are: oxygen—46.6 percent, aluminum—8.1 percent, silicon—27.7 percent, and iron—5.0 percent. Make a bar graph of these data. What might you infer from the low amount of iron?
You’ve learned how color often is used to estimate the composition of an igneous rock. The texture of an igneous rock describes its overall appearance, including mineral grain sizes and the presence or absence of bubble holes, for example. In most cases, grain size relates to how quickly the magma or lava cooled. Crystals you can see without a magnifying lens indicate slower cooling. Smaller, fine-grained crystals indicate quicker cooling, possibly due to volcanic activity. Rocks with glassy textures cooled so quickly that there was no time to form mineral grains.

Real-World Question
What does an igneous rock’s texture and color indicate about its formation history?

Goals
■ Classify different samples of igneous rocks by color and infer their composition.
■ Observe the textures of igneous rocks and infer how they formed.

Materials
rhyolite granite
basalt obsidian
vesicular basalt gabbro
pumice magnifying lens

Safety Precautions
WARNING: Some rock samples might have sharp edges. Always use caution while handling samples.

Procedure
1. Arrange rocks according to color (light or dark). Record your observations in your Science Journal.
2. Arrange rocks according to similar texture. Consider grain sizes and shapes, presence of holes, etc. Use your magnifying lens to see small features more clearly. Record your observations.

Conclude and Apply
1. Infer which rocks are granitic based on color.
2. Infer which rocks cooled quickly. What observations led you to this inference?
3. Identify any samples that suggest gases were escaping from them as they cooled.
4. Describe Which samples have a glassy appearance? How did these rocks form?
5. Infer which samples are not volcanic. Explain.

Communicating Your Data
Research the compositions of each of your samples. Did the colors of any samples lead you to infer the wrong compositions? Communicate to your class what you learned.
Formation of Metamorphic Rocks

Have you ever packed your lunch in the morning and not been able to recognize it at lunchtime? You might have packed a sandwich, banana, and a large bottle of water. You know you didn’t smash your lunch on the way to school. However, you didn’t think about how the heavy water bottle would damage your food if the bottle was allowed to rest on the food all day. The heat in your locker and the pressure from the heavy water bottle changed your sandwich. Like your lunch, rocks can be affected by changes in temperature and pressure.

**Metamorphic Rocks**  Rocks that have changed because of changes in temperature and pressure or the presence of hot, watery fluids are called **metamorphic rocks**. Changes that occur can be in the form of the rock, shown in Figure 7, the composition of the rock, or both. Metamorphic rocks can form from igneous, sedimentary, or other metamorphic rocks. What Earth processes can change these rocks?

**Review Vocabulary**
- **pressure**: the amount of force exerted per unit of area

**New Vocabulary**
- metamorphic rock
- foliated
- nonfoliated

**Figure 7** The mineral grains in granite are flattened and aligned when heat and pressure are applied to them. As a result, gneiss is formed.

Describe other conditions that can cause metamorphic rocks to form.
Heat and Pressure  Rocks beneath Earth’s surface are under great pressure from rock layers above them. Temperature also increases with depth in Earth. In some places, the heat and pressure are just right to cause rocks to melt and magma to form. In other areas where melting doesn’t occur, some mineral grains can change by dissolving and recrystallizing—especially in the presence of fluids. Sometimes, under these conditions, minerals exchange atoms with surrounding minerals and new, bigger minerals form.

Depending upon the amount of pressure and temperature applied, one type of rock can change into several different metamorphic rocks, and each type of metamorphic rock can come from several kinds of parent rocks. For example, the sedimentary rock shale will change into slate. As increasing pressure and temperature are applied, the slate can change into phyllite, then schist, and eventually gneiss. Schist also can form when basalt is metamorphosed, or changed, and gneiss can come from granite.

How can one type of rock change into several different metamorphic rocks?

Hot Fluids  Did you know that fluids can move through rock? These fluids, which are mostly water with dissolved elements and compounds, can react chemically with a rock and change its composition, especially when the fluids are hot. That’s what happens when rock surrounding a hot magma body reacts with hot fluids from the magma, as shown in Figure 8. Most fluids that transform rocks during metamorphic processes are hot and mainly are comprised of water and carbon dioxide.
Classifying Metamorphic Rocks

Metamorphic rocks form from igneous, sedimentary, or other metamorphic rocks. Heat, pressure, and hot fluids trigger the changes. Each resulting rock can be classified according to its composition and texture.

Foliated Rocks When mineral grains line up in parallel layers, the metamorphic rock is said to have a foliated texture. Two examples of foliated rocks are slate and gneiss. Slate forms from the sedimentary rock shale. The minerals in shale arrange into layers when they are exposed to heat and pressure. As Figure 9 shows, slate separates easily along these foliation layers.

The minerals in slate are pressed together so tightly that water can’t pass between them easily. Because it’s watertight, slate is ideal for paving around pools and patios. The naturally flat nature of slate and the fact that it splits easily make it useful for roofing and tiling many surfaces.

Gneiss (NISE), another foliated rock, forms when granite and other rocks are changed. Foliation in gneiss shows up as alternating light and dark bands. Movement of atoms has separated the dark minerals, such as biotite mica, from the light minerals, which are mainly quartz and feldspar.

What type of metamorphic rock is composed of mineral grains arranged in parallel layers?

Figure 9 Slate often is used as a building or landscaping material. Identify the properties that make slate so useful for these purposes.
Nonfoliated Rocks  In some metamorphic rocks, layering does not occur. The mineral grains grow and rearrange, but they don’t form layers. This process produces a nonfoliated texture.

Sandstone is a sedimentary rock that’s often composed mostly of quartz grains. When sandstone is heated under a lot of pressure, the grains of quartz grow in size and become interlocking, like the pieces of a jigsaw puzzle. The resulting rock is called quartzite.

Marble is another nonfoliated metamorphic rock. Marble forms from the sedimentary rock limestone, which is composed of the mineral calcite. Usually, marble contains several other minerals besides calcite. For example, hornblende and serpentine give marble a black or greenish tone, whereas hematite makes it red. As Figure 10 shows, marble is a popular material for artists to sculpt because it is not as hard as other rocks.

So far, you’ve investigated only a portion of the rock cycle. You still haven’t observed how sedimentary rocks are formed and how igneous and metamorphic rocks evolve from them. The next section will complete your investigation of the rock cycle.

Figure 10  This exhibit in Vermont shows the beauty of carved marble.
Formation of Sedimentary Rocks

Igneous rocks are the most common rocks on Earth, but because most of them exist below the surface, you might not have seen too many of them. That’s because 75 percent of the rocks exposed at the surface are sedimentary rocks.

Sediments are loose materials such as rock fragments, mineral grains, and bits of shell that have been moved by wind, water, ice, or gravity. If you look at the model of the rock cycle, you will see that sediments come from already-existing rocks that are weathered and eroded. Sedimentary rock forms when sediments are pressed and cemented together, or when minerals form from solutions.

Stacked Rocks Sedimentary rocks often form as layers. The older layers are on the bottom because they were deposited first. Sedimentary rock layers are a lot like the books and papers in your locker. Last week’s homework is on the bottom, and today’s notes will be deposited on top of the stack. However, if you disturb the stack, the order in which the books and papers are stacked will change, as shown in Figure 11. Sometimes, forces within Earth overturn layers of rock, and the oldest are no longer on the bottom.
Classifying Sedimentary Rocks

Sedimentary rocks can be made of just about any material found in nature. Sediments come from weathered and eroded igneous, metamorphic, and sedimentary rocks. Sediments also come from the remains of some organisms. The composition of a sedimentary rock depends upon the composition of the sediments from which it formed.

Like igneous and metamorphic rocks, sedimentary rocks are classified by their composition and by the manner in which they formed. Sedimentary rocks usually are classified as detrital, chemical, or organic.

Detrital Sedimentary Rocks

The word *detrital* (dih TRI tul) comes from the Latin word *detritus*, which means “to wear away.” Detrital sedimentary rocks, such as those shown in Table 2, are made from the broken fragments of other rocks. These loose sediments are compacted and cemented together to form solid rock.

**Weathering and Erosion** When rock is exposed to air, water, or ice, it is unstable and breaks down chemically and mechanically. This process, which breaks rocks into smaller pieces, is called weathering. Table 2 shows how these pieces are classified by size. The movement of weathered material is called erosion.

**Compaction** Erosion moves sediments to a new location, where they then are deposited. Here, layer upon layer of sediment builds up. Pressure from the upper layers pushes down on the lower layers. If the sediments are small, they can stick together and form solid rock. This process, shown in Figure 12, is called compaction.

**Classifying Sediments**

**Procedure**

**WARNING:** Use care when handling sharp objects.

1. Collect different samples of sediment.
2. Spread them on a sheet of paper.
3. Use Table 2 to determine the size range of gravel-sized sediment.
4. Use tweezers or a dissecting probe and a magnifying lens to separate the gravel-sized sediments.
5. Separate the gravel into piles—rounded or angular.

**Analysis**

1. Describe the grains in both piles.
2. Determine what rock could form from each type of sediment you have.

**Figure 12** During compaction, pore space between sediments decreases, causing them to become packed together more tightly.

**Reading Check** How do rocks form through compaction?
Cementation  If sediments are large, like sand and pebbles, pressure alone can’t make them stick together. Large sediments have to be cemented together. As water moves through soil and rock, it picks up materials released from minerals during weathering. The resulting solution of water and dissolved materials moves through open spaces between sediments. Cementation, which is shown in Figure 13, occurs when minerals such as quartz, calcite, and hematite are deposited between the pieces of sediment. These minerals, acting as natural cements, hold the sediment together like glue, making a detrital sedimentary rock.

Shape and Size of Sediments  Detrital rocks have granular textures, much like granulated sugar. They are named according to the shapes and sizes of the sediments that form them. For example, conglomerate and breccia both form from large sediments, as shown in Table 2. If the sediments are rounded, the rock is called conglomerate. If the sediments have sharp angles, the rock is called breccia. The roundness of sediment particles depends on how far they have been moved by wind or water.

<table>
<thead>
<tr>
<th>Sediment</th>
<th>Clay</th>
<th>Silt</th>
<th>Sand</th>
<th>Gravel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size Range</td>
<td>&lt;0.004 mm</td>
<td>0.004–0.063 mm</td>
<td>0.063–2 mm</td>
<td>&gt;2 mm</td>
</tr>
<tr>
<td>Example</td>
<td>Shale</td>
<td>Siltstone</td>
<td>Sandstone</td>
<td>Conglomerate (shown) or Breccia</td>
</tr>
</tbody>
</table>

Figure 13  Sediments are cemented together as minerals crystallize between grains.
Materials Found in Sedimentary Rocks  The gravel-sized sediments in conglomerate and breccia can consist of any type of rock or mineral. Often, they are composed of chunks of the minerals quartz and feldspar. They also can be pieces of rocks such as gneiss, granite, or limestone. The cement that holds the sediments together usually is made of quartz or calcite.

Have you ever looked at the concrete in sidewalks, driveways, and stepping stones? The concrete in Figure 14 is made of gravel and sand grains that have been cemented together. Although the structure is similar to that of naturally occurring conglomerate, it cannot be considered a rock.

Sandstone is formed from smaller particles than conglomerates and breccias. Its sand-sized sediments can be just about any mineral, but they are usually grains of minerals such as quartz and feldspar that are resistant to weathering. Siltstone is similar to sandstone except it is made of smaller, silt-sized particles. Shale is a detrital sedimentary rock that is made mainly of clay-sized particles. Clay-sized sediments are compacted together by pressure from overlying layers.

Chemical Sedimentary Rocks  Chemical sedimentary rocks form when dissolved minerals come out of solution. You can show that salt is deposited in the bottom of a glass or pan when saltwater solution evaporates. In a similar way, minerals collect when seas or lakes evaporate. The deposits of minerals that come out of solution form sediments and rocks. For example, the sediment making up New Mexico's White Sands desert consists of pieces of a chemical sedimentary rock called rock gypsum. Chemical sedimentary rocks are different. They are not made from pieces of preexisting rocks.
Limestone  Calcium carbonate is carried in solution in ocean water. When calcium carbonate (CaCO₃) comes out of solution as calcite and its many crystals grow together, limestone forms. Limestone also can contain other minerals and sediments, but it must be at least 50 percent calcite. Limestone usually is deposited on the bottom of lakes or shallow seas. Large areas of the central United States have limestone bedrock because seas covered much of the country for millions of years. It is hard to imagine Kansas being covered by ocean water, but it has happened several times throughout geological history.

Rock Salt  When water that is rich in dissolved salt evaporates, it often deposits the mineral halite. Halite forms rock salt, shown in Figure 15. Rock salt deposits can range in thickness from a few meters to more than 400 m. Companies mine these deposits because rock salt is an important resource. It’s used in the manufacturing of glass, paper, soap, and dairy products. The halite in rock salt is processed and used as table salt.

Organic Sedimentary Rocks  Rocks made of the remains of once-living things are called organic sedimentary rocks. One of the most common organic sedimentary rocks is fossil-rich limestone. Like chemical limestone, fossil-rich limestone is made of the mineral calcite. However, fossil-rich limestone mostly contains remains of once-living ocean organisms instead of only calcite that formed directly from ocean water.

Animals such as mussels, clams, corals, and snails make their shells from CaCO₃ that eventually becomes calcite. When they die, their shells accumulate on the ocean floor. When these shells are cemented together, fossil-rich limestone forms. If a rock is made completely of shell fragments that you can see, the rock is called coquina (koh KEE nuh).

Chalk  Chalk is another organic sedimentary rock that is made of microscopic shells. When you write with naturally occurring chalk, you’re crushing and smearing the calcite-shell remains of once-living ocean organisms.
Coal Another useful organic sedimentary rock is coal, shown in Figure 16. Coal forms when pieces of dead plants are buried under other sediments in swamps. These plant materials are chemically changed by microorganisms. The resulting sediments are compacted over millions of years to form coal, an important source of energy. Much of the coal in North America and Europe formed during a period of geologic time that is so named because of this important reason. The Carboniferous Period, which spans from approximately 360 to 286 million years ago, was named in Europe. So much coal formed during this interval of time that coal’s composition—primarily carbon—was the basis for naming a geologic period.

COAL FORMATION It took 300 million years for a layer of plant matter about 0.9 m thick to produce a bed of bituminous coal 0.3 m thick. Estimate the thickness of plant matter that produced a bed of coal 0.15 m thick.

Solution
1. This is what you know:
   - original thickness of plant matter = 0.9 m
   - original coal thickness = 0.3 m
   - new coal thickness = 0.15 m
2. This is what you need to know:
   thickness of plant matter needed to form 0.15 m of coal
3. This is the equation you need to use:
   \[
   \frac{\text{thickness of plant matter}}{\text{new coal thickness}} = \frac{\text{original thickness of plant matter}}{\text{original coal thickness}}
   \]
4. Substitute the known values:
   \[
   \frac{? \ m \text{ plant matter}}{0.15 \ m \text{ coal}} = \frac{0.9 \ m \text{ plant matter}}{0.3 \ m \text{ coal}}
   \]
5. Solve the equation:
   \[
   (? \ m \text{ plant matter}) = (0.9 \ m \text{ plant matter})
   (0.15 \ m \text{ coal})/(0.3 \ m \text{ coal}) = 0.45 \ m \text{ plant matter}
   \]
6. Check your answer:
   Multiply your answer by the original coal thickness. Divide by the original plant matter thickness to get the new coal thickness.

Practice Problems
1. Estimate the thickness of plant matter that produced a bed of coal 0.6 m thick.
2. About how much coal would have been produced from a layer of plant matter 0.50 m thick?
Self Check

1. Identify where sediments come from.
2. Explain how compaction is important in the formation of coal.
3. Compare and contrast detrital and chemical sedimentary rock.
4. List chemical sedimentary rocks that are essential to your health or that are used to make life more convenient. How is each used?
5. Think Critically Explain how pieces of granite and slate could both be found in the same conglomerate. How would the granite and slate pieces be held together?

Summary

Formation of Sedimentary Rocks
- Sedimentary rocks form as layers, with older layers near the bottom of an undisturbed stack.

Classifying Sedimentary Rocks
- To classify a sedimentary rock, determine its composition and texture.

Detrital Sedimentary Rocks
- Rock and mineral fragments make up detrital rocks.

Chemical Sedimentary Rocks
- Chemical sedimentary rocks form from solutions of dissolved minerals.

Organic Sedimentary Rocks
- The remains of once-living organisms make up organic sedimentary rocks.

Another Look at the Rock Cycle

You have seen that the rock cycle has no beginning and no end. Rocks change continually from one form to another. Sediments can become so deeply buried that they eventually become metamorphic or igneous rocks. These reformed rocks later can be uplifted and exposed to the surface—possibly as mountains to be worn away again by erosion.

All of the rocks that you’ve learned about in this chapter formed through some process within the rock cycle. All of the rocks around you, including those used to build houses and monuments, are part of the rock cycle. Slowly, they are all changing, because the rock cycle is a continuous, dynamic process.

Figure 16 This coal layer in Alaska is easily identified by its jet-black color, as compared with other sedimentary layers.
Sedimentary rocks are formed by compaction and cementation of sediment. Because sediment is found in all shapes and sizes, do you think these characteristics could be used to classify detrital sedimentary rocks? Sedimentary rocks also can be classified as chemical or organic.

**Real-World Question**

How are rock characteristics used to classify sedimentary rocks as detrital, chemical, or organic?

**Procedure**

1. Make a Sedimentary Rock Samples chart in your Science Journal similar to the one shown on the next page.
2. Determine the sizes of sediments in each sample, using a magnifying lens and a metric ruler. Using Table 2, classify any grains of sediment in the rocks as gravel, sand, silt, or clay. In general, the sediment is silt if it is gritty and just barely visible, and clay if it is smooth and if individual grains are not visible.
3. Place a few drops of 5% HCl solution on each rock sample. Bubbling on a rock indicates the presence of calcite.
4. Examine each sample for fossils and describe any that are present.
5. Determine whether each sample has a granular or nongranular texture.
Analyze Your Data

1. **Classify** your samples as detrital, chemical, or organic.
2. **Identify** each rock sample.

Conclude and Apply

1. **Explain** why you tested the rocks with acid. What minerals react with acid?
2. **Compare and contrast** sedimentary rocks that have a granular texture with sedimentary rocks that have a nongranular texture.

Communicating Your Data

**Compare** your conclusions with those of other students in your class. For more help, refer to the *Science Skill Handbook*.

---

### Sedimentary Rock Samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>Observations</th>
<th>Minerals or Fossils Present</th>
<th>Sediment Size</th>
<th>Detrital, Chemical, or Organic</th>
<th>Rock Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
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</tr>
</tbody>
</table>

*Do not write in this book.*
Uluru (yew LEW rew), also known as Ayers Rock, is one of the most popular tourist destinations in Australia. This sandstone skyscraper is more than 8 km around, over 300 m high, and extends as much as 4.8 km below the surface. One writer describes it as an iceberg in the desert. Geologists hypothesize that the mighty Uluru rock began forming 550 million years ago during Precambrian time. That’s when large mountain ranges started to form in Central Australia.

For more than 25,000 years, this geological wonder has played an important role in the lives of the Aboriginal peoples, the Anangu (a NA noo). These native Australians are the original owners of the rock and have spiritual explanations for its many caves, holes, and scars.

Tourists Take Over

In the 1980s, some 100,000 tourists visited—and many climbed—Uluru. In 2000, the rock attracted about 400,000 tourists. The Anangu take offense at anyone climbing their sacred rock. However, if climbing the rock were outlawed, tourism would be seriously hurt. That would mean less income for Australians.

To respect the Anangu’s wishes, the Australian government returned Ayers Rock to the Anangu in 1985 and agreed to call it by its traditional name. The Anangu leased back the rock to the Australian government until the year 2084, when its management will return to the Anangu. Until then, the Anangu will collect 25 percent of the money people pay to visit the rock.

The Aboriginal people encourage tourists to respect their beliefs. They offer a walking tour around the rock, and they show videos about Aboriginal traditions. The Anangu sell T-shirts that say “I didn’t climb Uluru.” They hope visitors to Uluru will wear the T-shirt with pride and respect.

Write Research a natural landmark or large natural land or water formation in your area. What is the geology behind it? When was it formed? How was it formed? Write a folktale that explains its formation. Share your folktale with the class.
Copy and complete the following concept map on rocks. Use the following terms: organic, metamorphic, foliated, extrusive, igneous, and chemical.

1. A rock is a mixture of one or more minerals, rock fragments, organic matter, or volcanic glass.
2. The rock cycle includes all processes by which rocks form.

1. Magma and lava are molten materials that harden to form igneous rocks.
2. Intrusive igneous rocks form when magma cools slowly below Earth's surface. Extrusive igneous rocks form when lava cools rapidly at the surface.
3. The compositions of most igneous rocks range from granitic to andesitic to basaltic.

1. Heat, pressure, and fluids can cause metamorphic rocks to form.
2. Slate and gneiss are examples of foliated metamorphic rocks. Quartzite and marble are examples of nonfoliated metamorphic rocks.

1. Detrital sedimentary rocks form when fragments of rocks and minerals are compacted and cemented together.
2. Chemical sedimentary rocks come out of solution or are left behind by evaporation.
3. Organic sedimentary rocks contain the remains of once-living organisms.
Using Vocabulary

- basaltic p.65
- cementation p.73
- compaction p.72
- extrusive p.63
- foliated p.69
- granitic p.65
- igneous rock p.62
- intrusive p.63
- lava p.62
- metamorphic rock p.67
- nonfoliated p.70
- rock p.58
- rock cycle p.59
- sediment p.71
- sedimentary rock p.71

Explain the difference between the vocabulary words in each of the following sets.

1. foliated—nonfoliated
2. cementation—compaction
3. sediment—lava
4. extrusive—intrusive
5. rock—rock cycle
6. metamorphic rock—igneous rock—sedimentary rock
7. sediment—sedimentary rock
8. lava—igneous rock
9. rock—sediment
10. basaltic—granitic

11. Why does magma tend to rise toward Earth’s surface?
   - A) It is more dense than surrounding rocks.
   - B) It is more massive than surrounding rocks.
   - C) It is cooler than surrounding rocks.
   - D) It is less dense than surrounding rocks.

12. During metamorphism of granite into gneiss, what happens to minerals?
   - A) They partly melt.
   - B) They become new sediments.
   - C) They grow smaller.
   - D) They align into layers.

13. Which rock has large mineral grains?
   - A) granite
   - B) basalt
   - C) obsidian
   - D) pumice

14. Which type of rock is shown in this photo?
   - A) foliated
   - B) nonfoliated
   - C) intrusive
   - D) extrusive

15. What do igneous rocks form from?
   - A) sediments
   - B) mud
   - C) gravel
   - D) magma

16. What sedimentary rock is made of large, angular pieces of sediments?
   - A) conglomerate
   - B) breccia
   - C) limestone
   - D) chalk

17. Which of the following is an example of a detrital sedimentary rock?
   - A) limestone
   - B) evaporite
   - C) breccia
   - D) chalk

18. What is molten material at Earth’s surface called?
   - A) limestone
   - B) lava
   - C) breccia
   - D) granite

19. Which of these is an organic sedimentary rock?
   - A) coquina
   - B) sandstone
   - C) rock salt
   - D) conglomerate
20. **Infer** Granite, pumice, and scoria are igneous rocks. Why doesn’t granite have airholes like the other two?

21. **Infer** why marble rarely contains fossils.

22. **Predict** Would you expect quartzite or sandstone to break more easily? Explain your answer.

23. **Compare and contrast** basaltic and granitic magmas.

24. **Form Hypotheses** A geologist was studying rocks in a mountain range. She found a layer of sedimentary rock that had formed in the ocean. Hypothesize how this could happen.

25. **Concept Map** Copy and complete the concept map shown below. Use the following terms and phrases: *magma*, *sediments*, *igneous rock*, *sedimentary rock*, *metamorphic rock*. Add and label any missing arrows.

26. **Poster** Collect a group of rocks. Make a poster that shows the classifications of rocks, and glue your rocks to the poster under the proper headings. Describe your rocks and explain where you found them.

27. **Grain Size** Assume that the conglomerate shown on the second page of the “Sedimentary Rocks” lab is one-half of its actual size. Determine the average length of the gravel in the rock.

28. **Plant Matter** Suppose that a 4-m layer of plant matter was compacted to form a coal layer 1 m thick. By what percent has the thickness of organic material been reduced?

29. **Melting Granite** Determine the melting temperature of a water-rich granite at a pressure of 0.2 GPa.

   **Pressure conversions:**
   1 GPa, or gigapascal, = 10,000 bars
   1 bar = 0.9869 atmospheres

30. **Melting Pressure** At about what pressure will a water-rich granite melt at 680°C?
Part 1 | Multiple Choice

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

Use the illustration below to answer question 1.

1. These layers of sedimentary rock were not disturbed after they were deposited. Which layer was deposited first?
   A. layer L   C. layer M
   B. layer Z   D. layer A

2. Who realized that rocks undergo changes through long periods of time after observing rocks at Siccar Point, Scotland?
   A. James Hutton   C. Galileo Galilei
   B. Neil Armstrong   D. Albert Einstein

3. During which process do minerals precipitate in the spaces between sediment grains?
   A. compaction   C. cementation
   B. weathering   D. conglomerate

4. Which rock often is sculpted to create statues?
   A. shale   C. coquina
   B. marble   D. conglomerate

5. Which of the following rocks is a metamorphic rock?
   A. shale   C. slate
   B. granite   D. pumice

6. Which rock consists mostly of pieces of seashell?
   A. sandstone   C. pumice
   B. coquina   D. granite

Use the diagram below to answer questions 7–9.

7. Which process in the rock cycle causes magma to form?
   A. melting   C. weathering
   B. erosion   D. cooling

8. What forms when rocks are weathered and eroded?
   A. igneous rock   C. sedimentary rock
   B. sediment   D. metamorphic rock

9. Which type of rock forms because of high heat and pressure without melting?
   A. igneous rock   C. sedimentary rock
   B. intrusive rock   D. metamorphic rock
10. What is a rock? How is a rock different from a mineral?

11. Explain why some igneous rocks are coarse and others are fine.

12. What is foliation? How does it form?

13. How do chemical sedimentary rocks, such as rock salt, form?

14. Why do some rocks contain fossils?

15. How is the formation of chemical sedimentary rocks similar to the formation of cement in detrital sedimentary rocks?

Use the graph below to answer questions 16–17.

16. According to the graph, about how deep below a continent does the temperature reach 1,000°C?

17. In general, what happens to temperature as depth below Earth’s surface increases?

18. Copy the table on your paper. Then, fill in the empty squares with a correct rock name.

<table>
<thead>
<tr>
<th>Magma Type</th>
<th>Basaltic</th>
<th>Andesitic</th>
<th>Granitic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrusive</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extrusive</td>
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</tr>
</tbody>
</table>

19. Explain how igneous rocks are classified.

20. Explain how loose sediment can become sedimentary rock.

21. Why does pressure increase with depth in Earth? How does higher pressure affect rocks?

22. Why is slate sometimes used as shingles for roofs? What other rocks are used for important purposes in society?

23. How are organic sedimentary rocks different from other rocks? List an example of an organic sedimentary rock.

24. Why is the rock cycle called a cycle?

25. A geologist found a sequence of rocks in which 200-million-year-old shales were on top of 100-million-year-old sandstones. Hypothesize how this could happen.

26. Explain why coquina could be classified in more than one way.