Beautiful but Dangerous?

In late October, 2002, earthquakes triggered this vigorous eruption from Mt. Etna, a volcano on the Italian island of Sicily. Strombolian eruptions and lava fountains spewed gas, bombs, blocks, and liquid lava. Ash settled as far away as Libya.

Science Journal Do all volcanoes begin with violent, explosive eruptions? Write about your current beliefs, then do some research and write about your discoveries.
Start-Up Activities

Launch Lab

Map a Volcano
You’ve seen pictures of volcanoes from the ground, but what would a volcano look like on a map? Volcanoes can be represented on maps that show the elevation of the land, topographic maps.

1. Obtain half of a foam ball from your teacher and place it on the top of a table with the flat side down.

2. Using a metric ruler and a permanent marker, mark 1-cm intervals on the foam ball. Start at the base of the ball and mark up at several places around the ball.

3. Connect the marks of equal elevation by drawing a line around the ball at the 1-cm mark, at the 2-cm mark, etc.

4. Look directly down on the top of the ball. Make a drawing of what you see in your Science Journal.

5. Think Critically In your Science Journal, write a paragraph that explains how your drawing shows the volcano’s general shape.

Foldables Study Organizer
Volcanoes Make the following Foldable to compare and contrast the characteristics of explosive and quiet volcanic eruptions.

STEP 1 Fold one sheet of paper lengthwise.

STEP 2 Fold into thirds.

STEP 3 Unfold and draw overlapping ovals. Cut the top sheet along the folds.

STEP 4 Label the ovals Explosive Eruptions, Both, and Quiet Eruptions, as shown.

Construct a Venn Diagram As you read the chapter, list the characteristics unique to explosive eruptions under the left tab, those unique to quiet eruptions under the right tab, and those characteristics common to both under the middle tab.

ScienceOnline Preview this chapter’s content and activities at earth.msscience.com
**What are volcanoes?**

A *volcano* is an opening in Earth that erupts gases, ash, and lava. Volcanic mountains form when layers of lava, ash, and other material build up around these openings. Can you name any volcanoes? Did you know that Earth has more than 600 active volcanoes?

**Most Active Volcanoes** Kilauea (kee low AY ah), located in Hawaii, is the world’s most active volcano. For centuries, this volcano has been erupting, but not explosively. In May of 1990, most of the town of Kalapana Gardens was destroyed, but no one was hurt because the lava moved slowly and people could escape. The most recent series of eruptions from Kilauea began in January 1983 and still continues.

The island country of Iceland is also famous for its active volcanoes. It sits on an area where Earth’s plates move apart and is known as the land of fire and ice. The February 26, 2000, eruption of Hekla, in Iceland, is shown in **Figure 1**.
Effects of Eruptions

When volcanoes erupt, they often have direct, dramatic effects on the lives of people and their property. Lava flows destroy everything in their path. Falling volcanic ash can collapse buildings, block roads, and in some cases cause lung disease in people and animals. Sometimes, volcanic ash and debris rush down the side of the volcano. This is called a pyroclastic flow. The temperatures inside the flow can be high enough to ignite wood. When big eruptions occur, people often are forced to abandon their land and homes. People who live farther away from volcanoes are more likely to survive, but cities, towns, crops, and buildings in the area can be damaged by falling debris.

Human and Environmental Impacts

The eruption of Soufrière (saw FREE er) Hills volcano in Montserrat, which began in July of 1995, was one of the largest recent volcanic eruptions near North America. Geologists knew it was about to erupt, and the people who lived near it were evacuated. On June 25, 1997, large pyroclastic flows swept down the volcano. As shown in Figure 2, they buried cities and towns that were in their path. The eruption killed 20 people who ignored the evacuation order.

When sulfurous gases from volcanoes mix with water vapor in the atmosphere, acid rain forms. The vegetation, lakes, and streams around Soufrière Hills volcano were impacted significantly by acid rain. As the vegetation died, shown in Figure 3, the organisms that lived in the forest were forced to leave or also died.
How do volcanoes form?

What happens inside Earth to create volcanoes? Why are some areas of Earth more likely to have volcanoes than others? Deep inside Earth, heat and pressure changes cause rock to melt, forming liquid rock or magma. Some deep rocks already are melted. Others are hot enough that a small rise in temperature or drop in pressure can cause them to melt and form magma. What makes magma come to the surface?

Magma Forced Upward  Magma is less dense than the rock around it, so it is forced slowly toward Earth’s surface. You can see this process if you turn a bottle of cold syrup upside down. Watch the dense syrup force the less dense air bubbles slowly toward the top.

Why is magma forced toward Earth’s surface?

After many thousands or even millions of years, magma reaches Earth’s surface and flows out through an opening called a vent. As lava flows out, it cools quickly and becomes solid, forming layers of igneous rock around the vent. The steep-walled depression around a volcano’s vent is the crater. Figure 4 shows magma being forced out of a volcano.

Volcanologists

Volcanologists research many aspects of volcanoes, including space volcanoes. Io, a moon of Jupiter, has many active volcanoes. Become an amateur volcanologist; choose an aspect of volcanology that interests you, research your topic, and then create an exciting news broadcast to share the information with the class.

Figure 4 This cutaway diagram shows how a volcano is formed and how magma from inside Earth is forced to the surface.
Where do volcanoes occur?

Volcanoes often form in places where plates are moving apart, where plates are moving together, and at locations called hot spots. You can find locations of active volcanoes at plate boundaries and at hot spots on the map in Figure 5. Many examples can be found of volcanoes around the world that form at these three different kinds of areas. You’ll explore volcanoes in Iceland, on the island of Montserrat, and in Hawaii.

Divergent Plate Boundaries  Iceland is a large island in the North Atlantic Ocean. It is near the Arctic Circle and therefore has some glaciers. Iceland has volcanic activity because it is part of the Mid-Atlantic Ridge.

The Mid-Atlantic Ridge is a divergent plate boundary, which is an area where Earth’s plates are moving apart. When plates separate, they form long, deep cracks called rifts. Lava flows from these rifts and is cooled quickly by seawater. Figure 6 shows how magma rises at rifts to form new volcanic rock. As more lava flows and hardens, it builds up on the seafloor. Sometimes, the volcanoes and rift eruptions rise above sea level, forming islands such as Iceland. In 1963, the new island Surtsey was formed during a volcanic eruption.

Figure 5 This map shows the locations of volcanoes, hot spots, and plate boundaries around the world. The Ring of Fire is a belt of active volcanoes that circles the Pacific Ocean.

Figure 6 This diagram shows how volcanic activity occurs where Earth’s plates move apart.
Convergent Plate Boundaries

Places where Earth’s plates move together are called convergent plate boundaries. They include areas where an oceanic plate slides below a continental plate as in Figure 7, and where one oceanic plate slides below another oceanic plate. The Andes in South America began forming when an oceanic plate started sliding below a continental plate. Volcanoes that form on convergent plate boundaries tend to erupt more violently than other volcanoes do.

Magma forms when the plate sliding below another plate gets deep enough and hot enough to melt partially. The magma then is forced upward to the surface, forming volcanoes like Soufrière Hills on the island of Montserrat.

Hot Spots

The Hawaiian Islands are forming as a result of volcanic activity. However, unlike Iceland, they haven’t formed at a plate boundary. The Hawaiian Islands are in the middle of the Pacific Plate, far from its edges. What process could be forming them?

It is thought that some areas at the boundary between Earth’s mantle and core are unusually hot. Hot rock at these areas is forced toward the crust where it melts partially to form a hot spot. The Hawaiian Islands sit on top of a hot spot under the Pacific Plate. Magma has broken through the crust to form several volcanoes. The volcanoes that rise above the water form the Hawaiian Islands, shown in Figure 8.
Self Check

1. Explain why volcanoes are commonly found at the edges of Earth’s moving plates.
2. Describe what effects pyroclastic flows have on people.
3. Explain why lava cools rapidly along a mid-ocean ridge. How might underwater lava differ from surface lava?
4. Describe the processes that cause Soufrière Hills volcano to erupt.
5. Think Critically If the Pacific Plate stopped moving, what might happen to the Big Island of Hawaii?

Summary

What are volcanoes?
- A volcano is an opening in Earth’s surface that erupts gases, ash, and lava.

Effects of Eruptions
- Direct effects of volcanic eruptions can be caused by lava flows, pyroclastic flows, and falling ash.
- Volcanic eruptions also produce indirect effects, such as acid rain.

How do volcanoes form?
- Volcanoes form when magma is forced up and flows onto Earth’s surface as lava.
- A crater is a steep-walled depression around a volcano’s vent.

Where do volcanoes occur?
- Volcanoes form where one plate sinks beneath another plate, where two plates are moving apart, and at hot spots.

The Hawaiian Islands
As you can see in Figure 8, the Hawaiian Islands are all in a line. This is because the Pacific Plate is moving over a stationary hot spot. Kauai, the oldest Hawaiian island, was once located where the big island, Hawaii, is situated today. As the plate moved, Kauai moved away from the hot spot and became dormant. As the Pacific Plate continued to move, the islands of Oahu, Molokai, Maui, and Hawaii were formed. The Hawaiian Islands formed over a period of about 5 million years.

Figure 8  This satellite photo shows five of the Hawaiian Islands, which actually are volcanoes. Explain why they are in a relatively straight line.

The Hawaiian Islands
This illustration shows that the Hawaiian Islands were formed over a hot spot.
What controls eruptions?

Some volcanic eruptions are explosive, like those from Soufrière Hills volcano, Mount Pinatubo, and Mount St. Helens. In others, the lava quietly flows from a vent, as in the Kilauea eruptions. What causes these differences?

Two important factors control whether an eruption will be explosive or quiet. One factor is the amount of water vapor and other gases that are trapped in the magma. The second factor is how much silica is present in the magma. Silica is a compound composed of the elements silicon and oxygen.

Trapped Gases When you shake a soft-drink container and then quickly open it, the pressure from the gas in the drink is released suddenly, spraying the drink all over. In the same way, gases such as water vapor and carbon dioxide are trapped in magma by the pressure of the surrounding magma and rock. As magma nears the surface, it is under less pressure. This allows the gas to escape from the magma. Gas escapes easily from some magma during quiet eruptions. However, gas that builds up to high pressures eventually causes explosive eruptions such as the one shown in Figure 9.

Figure 9 Mount St. Helens erupted on May 18, 1980.

8:32 A.M. 38 seconds later
**Water Vapor** The magma at some convergent plate boundaries contains a lot of water vapor. This is because oceanic plate material and some of its water slide under other plate material at some convergent plate boundaries. The trapped water vapor in the magma can cause explosive eruptions.

**Composition of Magma**

The second major factor that affects the nature of the eruption is the composition of the magma. Magma can be divided into two major types—silica poor and silica rich.

**Quiet Eruptions** Magma that is relatively low in silica is called basaltic magma. It is fluid and produces quiet, non-explosive eruptions such as those at Kilauea. This type of lava pours from volcanic vents and runs down the sides of a volcano. As this *pahoehoe* (pa-HOY-hoy) lava cools, it forms a ropelike structure. If the same lava flows at a lower temperature, a stiff, slowly moving *aa* (AH-ah) lava forms. In fact, you can walk right up to some *aa* lava flows on Kilauea.

*Figure 10* shows some different types of lava. These quiet eruptions form volcanoes over hot spots such as the Hawaiian volcanoes. Basaltic magmas also flow from rift zones, which are long, deep cracks in Earth's surface. Many lava flows in Iceland are of this type. Because basaltic magma is fluid when it is forced upward in a vent, trapped gases can escape easily in a non-explosive manner, sometimes forming lava fountains. Lavas that flow underwater form pillow lava formations. They consist of rock structures shaped like tubes, balloons, or pillows.
Lava rarely travels faster than a few kilometers an hour. Therefore, it poses little danger to people. However, homes and property can be damaged. On land, there are two main types of lava flows—aa and pahoehoe. When lava comes out of cracks in the ocean floor, it is called pillow lava. The lava cooling here came from a volcanic eruption on the island of Hawaii.

Pillow lava occurs where lava oozes out of cracks in the ocean floor. It forms pillow-shaped lumps as it cools. Pillow lava is the most common type of lava on Earth.

Aa flows, like this one on Mount Etna in Italy, carry sharp angular chunks of rock called scoria. Aa flows move slowly and are intensely hot.

Pahoehoe flows, like this one near Kilauea’s Mauna Ulu Crater in Hawaii, are more fluid than aa flows. They develop a smooth skin and form ropelike patterns when they cool.

Figure 10

VISUALIZING LAVA
Explosive Magma  Silica-rich, or granitic, magma produces explosive eruptions such as those at Soufrière Hills volcano. This magma sometimes forms where Earth’s plates are moving together and one plate slides under another. As the plate that is sliding under the other goes deeper, some rock is melted. The magma is forced upward by denser surrounding rock, comes in contact with the crust, and becomes enriched in silica. Silica-rich granitic magma is thick, and gas gets trapped inside, causing pressure to build up. When an explosive eruption occurs, as shown in Figure 11, the gases expand rapidly, often carrying pieces of lava in the explosion.

What type of magmas produce violent eruptions?

Some magmas have an andesitic composition. Andesitic magma is more silica rich than basaltic magma is, but it is less silica rich than granitic magma. It often forms at convergent plate boundaries where one plate slides under the other. Because of their higher silica content, they also erupt more violently than basaltic magmas. One of the biggest eruptions in recorded history, Krakatau, was primarily andesitic in composition. The word andesitic comes from the Andes, which are mountains located along the western edge of South America, where andesite rock is common. Many of the volcanoes encircling the Pacific Ocean also are made of andesite.
Forms of Volcanoes

A volcano’s form depends on whether it is the result of a quiet or an explosive eruption and the type of lava it is made of—basaltic, granitic, or andesitic (intermediate). The three basic types of volcanoes are shield volcanoes, cinder cone volcanoes, and composite volcanoes.

**Shield Volcano** Quiet eruptions of basaltic lava spread out in flat layers. The buildup of these layers forms a broad volcano with gently sloping sides called a shield volcano, as seen in Figure 12. The Hawaiian Islands are examples of shield volcanoes. Basaltic lava also can flow onto Earth’s surface through large cracks called fissures. This type of eruption forms flood basalts, not volcanoes, and accounts for the greatest volume of erupted volcanic material. The basaltic lava flows over Earth’s surface, covering large areas with thick deposits of basaltic igneous rock when it cools. The Columbia Plateau located in the northwestern United States was formed in this way. Much of the new seafloor that originates at mid-ocean ridges forms as underwater flood basalts.

**Cinder Cone Volcano** Explosive eruptions throw lava and rock high into the air. Bits of rock or solidified lava dropped from the air are called tephra (TEH fruh). Tephra varies in size from volcanic ash, to cinders, to larger rocks called bombs and blocks. When tephra falls to the ground, it forms a steep-sided, loosely packed cinder cone volcano, as seen in Figure 13.

---

**Modeling Volcanic Cones**

**Procedure**
1. Pour dry sand or sugar onto one spot on a paper plate. **WARNING:** Do not taste, eat, or drink any materials used in the lab.
2. Mix a batch of plaster of paris and pour it onto one spot on another paper plate.
3. Allow the plaster of paris to dry. Use a protractor to measure the slope angles of the sides of the volcanoes.

**Analysis**
What form of volcano is represented by the model with steeper sides?

---

**Figure 12** A shield volcano like Mauna Loa, shown here, is formed when lava flows from one or more vents without erupting violently.
Paricutín  On February 20, 1943, a Mexican farmer learned about cinder cones when he went to his cornfield. He noticed that a hole in his cornfield that had been there for as long as he could remember was giving off smoke. Throughout the night, hot glowing cinders were thrown high into the air. In just a few days, a cinder cone several hundred meters high covered his cornfield. This is the volcano named Paricutín.

Composite Volcano  Some volcanic eruptions can vary between quiet and violent, depending on the amount of trapped gases and how rich in silica the magma is. An explosive period can release gas and ash, forming a tephra layer. Then, the eruption can switch to a quieter period, erupting lava over the top of the tephra layer. When this cycle of lava and tephra is repeated over and over in alternating layers, a composite volcano is formed. Composite volcanoes, shown in Figure 14, are found mostly where Earth’s plates come together and one plate slides below the other. Soufrière Hills volcano is an example. As you can see in Table 1 on the next page, many things affect eruptions and the form of a volcano.

Figure 13  Paricutín is a large, cinder cone volcano located in Mexico.

Figure 14  Mount Rainier in the state of Washington is an example of a composite volcano.
Violent Eruptions  Soufrière Hills volcano formed as ocean floor of the North American Plate and the South American Plate slid beneath the Caribbean Plate, causing magma to form. Successive eruptions of lava and tephra produced the majestic composite volcanoes that tower above the surrounding landscape on Montserrat and other islands in the Lesser Antilles. Before the 1995 eruption, silica-rich magma rose and was trapped beneath the surface. As the magma was forced toward Earth’s surface, the pressure on the underlying magma was released. This started a series of eruptions that were still continuing in the year 2003.

<table>
<thead>
<tr>
<th>Volcano and Location</th>
<th>Year</th>
<th>Type</th>
<th>Eruptive Force</th>
<th>Magma Content</th>
<th>Ability of Magma to Flow</th>
<th>Products of Eruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mount Etna, Sicily</td>
<td>1669</td>
<td>composite</td>
<td>moderate</td>
<td>high</td>
<td>low</td>
<td>medium, lava, ash</td>
</tr>
<tr>
<td>Tambora, Indonesia</td>
<td>1815</td>
<td>cinder cone</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>low, cinders, ash</td>
</tr>
<tr>
<td>Krakatau, Indonesia</td>
<td>1883</td>
<td>composite</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>low, cinders, ash</td>
</tr>
<tr>
<td>Mount Pelée, Martinique</td>
<td>1902</td>
<td>cinder cone</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>low, gas, ash</td>
</tr>
<tr>
<td>Vesuvius, Italy</td>
<td>1906</td>
<td>composite</td>
<td>moderate</td>
<td>high</td>
<td>low</td>
<td>medium, lava, ash</td>
</tr>
<tr>
<td>Mount Katmai, Alaska</td>
<td>1912</td>
<td>composite</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>low, lava, ash, gas</td>
</tr>
<tr>
<td>Paricutín, Mexico</td>
<td>1943</td>
<td>cinder cone</td>
<td>moderate</td>
<td>high</td>
<td>low</td>
<td>medium, ash, cinders</td>
</tr>
<tr>
<td>Surtsey, Iceland</td>
<td>1963</td>
<td>shield</td>
<td>moderate</td>
<td>low</td>
<td>low</td>
<td>high, lava, ash</td>
</tr>
<tr>
<td>Mount St. Helens, Washington</td>
<td>1980</td>
<td>composite</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>low, gas, ash</td>
</tr>
<tr>
<td>Kilauea, Hawaii</td>
<td>1983</td>
<td>shield</td>
<td>low</td>
<td>low</td>
<td>low</td>
<td>high, lava</td>
</tr>
<tr>
<td>Mount Pinatubo, Philippines</td>
<td>1991</td>
<td>composite</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>low, gas, ash</td>
</tr>
<tr>
<td>Soufrière Hills, Montserrat</td>
<td>1995</td>
<td>composite</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>low, gas, ash, rocks</td>
</tr>
<tr>
<td>Popocatépetl, Mexico</td>
<td>2000</td>
<td>composite</td>
<td>moderate</td>
<td>high</td>
<td>low</td>
<td>medium, gas, ash</td>
</tr>
</tbody>
</table>
**Self Check**

1. Define the term *tephra*, and where it can be found.
2. Describe the differences between basaltic and granitic magma.
3. Identify the specific water vapor and silica conditions that cause differences in eruptions.
4. Describe how the Hawaiian Islands formed.
5. Think Critically In 1883, Krakatau in Indonesia erupted. Infer which kind of lava Krakatau erupted—lava rich in silica or lava low in silica. Support your inference using data in Table 1.

---

**Krakatau** One of the most violent eruptions in recent times occurred on an island in the Sunda Straits near Indonesia in August of 1883. Krakatau, a volcano on the island, erupted with such force that the island disappeared, as shown in **Figure 15A**. Most of the island collapsed into the emptied magma chamber. The noise of the eruption was so loud that it woke people in Australia and was heard as far away as 4,653 km from the island. Ash from the eruption fell in Singapore, which is 840 km to the north, and the area around the volcano was in complete darkness for 24 h. More than 36,000 people were killed, most by the giant tsunami waves created by the eruption. Global temperatures were lowered as much as 1.2°C by particles blown into the atmosphere and didn’t return to normal until 1888.

---

**Summary**

**What controls eruptions?**

- The amount of water vapor and other gases control the type of eruption and the amount of silica present in the magma.

**Composition of Magma**

- Magma can be divided into two major types—silica rich and silica poor.

**Forms of Volcanoes**

- A shield volcano is a broad, gently sloping volcano formed by quiet eruptions of basaltic lava.
- A cinder cone volcano is a steep-sided, loosely packed volcano formed from tephra.
- Composite volcanoes are formed by alternating explosive and quiet eruptions that produce layers of tephra and lava.

---

**Figure 15** Not much was left after Krakatau erupted in 1883.

---

**Applying Skills**

6. Compare and contrast Kilauea and Mount Pinatubo using information from Table 1.

---

**Table 1**

<table>
<thead>
<tr>
<th>Lava Type</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basaltic Lava</td>
<td>Low in silica, cool, and more viscous.</td>
</tr>
<tr>
<td>Granitic Lava</td>
<td>High in silica, hot, and less viscous.</td>
</tr>
</tbody>
</table>

---

**earth.msscience.com/self_check_quiz**

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**SECTION 2 Types of Volcanoes**

---
You have learned that certain properties of magma are related to the type of eruption and the form of the volcano that will develop. Do this lab to see how to make and use a table that relates the properties of magma to the form of volcano that develops.

**Real-World Question**
Are the silica and water content of a magma related to the form of volcano that develops?

**Goals**
- **Determine** any relationship between the ability of magma to flow and eruptive force.
- **Determine** any relationship between magma composition and eruptive force.

**Materials**
- Table 1 (thirteen selected eruptions)
- paper
- pencil

**Procedure**
1. Copy the graph shown above.
2. Using the information from Table 1, plot the magma content for each of the volcanoes listed by writing the name of the basic type of volcano in the correct spot on the graph.

**Conclude and Apply**
1. What relationship appears to exist between the ability of the magma to flow and the eruptive force of the volcano?
2. Which would be more liquidlike: magma that flows easily or magma that flows with difficulty?

**Communicating Your Data**
Create a flowchart that shows the relationship between magma composition and the type of volcano formed. For more help, refer to the Science Skill Handbook.
Intrusive Features

You can observe volcanic eruptions because they occur at Earth’s surface. However, far more activity occurs underground. In fact, most magma never reaches Earth’s surface to form volcanoes or to flow as flood basalts. This magma cools slowly underground and produces underground rock bodies that could become exposed later at Earth’s surface by erosion. These rock bodies are called intrusive igneous rock features. There are several different types of intrusive features. Some of the most common are batholiths, sills, dikes, and volcanic necks. What do intrusive igneous rock bodies look like? You can see illustrations of these features in Figure 16.

**Figure 16** This diagram shows intrusive and other features associated with volcanic activity.

**Identify** which features shown are formed above ground.

**Which are formed by intrusive activities?**

**New Vocabulary**
- batholith
- dike
- sill
- volcanic neck
- caldera

---

**What You’ll Learn**

- **Describe** intrusive igneous rock features and how they form.
- **Explain** how a volcanic neck and a caldera form.

**Why It’s Important**

Many features formed underground by igneous activity are exposed at Earth’s surface by erosion.

**Review Vocabulary**

- intrude: to enter by force; cut in
- extrude: to force or push out
**Batholiths** The largest intrusive igneous rock bodies are **batholiths**. They can be many hundreds of kilometers in width and length and several kilometers thick. Batholiths form when magma bodies that are being forced upward from inside Earth cool slowly and solidify before reaching the surface. However, not all of them remain hidden inside Earth. Some batholiths have been exposed at Earth’s surface by many millions of years of erosion. The granite domes of Yosemite National Park are the remains of a huge batholith that stretches across much of the length of California.

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### Applying Math

**Classifying Igneous Rocks**

Igneous rocks are classified into three types depending on the amount of silica they contain. Basaltic rocks contain approximately 45 percent to 52 percent silica. Andesitic, or intermediate, rocks contain about 52 percent to 66 percent silica, and granitic rocks have more than 66 percent silica. The lighter the color is, the higher the silica content is. A 900-kg block of igneous rock contains 630 kg of silica. Calculate the percent of silica in the rock to classify it.

**Solution**

1. **This is what you know:**
   - rock = 900 kg
   - silica = 630 kg

2. **This is what you need to find:**
   - The percentage of silica: \( x \)

3. **This is the equation you need to use:**
   - Mass of silica / mass of rock = \( x / 100 \)

4. **Solve the equation for \( x \):**
   - \( x = \frac{630 \text{ kg}}{900 \text{ kg}} \times 100 \)
   - \( x = 70 \) percent, therefore, the rock is granitic.

Check your answer by dividing it by 100, then multiplying by 900. Did you get the given amount of silica?

**Practice Problems**

1. A 250-kg boulder of basalt contains 125 kg of silica. Use the classification system to determine whether basalt is light or dark.

2. Andesite is an intermediate, medium-colored rock with a silica content ranging from 52 percent to 66 percent. About how many kilograms of silica would you predict to be in a 68-kg boulder of andesite?
**Dikes and Sills** Magma sometimes squeezes into cracks in rock below the surface. This is like squeezing toothpaste into the spaces between your teeth. Magma that is forced into a crack that cuts across rock layers and hardens is called a **dike**. Magma that is forced into a crack parallel to rock layers and hardens is called a **sill**. These features are shown in **Figure 17**. Most dikes and sills run from a few meters to hundreds of meters long.

**Other Features**

When a volcano stops erupting, the magma hardens inside the vent. Erosion, usually by water and wind, begins to wear away the volcano. The cone is much softer than the solid igneous rock in the vent. Thus, the cone erodes first, leaving behind the solid igneous core as a **volcanic neck**. Ship Rock in New Mexico, shown in **Figure 17**, is a good example of a volcanic neck.

**Activity** Create a collage for an artistic competition by using a variety of pictures of igneous rock features. For extra challenge, research Devils Tower, Wyoming. Develop your own hypothesis for its formation, and present your ideas as a panel discussion with other classmates.
Calderas Sometimes after an eruption, the top of a volcano can collapse, as seen in Figure 18. This produces a large depression called a caldera. Crater Lake in Oregon, shown in Figure 19, is a caldera that filled with water and is now a lake. Crater Lake formed after the violent eruption and destruction of Mount Mazama about 7,000 years ago.

Figure 18 Calderas form when the top of a volcano collapses.

Magma is forced upward, causing volcanic activity to occur.

The magma chamber partially empties, causing rock to collapse into the emptied chamber below the surface. This forms a circular-shaped caldera.

Crater Lake in Oregon formed when water collected in the circular space left when surface material collapsed.
Igneous Features Exposed You have learned in this chapter that Earth’s surface is built up and worn down continually. The surface of Earth is built up by volcanoes. Also, igneous rock is formed when magma hardens below ground. Eventually, the processes of weathering and erosion wear down rock at the surface, exposing features like batholiths, dikes, and sills.

Summary

**Intrusive Features**
- Intrusive igneous rock features are formed from magma that is forced upward toward Earth’s crust, then slowly cools and solidifies underground before reaching the surface.
- Batholiths, dikes, and sills are a few examples of intrusive igneous rock features.

**Other Features**
- A volcanic neck is the solid igneous core of a volcano left behind after the softer cone has been eroded.
- A caldera is a large, circular-shaped depression that forms when the top of a volcano collapses.

Self Check
1. Compare and contrast a caldera and a crater.
2. Illustrate how a sill forms. How is it different from a dike?
3. Describe a batholith and explain how it forms.
4. Think Critically Why are the large, granite dome features of Yosemite National Park in California considered to be intrusive volcanic features when they are exposed at the surface?

Calculating Basaltic Rocks
Basaltic rocks contain approximately 45 percent to 52 percent silica. About how many kilograms of silica would you predict to be in a 68-kg boulder of basalt?
A caldera is a depression that forms when the top of a volcano collapses after an eruption. What might cause the top of a volcano to collapse?

Based on your reading about volcanoes, state a hypothesis about what would happen if the magma inside the magma chamber of a volcano were suddenly removed.

How do calderas form?

Goals
- Design a volcano setup that will demonstrate how a caldera could form.
- Observe what happens during trials with your volcano setup.
- Describe what you observe.

Possible Materials
- small box
- small balloon
- paper
- newspaper
- flour
- plastic tubing
- clamp for tubing
- tape
- scissors

Safety Precautions

Real-World Question

A caldera is a depression that forms when the top of a volcano collapses after an eruption. What might cause the top of a volcano to collapse?

Form a Hypothesis

Based on your reading about volcanoes, state a hypothesis about what would happen if the magma inside the magma chamber of a volcano were suddenly removed.

Test Your Hypothesis

Make a Plan
1. As a group, agree upon the hypothesis and identify which results will support the hypothesis.
2. Design a volcano that allows you to test your hypothesis. What materials will you use to build your volcano?
3. What will you remove from inside your volcano to represent the loss of magma? How will you remove it?
4. Where will you place your volcano? What will you do to minimize messes?
5. Identify all constants, variables, and controls of the experiment.

Follow Your Plan
1. Make sure your teacher approves your plan before you start.
2. Construct your volcano with any features that will be required to test your hypothesis.
3. Conduct one or more appropriate trials to test your hypothesis. Record any observations that you make and any other data that are appropriate to test your hypothesis.
**Analyze Your Data**

1. **Describe** in words or with a drawing what your volcano looked like before you began.

2. **Observe** what happened to your volcano during the experiment that you conducted? Did its appearance change?

3. **Describe** in words or with a drawing what your volcano looked like after the trial.

4. **Observe** What other observations did you make?

5. **Describe** any other data that you recorded.

**Conclude and Apply**

1. **Draw Conclusions** Did your observations support your hypothesis? Explain.

2. **Explain** how your demonstration was similar to what might happen to a real volcano. How was it different?

**Communicating Your Data**

Make a 4-sequence time-lapse diagram with labels and descriptions of how a caldera forms. Use your visual aid to describe caldera formation to students in another class.
In the heat of the Italian Sun, a farmer digs a new well for water. He thrusts his shovel into the ground one more time. But instead of hitting water, the shovel strikes something hard; a slab of smooth white marble.

Under the ground lay the ancient city of Herculaneum (her kew LAY nee um). The city, and its neighbor Pompeii (pom PAY) had been buried for more than 1,600 years. On August 24, 79 A.D., Mount Vesuvius, a nearby volcano, erupted and buried both cities with pumice, rocks, mud, and ash.

Back in Time
The Sun shone over the peaceful town of Herculaneum on that August morning almost 2,000 years ago. But at about 1 P.M., that peace was shattered forever.

With massive force, the peak of Vesuvius exploded, sending six cubic kilometers of ash and pumice into the sky. Hours later, a fiery surge made its way from the volcano to the city. These pyroclastic flows continued as more buildings were crushed and buried by falling ash and pumice. Within six hours, much of the city was totally buried under the flows. After six surges from Vesuvius, the deadly eruption ceased. But the city had disappeared under approximately 21 m of ash, rock, and mud.

A City Vanishes
More than 3,600 people were killed in the natural disaster. Scientists believe that many died trying to protect their faces from the pyroclastic surges that filled the air with hot ash. Those able to escape returned to find no trace of their city. Over hundreds of years, grass and fields covered Herculaneum, erasing it from human memory.

Archaeologists have unearthed perfectly preserved mosaics and a library with ancient scrolls in excellent condition. Archaeologists found skeletons and voids that were filled with plaster to form casts of people who died the day Vesuvius erupted. Visitors to the site can see a Roman woman, a teen-aged girl, and a soldier with his sword still in his hand.

Much of Herculaneum still lies buried beneath thick layers of volcanic ash, and archaeologists still are digging to expose more of the ruins. Their work is helping scientists better understand everyday life in an ancient Italian town. But, if it weren’t for a farmer’s search for water, Herculaneum might not have been discovered at all!

Excavated ruins with Mount Vesuvius in the background.

Research the history of your town. Ask your local librarian to help “unearth” maps, drawings, or photos that let you travel back in time! Design a two-layer map that shows the past and the present.

For more information, visit earth.mssscience.com/oops
Section 1  Volcanoes and Earth’s Moving Plates

1. Volcanoes can be dangerous to people because they can cause deaths and destroy property.

2. Rocks in the crust and mantle melt to form magma, which is forced toward Earth’s surface. When the magma flows through vents, it’s called lava and forms volcanoes.

3. Volcanoes can form over hot spots or when Earth’s plates pull apart or come together.

Section 2  Types of Volcanoes

1. The three types of volcanoes are composite volcanoes, cinder cone volcanoes, and shield volcanoes.

2. Shield volcanoes produce quiet eruptions. Cinder cone and composite volcanoes can produce explosive eruptions.

3. Some lavas are thin and flow easily, producing quiet eruptions. Other lavas are thick and stiff, producing violent eruptions.

Section 3  Igneous Rock Features

1. Intrusive igneous rock bodies such as batholiths, dikes, and sills form when magma solidifies underground.

2. Batholiths are the most massive igneous rock bodies. Dikes and sills form when magma squeezes into cracks.

3. A caldera forms when the top of a volcano collapses, forming a large depression.

Copy and complete the following concept map on types of volcanic eruptions.

Volcanic Eruptions

- Can be quiet
- Can be explosive

- Characteristics
- Flows easily
- High silica

- Example of volcano
- Example of volcano
Fill in the blanks with the correct vocabulary word or words.

1. A broad volcano with gently sloping sides is called a(n) ________.
2. Bits of rock or solidified lava dropped from the air after a volcanic eruption are ________.
3. Magma squeezed into a horizontal crack between rock layers is a(n) ________.
4. The steep-walled depression around a volcano's vent is called a(n) ________.
5. Magma squeezed into a vertical crack across rock layers is called a(n) ________.

Choose the word or phrase that best answers the question.

6. What type of boundary is associated with composite volcanoes?
   A) plates moving apart  
   B) plates sticking and slipping  
   C) plates moving together  
   D) plates sliding past each other

7. Why is Hawaii made of volcanoes?
   A) Plates are moving apart.  
   B) A hot spot exists.  
   C) Plates are moving together.  
   D) Rift zones exist.

8. What kind of magmas produce violent volcanic eruptions?
   A) those rich in silica  
   B) those that are fluid  
   C) those forming shield volcanoes  
   D) those rich in iron

9. Magma that is low in silica generally produces what kind of eruptions?
   A) thick  
   B) caldera  
   C) quiet  
   D) explosive

10. Which type of volcano, shown above, is made entirely of tephra?
    A) shield  
    B) caldera  
    C) cinder cone  
    D) composite

11. What kind of volcano is Kilauea?
    A) shield  
    B) composite  
    C) cinder cone  
    D) caldera cone

12. What is the largest intrusive igneous rock body?
    A) dike  
    B) volcanic neck  
    C) sill  
    D) batholith

13. What is the process that formed Soufrière Hills volcano on Montserrat?
    A) plates sticking and slipping  
    B) caldera formation  
    C) plates sliding sideways  
    D) plates moving together
14. Explain how glaciers and volcanoes can exist on Iceland.

15. Describe what kind of eruption is produced when basaltic lava that is low in silica flows from a volcano.

16. Explain how volcanoes are related to earthquakes.

17. Infer Misti is a volcano in Peru. Peru is on the western edge of South America. How might this volcano have formed?

18. Describe the layers of a composite volcano. Which layers represent violent eruptions?

19. Classify the volcano Fuji, which has steep sides and is made of layers of silica-rich lava and ash.

21. Concept Map Make a network-tree concept map about where volcanoes can occur. Include the following words and phrases: hot spots, divergent plate boundaries, convergent plate boundaries, volcanoes, can occur, examples, Iceland, Soufrière Hills, and Hawaiian Islands.

22. Poster Make a Venn diagram of the three basic types of volcanoes. Label them and indicate what cone formation, lava composition, eruption, and geologic location are expected of each type of volcano.

23. Sea Level The base of the volcano Mauna Loa is about 5,000 m below sea level. The total height of the volcano is 9,170 m. What percentage of the volcano is above sea level? Below sea level?

Use the table below to answer questions 24 and 25.

<table>
<thead>
<tr>
<th>Volcano</th>
<th>Year of Eruption</th>
<th>Amount of Material Ejected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tambora</td>
<td>1815</td>
<td>131 km$^3$</td>
</tr>
<tr>
<td>Katmai</td>
<td>1912</td>
<td>30 km$^3$</td>
</tr>
<tr>
<td>Novarupta</td>
<td>1912</td>
<td>15 km$^3$</td>
</tr>
<tr>
<td>Mt. St. Helens</td>
<td>1980</td>
<td>1.3 km$^3$</td>
</tr>
<tr>
<td>Pinatubo</td>
<td>1991</td>
<td>5.5 km$^3$</td>
</tr>
</tbody>
</table>

24. Ejected Material How many times greater was the volume of ejected material from Tambora, as compared to Mt. St. Helens?

25. Graph Design a bar graph to show the amount of ejected material from the volcanoes. Present the information from least to greatest volume.
1. Which of the following terms best describes the rock in the photo above?
   A. aa  
   B. pahoehoe  
   C. pillow lava  
   D. ash

2. Which of the following is made of layers of ash and cooled lava flows?
   A. shield volcano  
   B. plateau basalts  
   C. composite volcano  
   D. cinder cone volcano

3. Which of the following volcanoes is located in the United States?
   A. Hekla  
   B. Paricutin  
   C. Mount Vesuvius  
   D. Mount St. Helens

4. Which of the following igneous features is parallel to the rock layers that it intrudes?
   A. batholith  
   B. volcanic neck  
   C. sill  
   D. dike

5. Which of the following forms when the top of a volcano collapses into a partially emptied magma chamber?
   A. fissure  
   B. crater  
   C. caldera  
   D. volcanic neck

6. What relationship can be inferred from the graph?
   A. Magmas that have more silica are more viscous.  
   B. Magmas that have less silica are more viscous.  
   C. Magmas always have low viscosity.  
   D. There is no relationship between silica content and viscosity.

7. What is the percentage of silica in Granitic magma?
   A. less than 45%  
   B. 45–52%  
   C. 53–65%  
   D. greater than 65%

8. Which of the following is the finest type of tephra?
   A. volcanic ash  
   B. volcanic bombs  
   C. volcanic cinders  
   D. volcanic blocks
9. What is a hot spot? Why do volcanoes often form at hot spots?

10. Why are the Hawaiian Islands in a line?

11. How is a dike different from a sill? Support your answer with a Venn diagram.

Use the table below to answer questions 12–14.

<table>
<thead>
<tr>
<th>Eruption</th>
<th>Volume Percent Water Vapor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>58.7</td>
</tr>
<tr>
<td>2</td>
<td>60.1</td>
</tr>
<tr>
<td>3</td>
<td>61.4</td>
</tr>
<tr>
<td>4</td>
<td>59.3</td>
</tr>
<tr>
<td>5</td>
<td>59.6</td>
</tr>
</tbody>
</table>

12. Calculate the mean, median, and range of the water vapor data in the table? Describe how this information would be helpful to a volcanologist.

13. Using the mean value that you calculated in question 12, what percentage of the volcanic gas consists of gases other than water vapor?

14. The water vapor content of Kilauea is above average when compared to other volcanoes. How might these data help to explain why lava fountains often occur on Kilauea?

15. What is the difference between magma and lava?

16. Explain how igneous rock forms from lava.

17. Explain how volcanic necks, such as Ship Rock, form. Support your answer with a labeled diagram.

18. How does tephra form?

19. Why do some volcanoes occur where one plate sinks beneath another plate? Support your answer with a labeled diagram.

20. How can pillow-shaped bodies form from lava?

Use the map below to answer questions 21 and 22.

21. What kind of magma was required to create the Columbia Plateau as compared to Mt. St. Helens, only 200 miles away? What would you predict would be the percentage of water vapor in the two types of magma?

22. Where do volcanoes occur in the United States?