Volcanic eruptions are more than spectacular sights. They are windows to Earth's interior. Because volcanoes eject molten rock that formed at great depth, they provide opportunities to observe the processes that occur deep beneath Earth's surface.

On May 18, 1980, one of the largest volcanic eruptions to occur in North America changed a scenic volcano into the smoldering wreck shown in Figure 1. On this date, Mount St. Helens erupted with tremendous force. The blast blew out the entire north flank of the volcano, leaving a gaping hole. The eruption ejected nearly a cubic kilometer of ash and rock debris. The air over Yakima, Washington, 130 kilometers to the east, was so filled with ash that noon became almost as dark as midnight. Why do volcanoes like Mount St. Helens erupt explosively, while others like Kilauea in Hawaii are relatively quiet?
### Table 1 Magma Composition

<table>
<thead>
<tr>
<th>Composition</th>
<th>Silica Content</th>
<th>Viscosity</th>
<th>Gas Content</th>
<th>Tendency to Form Pyroclastics (ejected rock fragments)</th>
<th>Volcanic Landform</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basaltic</td>
<td>Least (~50%)</td>
<td>Least</td>
<td>Least (1–2%)</td>
<td>Least</td>
<td>Shield Volcanoes Basalt Plateaus Cinder Cones</td>
</tr>
<tr>
<td>Andesitic</td>
<td>Intermediate (~60%)</td>
<td>Intermediate</td>
<td>Intermediate (3–4%)</td>
<td>Intermediate</td>
<td>Composite Cones</td>
</tr>
<tr>
<td>Rhyolitic</td>
<td>Most (~70%)</td>
<td>Greatest</td>
<td>Most (4–6%)</td>
<td>Greatest</td>
<td>Pyroclastic Flows Volcanic Domes</td>
</tr>
</tbody>
</table>

### Factors Affecting Eruptions

The primary factors that determine whether a volcano erupts violently or quietly include magma composition, magma temperature, and the amount of dissolved gases in the magma.

**Viscosity**  
Viscosity is a substance's resistance to flow. For example, maple syrup is more viscous than water and flows more slowly. Magma from an explosive eruption may be thousands of times more viscous than magma that is extruded quietly.

The effect of temperature on viscosity is easy to see. If you heat maple syrup, it becomes more fluid and less viscous. In the same way, the mobility of lava is strongly affected by temperature. As a lava flow cools and begins to harden, its viscosity increases, its mobility decreases, and eventually the flow halts.

The chemical composition of magmas has a more important effect on the type of eruption. The viscosity of magma is directly related to its silica content. In general, the more silica in magma, the greater is its viscosity. Because of their high silica content, rhyolitic lavas are very viscous and don't flow easily. Basaltic lavas, which contain less silica, tend to be more fluid.

**Dissolved Gases**  
During explosive eruptions, the gases trapped in magma provide the force to eject molten rock from the vent, an opening to the surface. These gases are mostly water vapor and carbon dioxide. As magma moves nearer the surface, the pressure in the upper part of the magma is greatly reduced. The reduced pressure allows dissolved gases to be released suddenly.

Very fluid basaltic magmas allow the expanding gases to bubble upward and escape relatively easily. Therefore, eruptions of fluid basaltic lavas, such as those that occur in Hawaii, are relatively quiet. At the other extreme, highly viscous magmas slow the upward movement of expanding gases. The gases collect in bubbles and pockets that increase in size until they explosively eject the molten rock from the volcano. The result is a Mount St. Helens.

#### Quick Lab

**Why are some volcanoes explosive?**

**Procedure**

1. Obtain two bottles of noncarbonated water and two bottles of club soda.
2. Open one bottle of the noncarbonated water and one bottle of the club soda. Record your observations.
3. Gently shake each of the remaining unopened bottles. **CAUTION:** Wear safety goggles and point the bottles away from everyone.
4. Carefully open each bottle over a sink or outside. Record your observations.

**Analyze and Conclude**

1. **Observing** What happened when the bottles were opened?
2. **Inferring** Which bottle represents lava with the most dissolved gas?
Lava Flows Hot basaltic lavas are usually very fluid because of their low silica content. Flow rates of 10 to 300 meters per hour are common. In contrast, the movement of silica-rich (rhyolitic) lava is often too slow to be visible. When fluid basaltic lavas harden, they commonly form a relatively smooth skin that wrinkles as the still-molten subsurface lava continues to move. These are known as pahoehoe (pah HOH ee hoh ee) flows and resemble the twisted braids in ropes, as shown in Figure 2. Another common type of basaltic lava called aa (AH ah) has a surface of rough, jagged blocks with dangerously sharp edges and spiny projections.

Gases Magmas contain varied amounts of dissolved gases held in the molten rock by confining pressure, just as carbon dioxide is held in soft drinks. As with soft drinks, as soon as the pressure is reduced, the gases begin to escape. The gaseous portion of most magmas is only about 1 to 6 percent of the total weight. The percentage may be small, but the actual quantity of emitted gas can exceed thousands of tons each day. Samples taken during a Hawaiian eruption consisted of about 70 percent water vapor, 15 percent carbon dioxide, 5 percent nitrogen, 5 percent sulfur, and lesser amounts of chlorine, hydrogen, and argon. Sulfur compounds are easily recognized because they smell like rotten eggs and readily form sulfuric acid, a natural source of air pollution. The composition of volcanic gases is important because they have contributed greatly to the gases that make up the atmosphere.
Pyroclastic Materials. When basaltic lava is extruded, dissolved gases propel blobs of lava to great heights. Some of this ejected material may land near the vent and build a cone-shaped structure. The wind will carry smaller particles great distances. Viscous rhyolitic magmas are highly charged with gases. As the gases expand, pulverized rock and lava fragments are blown from the vent. Pyroclastic material is the name given to particles produced in volcanic eruptions. The fragments ejected during eruptions range in size from very fine dust and volcanic ash (less than 2 millimeters) to pieces that weigh several tons.

Particles that range in size from small beads to walnuts (2–64 millimeters) are called lapilli or more commonly cinders. Particles larger than 64 millimeters in diameter are called blocks when they are made of hardened lava and bombs when they are ejected as glowing lava. Because bombs are semimolten upon ejection, they often take on a streamlined shape as they hurtle through the air.

Types of Volcanoes

Volcanic landforms come in a wide variety of shapes and sizes. Each structure has a unique eruptive history. The three main volcanic types are shield volcanoes, cinder cones, and composite cones.

Anatomy of a Volcano. Volcanic activity often begins when a fissure, or crack, develops in the crust as magma is forced toward the surface. The gas-rich magma moves up this fissure, through a circular pipe, ending at a vent, as shown in Figure 3. Repeated eruptions of lava or pyroclastic material often separated by long inactive periods eventually build the mountain called a volcano. Located at the summit of many volcanoes is a steep-walled depression called a crater.

Go Online

For: Links on volcanic eruptions
Visit: www.SciLinks.org
Web Code: cjn-3101
The form of a volcano is largely determined by the composition of the magma. As you will see, fluid lavas tend to produce broad structures with gentle slopes. More viscous silica-rich lavas generate cones with moderate to steep slopes.

**Shield Volcanoes** Shield volcanoes are produced by the accumulation of fluid basaltic lavas. Shield volcanoes have the shape of a broad, slightly domed structure that resembles a warrior's shield, as shown in Figure 4. Most shield volcanoes have grown up from the deep-ocean floor to form islands. Examples of shield volcanoes include the Hawaiian Islands and Iceland.

**Cinder Cones** Ejected lava fragments the size of cinders, which harden in the air, build a cinder cone. These fragments range in size from fine ash to bombs but consist mostly of lapilli, or cinders. Cinder cones are usually a product of relatively gas-rich basaltic magma. Although cinder cones are composed mostly of loose pyroclastic material, they sometimes extrude lava.

Cinder cones have a very simple shape as shown in Figure 5A. The shape is determined by the steep-sided slope that loose pyroclastic material maintains as it comes to rest. Cinder cones are usually the product of a single eruption that sometimes lasts only a few weeks and rarely more than a few years. Once the eruption ends, the magma in the pipe connecting the vent to the magma chamber solidifies, and the volcano never erupts again. Because of this short life span, cinder cones are small, usually between 30 meters and 300 meters and rarely exceed 700 meters in height.
Cinder cones are found by the thousands all around Earth. Some, like the one shown in Figure 5B, near Flagstaff, Arizona, are located in volcanic fields. This field consists of about 600 cones. Others form on the sides of larger volcanoes. Mount Etna, for example, has dozens of cinder cones dotting its flanks.

**Composite Cones** Earth’s most beautiful and potentially dangerous volcanoes are composite cones, or stratovolcanoes. Most are located in a relatively narrow zone that rims the Pacific Ocean, appropriately called the Ring of Fire. The Ring of Fire includes the large cones of the Andes in South America and the Cascade Range of the western United States and Canada. The Cascade Range includes Mount St. Helens, Mount Rainier, and Mount Garibaldi. The most active regions in the Ring of Fire are located along curved belts of volcanic islands next to the deep ocean trenches of the northern and western Pacific. This nearly continuous chain of volcanoes stretches from the Aleutian Islands to Japan, the Philippines, and New Zealand.

A composite cone is a large, nearly symmetrical structure composed of layers of both lava and pyroclastic deposits. For the most part, composite cones are the product of gas-rich magma having an andesitic composition. The silica-rich magmas typical of composite cones generate viscous lavas that can only travel short distances. Composite cones may generate the most explosive eruptions that eject huge quantities of pyroclastic material. Compare the shape and height of composite cones with other types of volcanoes in Figure 6.
Figure 7 Composite Cone
Mount Shasta, California, is one of the largest composite cones in the Cascade Range. Shastina is the smaller cone that formed on the left flank of Mt. Shasta.

Fujiyama in Japan and Mount Shasta in California show the classic shape you would expect of a composite cone, with its steep summit and gently sloping flanks, as shown in Figure 7. About 50 such volcanoes have erupted in the United States in the past 200 years. On a global scale, numerous destructive eruptions of composite cones have occurred during the past few thousand years. A few of these have had a major influence on human civilization.

Dangers from Composite Cones One of the most devastating features associated with composite cones are pyroclastic flows. They consist of hot gases, glowing ash, and larger rock fragments. The most destructive of these fiery flows are capable of racing down steep volcanic slopes at speeds of nearly 200 kilometers per hour. Some pyroclastic flows result when a powerful eruption blasts material out the side of a volcano. Usually they form from the collapse of tall eruption columns that form over a volcano during an explosive event. Once gravity overcomes the upward thrust provided by the escaping gases, the material begins to fall. Massive amounts of hot fragments, ash, and gases begin to race downhill under the influence of gravity.

Large composite cones may also generate mudflows called lahars. These destructive mudflows occur when volcanic debris becomes saturated with water and rapidly moves down steep volcanic slopes, often following stream valleys. Some lahars are triggered when large volumes of ice and snow melt during an eruption. Others are generated when heavy rainfall saturates weathered volcanic deposits. Lahars can occur even when a volcano is not erupting.

What is a lahar?
Other Volcanic Landforms

**Calderas** A caldera is a large depression in a volcano. Most calderas form in one of two ways: by the collapse of the top of a composite volcano after an explosive eruption, or from the collapse of the top of a shield volcano after the magma chamber is drained. Crater Lake, Oregon, is located in a caldera. This caldera formed about 7000 years ago when a composite cone, Mount Mazama, violently erupted and collapsed, as shown in Figure 8.

**Necks and Pipes** Most volcanoes are fed magma through conduits, called pipes, connecting a magma chamber to the surface. Volcanoes are always being weathered and eroded. Cinder cones are easily eroded because they are made up of loose materials. When the rock in the pipe is more resistant and remains standing above the surrounding terrain after most of the cone has been eroded, the structure is called a volcanic neck, as shown in Figure 9A on page 288.

The best-known volcanic pipes are the diamond-bearing pipes of South Africa. The rocks filling these pipes formed at depths of at least 150 kilometers, where pressure is high enough to form diamonds. The process of moving unaltered magma through 150 kilometers of solid rock is unusual, resulting in the rarity of diamonds.
Lava Plateaus  You probably think of volcanic eruptions as building a mountain from a central vent. But the greatest volume of volcanic material is extruded from fissures. Rather than building a cone, low-viscosity basaltic lava flows from these fissures, covering a wide area, as shown in Figure 9B. The extensive Columbia Plateau in the northwestern United States was formed this way. Here, numerous fissure eruptions extruded very fluid basaltic lava flows, shown in Figure 9C. Successive flows, some 50 meters thick, buried the landscape, building a lava plateau nearly 1.6 kilometers thick.

**Section 10.1 Assessment**

**Reviewing Concepts**
1. What factors determine the type of volcanic eruption?
2. List the materials ejected from volcanoes.
3. Describe the three types of volcanoes.
4. What is a caldera?

**Critical Thinking**
5. **Comparing and Contrasting** Compare the formation of a lava plateau with the formation of a cinder cone.
6. **Applying Concepts** What type of eruption produces a viscous magma containing 53 percent silica and a gas content of 2 percent?

**Writing in Science**

**Summary** Research a volcanic eruption. Write a paragraph describing the eruption. Make sure to classify what type of volcano erupted.
10.2 Intrusive Igneous Activity

Reading Focus

Key Concepts
- How are intrusive igneous features classified?
- What are the major intrusive igneous features?
- What is the origin of magma?

Vocabulary
- pluton
- sill
- laccolith
- dike
- batholith
- geothermal gradient
- decompression melting

Reading Strategy
Comparing and Contrasting After you read the section, compare the types of plutons by completing the table.

<table>
<thead>
<tr>
<th>Types of Plutons</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sill</td>
<td>a.</td>
</tr>
<tr>
<td>Laccolith</td>
<td>b.</td>
</tr>
<tr>
<td>Dike</td>
<td>c.</td>
</tr>
<tr>
<td>Batholith</td>
<td>d.</td>
</tr>
</tbody>
</table>

Although volcanic eruptions are among the most violent and spectacular events in nature, most magma cools deep within Earth. The structures that result form the roots of mountain ranges and some of the most familiar features in the landscape.

Plutons

The structures that result from the cooling and hardening of magma at depth are called plutons. Because all plutons form beneath Earth’s surface, they can be studied only after uplift and erosion have exposed them. Plutons occur in a great variety of sizes and shapes. Intrusive igneous bodies, or plutons, are generally classified according to their shape, size, and relationship to the surrounding rock layers.

Sills and Laccoliths

Sills and laccoliths are plutons that form when magma is intruded close to the surface. Sills and laccoliths differ in shape and often differ in composition. A sill forms when magma is injected along sedimentary bedding surfaces, parallel to the bedding planes. Horizontal sills, like the one shown in Figure 10, are the most common.

For a sill to form, the overlying sedimentary rock must be lifted to a height equal to the thickness of the sill. Although this is a not an easy task, at shallow levels it often requires less energy than forcing the magma up to the surface. Because of this, sills form only at shallow depths, where the pressure exerted by the weight of overlying rock layers is low. As shown in Figure 11A on page 290, sills look like buried lava flows.

Inferring How could you determine if a horizontal igneous rock layer was a lava flow or a sill?
Types of Igneous Plutons

Laccoliths are similar to sills because they form when magma is intruded between sedimentary layers close to the surface. However, the magma that generates laccoliths is more viscous. This less-fluid magma collects as a lens-shaped mass that pushes the overlying strata upward. Most laccoliths are not much wider than a few kilometers.

Reading Checkpoint Compare and contrast sills and laccoliths.

Dikes Some plutons form when magma is injected into fractures, cutting across preexisting rock layers. Such plutons are called dikes, as in Figure 11B. These sheetlike structures have thicknesses ranging from less than a centimeter to more than a kilometer. Most dikes, however, are a few meters thick and extend laterally for no more than a few kilometers.

Some dikes radiate, like spokes on a wheel, from an eroded volcanic neck. The movement of magma probably formed fissures in the volcanic cone from which the magma flowed to form the dikes. Many dikes form when magma from a large magma chamber invades fractures in the surrounding rocks.

Batholiths The largest intrusive igneous bodies are batholiths. The Idaho batholith, for example, covers an area of more than 40,000 square kilometers and consists of many individual plutons. Indirect evidence from gravity and seismic studies indicates that batholiths are also very thick, possibly extending dozens of kilometers into the crust.
An intrusive igneous body must have a surface exposure greater than 100 square kilometers to be considered a batholith. Smaller plutons are called stocks. Many stocks appear to be portions of batholiths that are not yet fully exposed. Batholiths may form the core of mountain ranges, as shown in Figure 12. In this case, uplift and erosion have removed the surrounding rock, exposing the batholith.

**Origin of Magma**

The origin of magma has been controversial in geology for a long time. Based on available scientific evidence, Earth's crust and mantle are composed primarily of solid, not molten, rock. Although the outer core is a fluid, its iron-rich material is very dense and stays deep within Earth. What is the source of magma that produces igneous activity? Geologists conclude that magma originates when essentially solid rock, located in the crust and upper mantle, partially melts. The most obvious way to generate magma from solid rock is to raise the temperature above the level at which the rock begins to melt.

**Role of Heat** What source of heat is sufficient to melt rock? Workers in underground mines know that temperatures get higher as they go deeper. The rate of temperature change averages between 20°C and 30°C per kilometer in the upper crust. This change in temperature with depth is known as the geothermal gradient. Estimates indicate that the temperature at a depth of 100 kilometers ranges between 1400°C and 1600°C. At these high temperatures, rocks in the lower crust and upper mantle are near, but not quite at their melting point temperatures. So they are very hot but still essentially solid.

There are several ways that enough additional heat can be generated within the crust or upper mantle to produce some magma. First, at subduction zones, friction generates heat as huge slabs of crust slide past each other. Second, crustal rocks are heated as they descend into the mantle during subduction. Third, hotter mantle rocks can rise and intrude crustal rocks. All of these processes only form relatively small amounts of magma. As you'll see, the vast bulk of magma forms without an additional heat source.

---

**Figure 12 Batholiths** Mount Whitney in California makes up just a tiny portion of the Sierra Nevada batholith, a huge structure that extends for approximately 400 kilometers.
**Role of Pressure** If temperature were the only factor that determined whether or not rock melts, Earth would be a molten ball covered with a thin, solid outer shell. This is not the case because pressure also increases with depth. Melting, which causes an increase in volume, occurs at higher temperatures at depth because of greater confining pressure. In this way, an increase in confining pressure causes an increase in the rock's melting temperature. The opposite is also true. Reducing confining pressure lowers a rock’s melting temperature. When confining pressure drops enough, decompression melting is triggered. This process generates magma beneath Hawaii where plumes of hot rock melt as they rise toward the surface.

**Role of Water** Another important factor affecting the melting temperature of rock is its water content. Water causes rock to melt at lower temperatures. Because of this, “wet” rock buried at depth has a much lower melting temperature than does “dry” rock of the same composition and under the same pressure. Laboratory studies have shown that the melting point of basalt can be lowered by up to 100°C by adding only 0.1 percent water. In addition to a rock’s composition, its temperature, depth (confining pressure), and water content determine if it is a solid or liquid.

In summary, magma can be formed in three ways. First, heat may be added when a magma body from a deeper source intrudes and melts crustal rock. Second, a decrease in pressure (without the addition of heat) can result in decompression melting. Third, water can lower the melting temperature of mantle rock enough to form magma.

**Section 10.2 Assessment**

### Reviewing Concepts
1. How are intrusive features classified?
2. List the major intrusive igneous bodies.
3. What are the three major ways that magma forms?
4. What is a pluton?

### Critical Thinking
5. **Comparing and Contrasting** Describe the difference between a sill and a dike.

### 6. Relating Cause and Effect
What effect does a decrease in confining pressure have on the melting temperature of rocks in the upper mantle?

### Convection Currents
Recall what you learned about convection currents in Chapter 9. Explain how convection currents could affect the depth at which molten rocks are found.
More than 800 active volcanoes have been identified worldwide. Most of them are located along the margins of the ocean basins, mainly within the circum-Pacific belt known as the Ring of Fire. A second group of volcanoes is found in the deep-ocean basins, including on Hawaii and Iceland. A third group includes volcanic structures that are irregularly distributed in the interiors of the continents. Until the late 1960s, geologists had no explanation for the distribution of volcanoes. With the development of the theory of plate tectonics, the picture became clearer.

Convergent Plate Boundaries

The basic connection between plate tectonics and volcanism is that plate motions provide the mechanisms by which mantle rocks melt to generate magma. At convergent plate boundaries, slabs of oceanic crust are pushed down into the mantle. As a slab sinks deeper into the mantle, the increase in temperature and pressure drives water from the oceanic crust. Once the sinking slab reaches a depth of about 100 to 150 kilometers, the fluids reduce the melting point of hot mantle rock enough for melting to begin. The magma formed slowly migrates upward forming volcanoes such as Mount St. Helens shown here. As you read about the relationships between plate tectonics and igneous activity, refer to Figure 17 on pages 296-297, which summarizes the relationships.
Ocean-Ocean  Volcanism at a convergent plate where one oceanic slab descends beneath another results in the formation of a chain of volcanoes on the ocean floor. Eventually, these volcanic structures grow large enough to rise above the surface and are called volcanic island arcs. Several volcanic island arcs border the Pacific basin, including the Aleutians.

Ocean-Continent  Volcanism associated with convergent plate boundaries may also develop where slabs of oceanic lithosphere are subducted under continental lithosphere to produce a continental volcanic arc. The mechanisms are basically the same as those at island arcs. The major difference is that continental crust is much thicker and is composed of rocks with a higher silica content than oceanic crust. As the silica-rich crustal rocks melt, the magma may change composition as it rises through continental crust. The volcanoes of the Andes Mountains along the western edge of South America are an example of a continental volcanic arc, as shown in Figure 15.

Divergent Plate Boundaries
Most magma is produced along the oceanic ridges during seafloor spreading. Below the ridge axis where the plates are being pulled apart, the solid yet mobile mantle rises upward to fill in the rift where the plates have separated. As rock rises, confining pressure decreases. The rock undergoes decompression melting, producing large amounts of magma. This newly formed basaltic magma is less dense than the mantle rock from which it was formed, so it buoyantly rises.

Partial melting of mantle rock at spreading centers produces basaltic magma. Although most spreading centers are located along the axis of an oceanic ridge, some are not. The East African Rift in Africa is a site where continental crust is being rifted apart.
Intraplate Igneous Activity

Kilauea is Earth’s most active volcano, but it is in the middle of the Pacific plate, thousands of kilometers from a plate boundary. Intraplate volcanism occurs within a plate, not at a plate boundary. Another site of intraplate volcanism is Yellowstone National Park.

Most intraplate volcanism occurs where a mass of hotter than normal mantle material called a mantle plume rises toward the surface. Most mantle plumes appear to form deep within Earth at the core-mantle boundary. These plumes of hot mantle rock rise toward the surface in a way similar to the blobs that form within a lava lamp. Once the plume nears the top of the mantle, decompression melting forms basaltic magma. The result may be a small volcanic region a few hundred kilometers across called a hot spot. More than 40 hot spots have been identified, and most have lasted for millions of years. By measuring the heat flow at hot spots, geologists found that the mantle beneath some hot spots may be 100–150°C hotter than normal.

The volcanic activity on the island of Hawaii, shown in Figure 16, is the result of a hot spot. Where a mantle plume has persisted for long periods of time, a chain of volcanoes may form as the overlying plate moves over it. Mantle plumes are also thought to cause the vast outpourings of lava that create large lava plateaus such as the Columbia Plateau in the northwestern United States.

Section 10.3 Assessment

Reviewing Concepts
1. How are the locations of volcanoes related to plate boundaries?
2. What causes intraplate volcanism?
3. Where is most of the magma produced on Earth on a yearly basis?
4. What is the Ring of Fire?

Critical Thinking
5. Comparing and Contrasting What are the differences between volcanic island arcs and continental volcanic arcs?

6. Predicting Would it be more likely for a major explosive eruption to occur at an ocean ridge or at a convergent ocean-continental boundary? Explain your answer.

Writing in Science

Explanatory Paragraph Write a paragraph to explain how magma is formed in the crust without adding heat.
Three Zones of Volcanism

Convergent plate volcanism

Intraplate volcanism

Eruptions

Decompression melting

Rising mantle plume

Subduction of oceanic crust

Water driven from plate

Mantle rock melts

Figure 17

Regions The three zones of volcanism are convergent plate volcanism, divergent plate volcanism, and intraplate volcanism. Two of these zones are plate boundaries, and the third is the interior area of the plates.

Drawing Conclusions In which zones do volcanoes occur on both continental plates and oceanic plates?
10.1 The Nature of Volcanic Eruptions

**Key Concepts**
- The primary factors that determine whether a volcano erupts violently or quietly include magma composition, magma temperature, and the amount of dissolved gases in the magma.
- The fragments ejected during eruptions range in size from very fine dust and volcanic ash (less than 2 millimeters) to pieces that weigh several tons.
- The three main volcanic types are shield volcanoes, cinder cones, and composite cones.
- A caldera is a large depression in a volcano.
- Most volcanoes are fed magma through conduits, called pipes, connecting a magma chamber to the surface.

**Vocabulary**
- viscosity, p. 281; vent, p. 281; pyroclastic material, p. 283; volcano, p. 283; crater, p. 283; shield volcano, p. 284; cinder cone, p. 284; composite cone, p. 285; caldera, p. 287

10.2 Intrusive Igneous Activity

**Key Concepts**
- Intrusive igneous bodies, or plutons, are generally classified according to their shape, size and relationship to the surrounding rock layers.
- Sills and laccoliths are plutons that form when magma is intruded close to the surface.
- Many dikes form when magma from a large magma chamber invades fractures in the surrounding rocks.
- An intrusive igneous body must have a surface exposure greater than 100 square kilometers to be considered a batholith.
- Geologists conclude that magma originates when essentially solid rock, located in the crust and upper mantle, partially melts. The most obvious way to generate magma from solid rock is to raise the temperature above the level at which the rock begins to melt.

**Vocabulary**
- pluton, p. 289; sill, p. 289; laccolith, p. 290; dike, p. 290; batholith, p. 290; geothermal gradient, p. 291; decompression melting, p. 292

10.3 Plate Tectonics and Igneous Activity

**Key Concepts**
- The basic connection between plate tectonics and volcanism is that plate motions provide the mechanisms by which mantle rocks melt to generate magma.
- Most intraplate volcanism occurs where a mass of hotter than normal mantle material called a mantle plume rises toward the surface.

**Vocabulary**
- intraplate volcanism, p. 295

**Thinking Visually**

**Web Diagram** Copy the web diagram below and use information from the chapter to complete it.
CHAPTER 10 Assessment

Reviewing Content

Choose the letter that best answers the question or completes the statement.

1. Underground igneous rock bodies are called
   a. lava flows.   b. plutons.
   c. volcanoes.   d. calderas.

2. The greatest volume of volcanic material is produced by
   a. eruptions of cinder cones.
   b. eruptions of composite cones.
   c. eruptions along ocean ridges.
   d. eruptions of shield volcanoes.

3. The most violent type of volcanic activity is associated with
   a. cinder cones.   b. sills.
   c. composite cones.   d. shield volcanoes.

4. A magma's viscosity is directly related to its
   a. depth.   b. age.
   c. color.   d. silica content.

5. What are the pulverized rock, lava, ash, and other fragments ejected from the vent of a volcano called?
   a. sills   b. craters
   c. pahoehoe   d. pyroclastic material

6. Which type of volcano consists of layers of lava flows and pyroclastic material?
   a. composite cone   b. cinder cone
   c. shield volcano   d. laccolith

7. Fluid basaltic lavas, like those in Hawaii, commonly form
   a. aa flows.   b. pahoehoe flows.
   c. pyroclastic flows.   d. lapilli flows.

8. What is the very large depression at the top of some volcanoes called?
   a. a vent   b. a lava plateau
   c. a volcanic neck   d. a caldera

9. When silica-rich magma is extruded, ash, hot gases, and larger fragments may be propelled from the vent at high speeds and produce which of the following?
   a. a lava plateau   b. a lahar
   c. a pahoehoe flow   d. a pyroclastic flow

10. What feature may form in an intraplate area over a rising plume of hot mantle material?
    a. a hot spot   b. a dike
    c. a subduction zone   d. an ocean ridge

Understanding Concepts

11. What is a volcanic neck and how does it form?

12. Describe the Ring of Fire.

13. The Hawaiian Islands and Yellowstone National Park are associated with which of the three zones of volcanism?

14. What is the chain of volcanoes called that forms at a convergent boundary between a subducting oceanic plate and a continental plate? What type of volcano commonly forms?

15. Explain how most magma is theorized to originate.

Use the diagram below to answer Questions 16 and 17.

16. Identify the type of volcano shown in the diagram.

17. What types of eruptions are commonly associated with this type of volcano?

18. How do hot spots form?

19. How are pyroclastic materials classified?

20. What is viscosity and how does it affect volcanic eruptions?

21. Give an example of each of the three types of volcanoes.

22. How do dikes form?
Critical Thinking

23. **Applying Concepts** Why might a laccolith be detected at Earth’s surface before being exposed by erosion?

24. **Inferring** Why is a volcano fed by a highly viscous magma likely to be a greater threat to people than a volcano fed by very fluid magma?

25. **Comparing and Contrasting** Compare pahoehoe lava flows and aa lava flows.

26. **Relating Cause and Effect** What is a lahar? Explain why a lahar can occur on a volcano without an eruption.

27. **Drawing Conclusions** Why are cinder cones usually small?

Analyzing Data

Use the data table below to answer Questions 28–31.

<table>
<thead>
<tr>
<th>Notable Volcanic Eruptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volcano</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>Toba</td>
</tr>
<tr>
<td>Vesuvius</td>
</tr>
<tr>
<td>Tambora</td>
</tr>
<tr>
<td>Krakatau</td>
</tr>
<tr>
<td>Mount St. Helens</td>
</tr>
<tr>
<td>Mount Pinatubo</td>
</tr>
</tbody>
</table>

28. **Interpreting Data** What volcanic eruption listed in the data table produced the most pyroclastic material?

29. **Calculating** The volume of material ejected by the eruption of Tambora in 1815 was how many times larger than the volume of material ejected in 1883 by the eruption of Krakatau?

30. **Forming Hypotheses** Develop a hypothesis to explain why the eruption of Mount Vesuvius in A.D. 79 was more deadly than the eruption of Mount Pinatubo in 1991, even though the eruptions were approximately the same size.

31. **Calculating** Calculate how much higher the plume of volcanic debris was during the eruption of Tambora in 1815 compared to the plume from the 1980 eruption of Mount St. Helens. Calculate the increase in kilometers and in percentage of increase.

Concepts in Action

32. **Hypothesizing** Large volcanic eruptions eject large amounts of gas, dust, and ash into the atmosphere. This volcanic material can affect the world’s climate by blocking incoming solar radiation. An eruption from what type of volcano is most likely to cause global climate changes? Explain your answer.

33. **Classifying** On the side of a composite cone you see a large area where there are no trees and the ground surface looks disturbed. What possible volcanic feature or event could have caused this?

34. **Applying Concepts** Would you be safer from a violent, explosive eruption while vacationing in Arizona near a cinder cone or while skiing in the Andes Mountains of South America? Explain.

35. **Writing in Science** Write a paragraph describing what an eruption of a nearby composite cone might be like.

Performance-Based Assessment

**Making a Poster** Make a poster illustrating the internal and external features that are typical of a composite cone. Include on your poster copies of photographs of some classic composite cones. Also explain some of the possible dangers associated with living near a composite cone.
Test-Taking Tip

Paying Attention to the Details
Sometimes two or more answers to a question may seem correct. If you do not read the question and answer choices carefully, you may select an incorrect answer by mistake. In the question below, two answer choices, (A) dissolved gases and (B) gravity, would seem to be possible correct answers to the question. However, the question asks what force extrudes magma from the vent, not down the slopes of the volcano. So only the answer choice, (A) dissolved gases, is correct.

What is the force that extrudes magma from a volcanic vent?
(A) dissolved gases
(B) gravity
(C) the magma's heat
(D) the volcano's slope

(Answer: A)

Choose the letter that best answers the question or completes the statement.

1. Which of the following is NOT a factor that determines if a volcano erupts violently or quietly?
   (A) temperature of the magma
   (B) size of the volcanic cone
   (C) the magma's composition
   (D) amount of dissolved gases in the magma

2. How does an increase in confining pressure affect a rock's melting temperature?
   (A) The melting temperature increases.
   (B) The melting temperature decreases.
   (C) The melting temperature is stabilized.
   (D) It has no effect on the melting temperature.

Answer the following questions in complete sentences.

3. What intrusive igneous feature in the diagram is labeled C?
   (A) a dike
   (B) a sill
   (C) a batholith
   (D) a laccolith

4. If the feature labeled E when exposed to erosion extended for over 100 square kilometers, what would it be classified as?
   (A) a dike
   (B) a stock
   (C) a laccolith
   (D) a batholith

Part A Explain the tectonic setting of volcanoes that occur at plate boundaries.
Part B Explain how volcanoes form in areas that are not associated with a plate boundary. Give an example.