20.2 Volcanoes

Have you ever heard of the Ring of Fire? About half of the active volcanoes on Earth are present along the shores of the Pacific Ocean in this region. Mount St. Helens in Washington State (Figure 20.10) and Mount Fuji in Japan are part of the Ring of Fire. In this section, you will learn about the different kinds of volcanoes and how magma affects how they erupt and are shaped.

Where you find volcanoes

The Ring of Fire The Ring of Fire rims the Pacific Ocean along subduction zones where the Pacific Plate is being subducted under other surrounding plates (see diagram below). The island of Japan and neighboring islands—also part of the Ring of Fire—are near subduction zones where three plates come together (Figure 20.11).

Where else do you find volcanoes? In addition to being located at convergent plate boundaries such as subduction zones, volcanoes are also present along divergent boundaries and within plates. For example, the volcanic Hawaiian Islands have formed in the middle of the Pacific Plate.

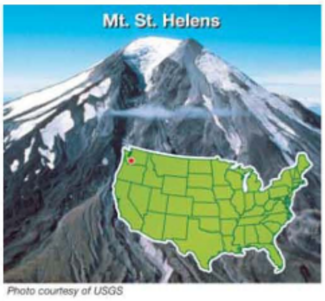
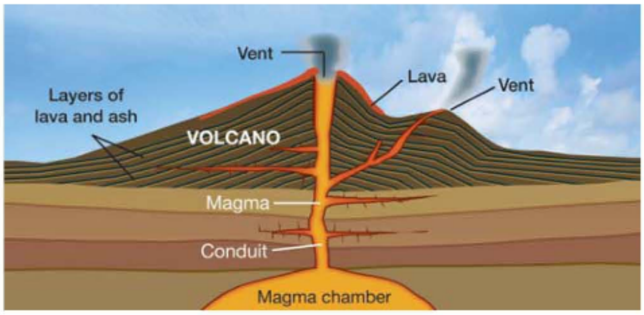


Figure 20.10: *Mount St. Helens in Washington State erupted violently in 1980. A much quieter, three-year eruption that produced a "lava dome" ended in 2008.*

Figure 20.11: *Japan is part of the Ring of Fire.*

What is a volcano?

Parts of a volcano A **volcano** is an erupting vent through which melted rock, gases, ash, and other materials from Earth's mantle are released or erupted. During an eruption, melted rock called **magma** leaves the **magma chamber** and moves upward through the conduit and out of the vent at the top of the volcano. Once it leaves the vent, magma is called **lava**. The composition of the magma and lava and the character of the associated eruption affect the shape of a volcano. The cone-shaped, mountainous volcano below has layers of lava and ash. This is just one example of what a volcano can look like.



Volcanoes have a lifetime The life cycle of a volcano occurs in three phases: active, dormant, and extinct. An active volcano, like Mount St. Helens, has erupted recently and is expected to erupt again in the near future. A dormant volcano is not active now, but may become active again in the future. Many of the volcanoes along the northern Pacific coast of North America are dormant. An extinct volcano is at the end of its life and is no longer able to erupt. The now-solid magma that filled the conduit is exposed due to erosion of the surrounding volcano by wind and water. This solid core is called a volcanic neck. Examples of volcanic necks include Ship Rock in New Mexico and Devil's Tower National Monument in Wyoming. Devil's Tower was featured in the 1977 Steven Spielberg movie *Close Encounters of the Third Kind* (Figure 20.12).

VOCABULARY

volcano - an erupting vent through which molten rock and other materials reach Earth's surface, or a mountain built from the products of an eruption.

magma - underground melted rock.

magma chamber - a location where magma collects inside Earth.

lava - magma that has erupted onto Earth's surface and cooled.

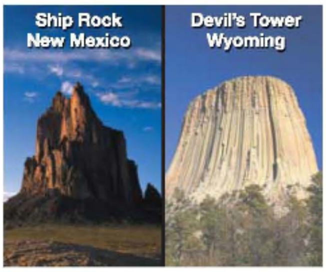


Figure 20.12: *The volcanic necks of Ship Rock and Devil's Tower have been exposed by erosion.*

What makes magma?

Solid mantle rock melts The rock of Earth's mantle is hot but solid. This rock melts and becomes magma under the right conditions. What are the conditions for rock to melt?

Lowering pressure Rocks melt when the temperature becomes greater than their melting point. Neither the cool lithosphere nor the hot upper mantle is hot enough to melt rock. The only way to make magma is to lower the melting point of the rock. Lowering the pressure on rock is one way to lower its melting point. The hot rock of the mantle is solid because of the great pressure of the material above it. However, this solid material can melt if the pressure on the hot rock decreases. In fact, pressure on the underlying mantle is lowered near divergent plate boundaries where the plates pull apart. The melted rock, now magma, is less dense than the surrounding solid rock, so it rises and might eventually erupt onto Earth's surface as lava.

Adding water Another way to lower the melting temperature of rock is to mix water with the rock. Water comes into the mantle at subduction zones as liquid and as part of the mineral composition of certain rocks. Once mixed with the solid mantle rock, the water is present as individual molecules that react chemically with the minerals in the mantle rock, causing it to melt.

Magma is made by lowering the melting point of mantle rock.

Pressure and water affect melting temperature The two graphics in Figure 20.13 show how pressure and water affect the melting of hot rock.

- Graph A: The rock in the bottom right corner of graph A is solid because it isn't hot enough to melt under high pressure. The rock above the solid rock is melting at the same high pressure because the temperature is higher. The rock in the bottom left corner is melting at a lower temperature because of lower pressure.
- Graph B: In graph B, the rock in the bottom right corner is solid because it isn't hot enough to melt when dry. The dry rock above is melting because the temperature is higher. The rock in the bottom left corner is melting at a lower temperature because it contains water.

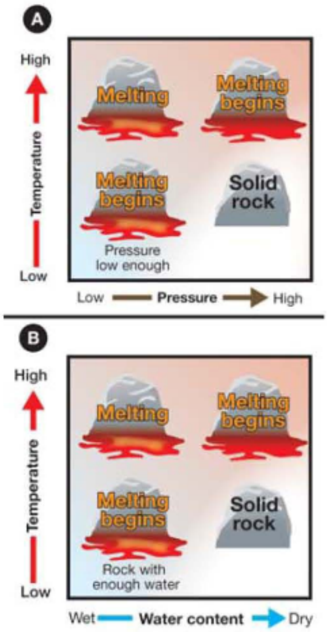


Figure 20.13: *Two graphs of the conditions for making magma.*

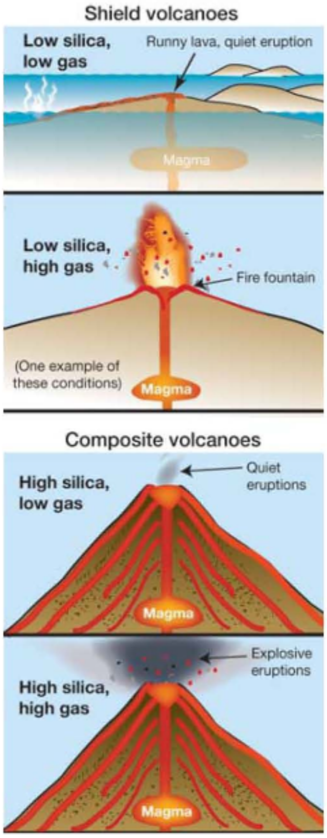
Volcanoes vary in shape and type of eruption

The shapes of volcanoes The shapes of volcanoes depend on the composition of the magma that formed them. Volcanoes can look like wide, flat mounds (shield volcanoes), like tall cones (composite volcanoes), or like a heap of rock bits (cinder cones). The graphic to the right illustrates the shapes of shield and composite volcanoes.

Silica in magma affects how thick or runny it is The amount of silica in magma changes its consistency, or viscosity. For example, magma that forms basalt, a low-silica rock, is dark in color and runny, or low in viscosity (think of ketchup). Magma that forms granite contains a higher proportion of silica. Granitic magma is light colored, less dense than basaltic magma, sticky like soft taffy, and thick (viscous).

Dissolved gas affects how gentle or explosive the eruption will be Together with silica content, the amount of gas dissolved in magma determines the character of a volcanic eruption. Magma is under great pressure when it's deep below the surface. This high pressure keeps gases such as sulfur dioxide in solution. Think about the carbon dioxide gas that gives soda its fizz. An unopened bottle of soda contains a large volume of dissolved carbon dioxide. Like soda, the gas in deep magma also is dissolved. However, the pressure drops as magma moves up toward the surface. The effect is like taking the cap off that soda bottle. The gas comes out of solution and forms bubbles within the magma. Some magma contains a large amount of gas, while other magma is like flat soda and contains much less gas. How this released gas moves through and around the magma greatly affects how lava erupts at the volcano's vent. The table below and the graphic at the right show how silica and gas content in magma determine the type of volcanic eruption that will take place for shield and composite volcanoes.

		Low Gas	High Gas
Shield Volcanoes	Low Silica	• Runny magma, like ketchup • Quiet eruption, lava flows easily	• Runny magma, bubbly • Fire fountain, lava flows easily
Composite Volcanoes	High Silica	• Thick, sticky magma, like taffy • Quiet eruption	• Thick, sticky magma • Explosive eruption

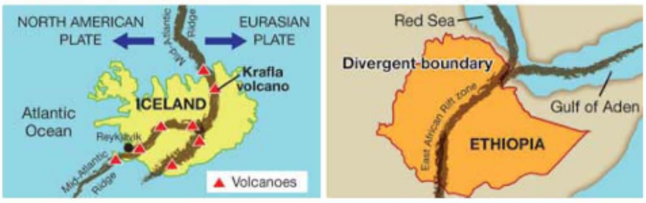


Volcanoes at divergent boundaries

Mid-ocean ridge volcanoes As lithospheric plates move apart at a divergent boundary, mantle material below is drawn toward Earth's surface (Figure 20.14). The hot and flexible rock of the mantle is solid because of the great pressure of the material above it. However, as the rock rises, the pressure decreases. The lower pressure lowers the melting temperature of the rock so it melts and becomes magma that erupts underwater at the mid-ocean ridge. In effect, mid-ocean ridges are long chains of volcanoes!

Low-silica magma The magma at mid-ocean ridges is chemically similar to mantle rock. It is dark colored, silica poor, and will form basalt. On land, basaltic lava flows like spilled syrup (Figure 20.15). At underwater mid-ocean ridges, hot, oozing lava immediately hits cold seawater. The seawater causes the lava to form a solid skin. Flowing lava fills the skin like air fills a balloon. If the skin (now a brittle crust) cracks, more lava oozes out and the cycle repeats. The result is a volcanic formation called *pillow lava* (Figure 20.15). When geologists find pillow lava on land, they know that there was once a mid-ocean ridge under an ancient ocean at that location.

Iceland and Ethiopia Since mid-ocean ridges are mostly under the ocean, it is hard to study the volcanic activity that occurs at divergent boundaries. However, Iceland and Ethiopia are places that are affected by divergent boundaries above sea level. Iceland is separating along the Mid-Atlantic Ridge. Similarly, Ethiopia is the site of the East African Rift zone. Due to the separation of plates at these locations, each is intensely volcanic and, at some point in the future, the valleys created by the separation will probably fill with ocean water.



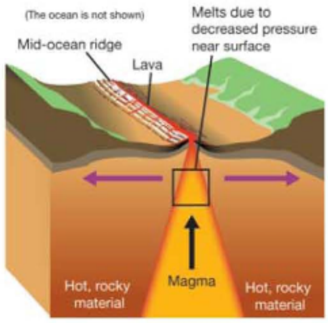
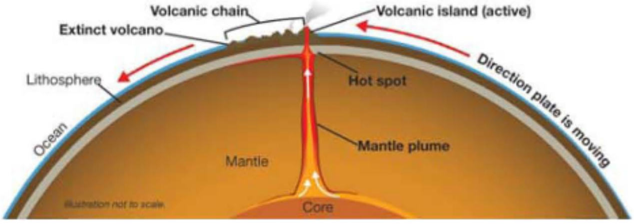


Figure 20.14: *As the plates move apart at a mid-ocean ridge, the mantle material is drawn upward. The pressure decreases as this material rises, causing the mantle material to melt.*

Figure 20.15: *Basaltic lava and pillow lava.*

Volcanic island chains and mantle plumes

Volcanic island chains Like mid-ocean ridge volcanoes, volcanic island chains are produced from basaltic magma. The magma that feeds mid-ocean ridge volcanoes comes from the upper part of the mantle at divergent plate boundaries. In contrast, volcanic island chain volcanoes are fed by a mantle plume, from the lower mantle, perhaps from near Earth's outer core. Since these mantle plumes pass through the whole mantle, they are long-duration structures and essentially fixed in place. As you learned in Chapter 19, the top of the mantle plume is called a hot spot. Volcanic islands form on the plate above the hot spot. Although lithospheric plates move very slowly, eventually their motion causes a plate to move off the hot spot. At that point, the island volcano is cut off from its magma source and becomes extinct while a new volcanic island begins to form over the hot spot. This process repeats and creates a string of volcanic islands—a volcanic island chain such as the Hawaiian Islands.



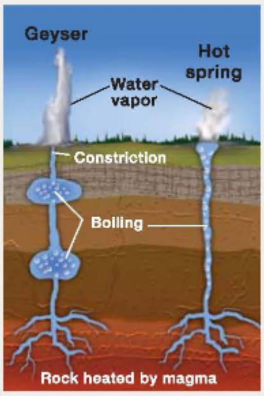
Mantle plumes Volcanoes caused by mantle plume hot spots can be found anywhere a plate is over the mantle plume. Volcanic island chains are formed when the mantle plume hot spot is under the ocean floor. Note that the Hawaiian Islands are in the middle of the Pacific Plate, nowhere near a plate boundary. Mantle plume hot spots are under continents, too. The geysers, hot springs, and other geothermal features of Yellowstone National Park are caused by a mantle plume hot spot.

SCIENCE FACT

Geysers, Hot Springs, and Energy

Geysers and hot springs are the result of water in the ground coming in contact with magma-heated rock below Earth's surface. This geothermal energy (heat energy from the hot rock) heats the water and creates steam. Whether a geyser or a hot spring forms depends on the temperature of the rock, the amount of water present, and the shape of the water passage to the surface.

Find out more about geothermal energy. Where is it used? Write a brief paragraph describing your findings.



Shield and composite volcanoes

What is a shield volcano?

A **shield volcano** gets its name from its resemblance to a warrior's shield lying on the ground. Their wide, flattened-pancake shape suggests that their magma is too runny to build a tall cone shape. As you might suspect, shield volcanoes are fed by basaltic magma. The Hawaiian Islands have many shield volcanoes.

Photo by D. Little, USGS

Fire fountains from shield volcanoes

A special condition occurs when runny, low-silica magma contains high levels of dissolved gas. Large volumes of gas are released as the magma rises in the conduit. This gas flings globules and ropes of glowing lava into the air without much danger to onlookers standing at a distance. The effect is identical to shaking a soda bottle to produce a shower of soda. This brilliant spectacle is called a fire fountain and is common on the island of Hawaii (Figure 20.16).

What is a composite volcano?

A **composite volcano** is a tall cone formed by layers of lava and ash. Popocatépetl in Mexico, Mount St. Helens in Washington State, and Mount Fuji in Japan are examples of composite volcanoes. The layers that make up a composite volcano accumulate over a long period of time. Unlike shield volcanoes and volcanoes formed at mid-ocean ridges or by a mantle plume, the lava of a composite volcano doesn't flow quickly. Instead, the lava builds up in a tall heap because it is thick, sticky, and silica rich.

Mt. Fuji

VOCABULARY

shield volcano - a flat and wide volcano that has low-silica magma and lava with low or high levels of dissolved gas.

composite volcano - a tall, cone-shaped volcano formed by layers of lava and ash.

Figure 20.16: *A fire fountain.*

The source of silica-rich magma

Composite volcanoes form in subduction zones Composite volcanoes form at subduction zones where water and sediment are carried downward as one plate slides beneath the edge of another plate. The subducted water combines chemically with hot mantle rock causing the subducting plate and sediments to melt. The resulting magma rises because it is less dense than the surrounding rock, and eventually melts through the overlying plate, forming a composite volcano (Figure 20.17).

Silica and magma Composite volcanoes are formed from silica-rich magma. Where does this magma come from? To begin to answer this question, let's look at the difference between shield and composite volcanoes. An important difference between these volcanoes is the distance between the magma source and the volcano on Earth's surface. In Figure 20.17, notice that the newly formed magma must pass upward through a thick continental plate. In contrast, Figure 20.14 shows that magma has a short distance to travel to reach Earth's surface to form volcanoes at mid-ocean ridges. The same is true for shield volcanoes. Clearly, something must change on this longer upward pathway.

What's different? The magma of both the mid-ocean ridge and a composite volcano starts out as silica-poor mantle material. This basaltic magma is released unchanged at mid-ocean ridges, but at subduction zones it must migrate upward before reaching the surface. During this migration, minerals begin to crystallize, first high-melting-point minerals, then lower-melting-point minerals. As these minerals crystallize, the silica increases in concentration. By the time this now silica-rich magma reaches the surface, it will form silica-rich rocks such as andesite and rhyolite. The table below summarizes this information.

	Shield volcanoes	Composite volcanoes
Volcano shape	• Flattened, gradual slopes	• Tall, steep slopes
Silica concentration	• Silica poor	• Silica rich
Magma source	• Mantle	• Mantle (and melted subducted ocean crust and sediment)
Distance from magma source to volcano on Earth's surface	• Short	• Long

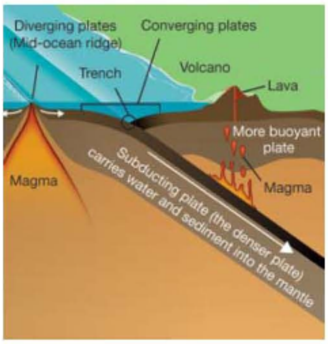


Figure 20.17: *Forming magma at a subduction zone.*

SCIENCE FACT

Continents vs. Ocean Floors

Granite and andesite form the mass of the continents. A key difference between these rocks and basalt, the rock of the ocean floor, is density. Both the ocean floor and the continents float on the mantle, but continents float higher because they have a lower density. As a result, we have dry land on which to live. The ocean floors are under the oceans because they are too dense to float higher on the mantle and rise above sea level.

What would Earth be like if the ocean floors were less dense?

Dissolved gas and cinder cones

Dissolved gas in sticky magma

When silica-rich magma is low in dissolved gas, the lava comes out like toothpaste and forms volcanic glass called *obsidian*. But if the silica-rich magma contains high levels of dissolved gas, pressure usually builds inside the volcano. In fact, the magma might be under so much gas pressure that a composite volcano cone bulges (see graphic below). In this situation, either the eruption will subside and the magma will return down the conduit, or the cone will explode. An explosive eruption results in a column of gas and bits of lava being expelled high into the atmosphere. The lava bits filled with gas bubbles break apart as the dissolved gas expands. The gas-filled fragments cool to produce pumice and ash (Figure 20.18). Pumice is a rock with lots of holes. Pumice has a low density because of its holes (which were made by gas bubbles) and will float in water. Ash is tiny particles of volcanic rock. Because ash is so fine, it drifts with the wind and might settle over a very wide area.

Photo by R.P. Hoblitt, USGS Photo by Harry Glicken, USGS Photo by R.L. Christiansen, USGS

Cinder cones

The shapes of shield and composite volcanoes are largely determined by the composition of their lava flows. However, the form of a **cinder cone**, a third type of volcano, is not the result of flowing lava (Figure 20.19). Rather, imagine a volcano that ejects a lot of gas with only small bits of lava. The lava bits (cinders) cool enough so that they are solid by the time they fall to the ground. Since they are not connected to one another, the falling bits form a loose, unstable pile. Sometimes the amount of magma produced increases enough to rise inside the cinder cone. The loose structure of the cinder cone conduit isn't strong enough to contain the magma, so the cone wall gives way and the molten rock flows out from the side. There are more cinder cones associated with shield volcanoes than composite volcanoes, but cinder cones can be found on both.

VOCABULARY

cinder cone - a volcano composed of a pile of solid lava pieces that form during a high-gas, low-lava eruption.

Photo by D. Wieprecht, USGS

Figure 20.18: *Pumice and ash form when a composite volcano explosively erupts.*

Photo by J. Lowenstern, USGS

Figure 20.19: *A cinder cone.*

Section 20.2 Review

1. What causes the region called the Ring of Fire?
2. What is the difference between a dormant volcano and an active volcano?
3. What is the difference between magma and lava?
4. A solid rock begins to melt:
   a. under what conditions of temperature and pressure?
   b. under what conditions of temperature and water content?
5. The word *viscosity* was used in this chapter and introduced in Chapter 10. If you could increase the silica content of lava, would the lava become more viscous or less viscous? Explain your answer.
6. What two ingredients in magma affect the type of eruption and shape of a volcano?
7. Describe what a high-gas, high-silica eruption is like. Then, describe a low-gas, low-silica eruption. What is the eruption of a cinder cone like?
8. Answer *continental plates* or *oceanic plates* in response to the following questions. Justify your answer in each case.
   a. Where is runny lava found?
   b. Where is thick and sticky lava found?
9. Describe the differences between a composite volcano and a shield volcano and give an example of each.
10. Each of the following is a clue that indicates a type of volcanic activity. Identify the volcanic activity that would cause the formation of each.
    a. pillow lava
    b. pumice and ash
    c. fire fountain
11. Ethiopia is a travel destination for individuals who want to see volcanoes. What explains Ethiopia's volcanic features?
12. Multiple choice: When volcanic island chains are formed, what moves?
    a. the mantle plume
    b. both the plate and the plume
    c. the plate above the mantle plume
    d. nothing moves

BIOGRAPHY

Katia and Maurice Krafft

Documenting volcanic eruptions was the passion of Katia and Maurice Krafft of France. Having met at the University of Strasbourg, they married in 1970 and spent the next 21 years filming and photographing volcanic eruptions. Because they were extremely daring in their work, they were able to show the public breathtaking footage of volcanic eruptions. Their work helped convince public officials of the seriousness of eruptions so that they could act quickly to evacuate areas near pending eruptions.

While filming Mount Unzen in Japan in 1991, the Kraffts and 40 journalists were killed during a pyroclastic flow.

Search for amazing photos of and by the Kraffts on the Internet using the search phrase: "Katia and Maurice Krafft."

JOURNAL

Travel to Iceland

Research, write, and design a travel brochure that describes to tourists what they would see when they visit volcanic Iceland.

What kinds of volcanoes would they find on Iceland? Justify your answer.