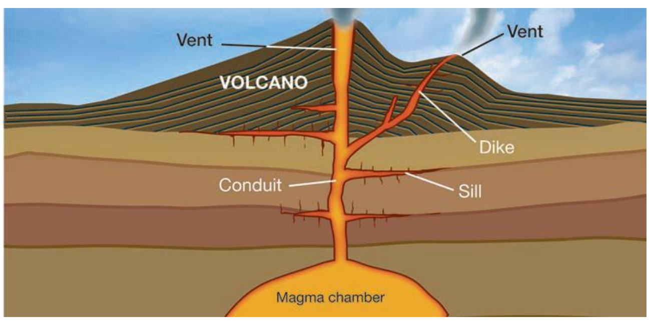
12.2 Volcanoes

Early explorers noticed that many volcanoes were located near coastlines, but they didn't know why. One volcano that is near a coastline is Mount St. Helens in Washington state. This famous volcano erupted in 1980 (Figure 12.14). Coastlines, plate tectonics, and volcanoes are all related. In this chapter you'll find out how.

Looking inside a volcano

What is a volcano?

A **volcano** is a site where 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 up the *conduit*. The magma leaves the conduit at the *vent*. Magma may leave the vent gently, or with violent force. Magma is called **lava** after it leaves the vent. Magma may leave the conduit by moving sideways along weaknesses between rock layers. This sideways movement of magma forms a *sill*. Magma may also move upward in a sheet to form a *dike*. If a sill or a dike breaks through to the surface, another vent will form.



Volcano features after an eruption

Formation of a caldera

Eventually, all volcanic eruptions end. The magma chamber is mostly or completely emptied and unable to support the weight of the overlying volcano. As a result, the volcano collapses in on itself forming a bowlshaped structure known as a **caldera**. Calderas can be very large—up to thousands of square meters.

Resurgent domes and lava lakes

If more magma returns up the conduit, a mound called a **resurgent dome** may form on the caldera floor. Water may fill the caldera forming a lake. It's also possible that the magma may not drain completely. In that case, the caldera will contain lava and become a **lava lake** (Figure 12.15).

The life of a volcano

Volcanoes have a lifetime

Volcanoes are not permanent features on the surface of Earth. They have a lifetime that occurs in phases. Volcanoes are described according to the phase they are in. The three phases are active, dormant, and extinct.

Active volcanoes

An **active volcano** is erupting or has erupted recently, and is expected to erupt again in the near future. However, volcanic activity during the life of a volcano doesn't last forever. Eventually, the conditions that make a volcano active change and the volcano becomes dormant.

Dormant volcanoes

A **dormant volcano** is a quiet volcano. *Dormant* means sleeping. Dormant volcanoes are not active now, but may become active again in the future. Most of the volcanoes along the northern Pacific coast of North America are dormant.

Extinct volcanoes

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 (Figure 12.16). Devil's Tower was featured in the 1977 Steven Spielberg movie *Close Encounters of the Third Kind*!

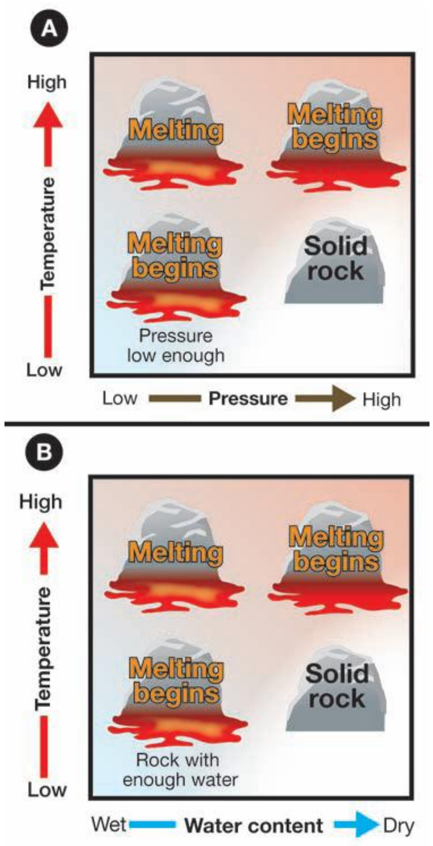
Where does magma come from?

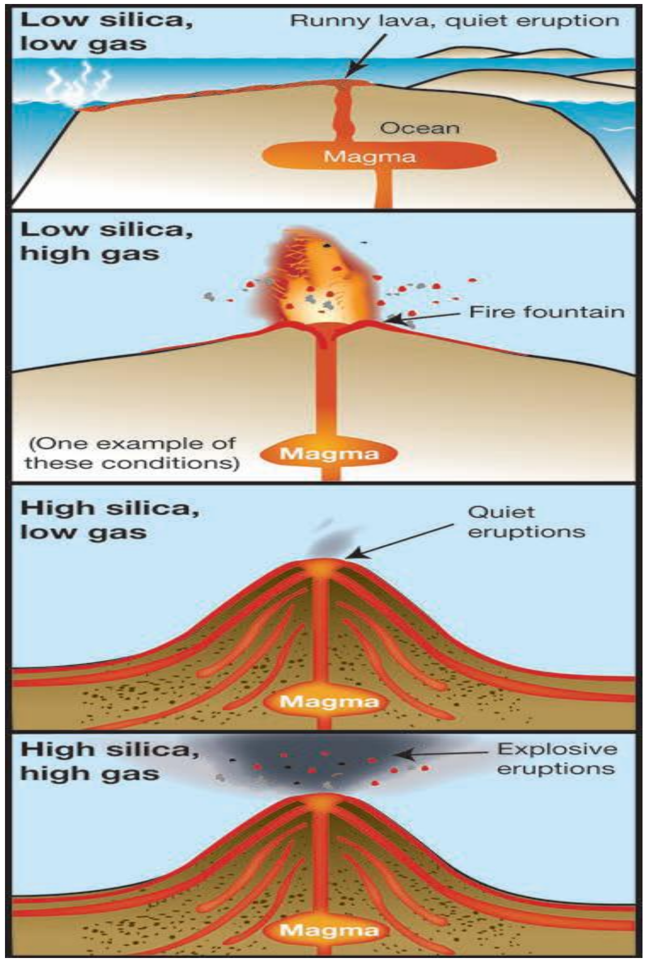
Solid mantle rock melts

The rock of Earth's mantle is hot but solid. Under the right conditions, this rock melts and becomes magma. Neither the cool lithosphere nor the hot upper mantle is hot enough to melt rock. So what are the conditions for rock to melt? **Pressure** You know that heating solids to their melting temperatures will make them melt. Another way to melt a solid is to lower its melting temperature. One way to lower the melting temperature is to lower the pressure. The hot rock of the mantle is solid because of the great pressure of the material above it. But the pressure decreases as the rock rises toward Earth's surface. Nearer the surface, the pressure is low enough and the temperature high enough for the rising rock to melt. The melted rock, now magma, is less dense than the surrounding solid rock, so it continues to rise and may eventually erupt onto Earth's surface as lava. **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 water. Once mixed with the solid mantle rock, the water occurs as individual molecules that react chemically with the minerals in the rock to promote melting within the mantle.

Pressure and water affect melting temperature

Figure 12.17 shows how pressure and water affect the melting temperature of hot rock. 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 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*. 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*.





Kinds of magma

The shape of volcanoes

Volcanoes can look like tall cones, wide flat mounds, or like a heap of rock bits. Why? The shape of a volcano is related to the composition of the magma that forms it. **Silica in magma** Silica, in one form or another, is present in all magmas. The amount of silica changes the consistency of the magma. Low-silica magma is runny. This magma may form basalt when it cools. High-silica magma is thick and sticky. This magma may form granite when it cools. Magma that can form andesite rocks is more silica-rich than basalt, but not as silica-rich as granite magma.

Dissolved gas in magma

Another important property of magma is how much gas is dissolved in it. Magma that has only a little dissolved gas doesn’t have bubbles. This magma is “flat,” like soda that has lost its fizz. Magma with a lot of dissolved gas is like soda before you open it. It can be bubbly or, under the right conditions, it can explode out just like when you open a shaken bottle of soda. The table below shows how silica and gas determine the kind of volcanic eruption that will take place.

	Low Gas Content	High Gas Content
Low Silica Content	Runny magma, like syrup	Runny magma, bubbly
	Quiet eruption, lava flows easily	Fire fountain, lava flows easily
High Silica Content	Thick, sticky magma	Thick, sticky magma
	Quiet eruption	Explosive eruption

Volcanoes with low silica magma

Shield volcanoes

A **shield volcano** is a flat, wide volcano that looks like a warrior's shield lying on the ground. The magma and lava associated with a shield volcano has a low amount of silica, and either low or high levels of dissolved gas. Because low-silica lava is runny, it can't build up a tall, cone-shaped volcano. This is why shield volcanoes are flattened. The volcanoes of the Hawaiian Islands are shield volcanoes.

Fire fountains

When low silica magma has high levels of dissolved gas, the gas bubbles out as it reaches the volcano vent. The effect is identical to shaking a soda bottle to produce a shower of soda. The high-gas magma produces a spectacular *fire fountain* (Figure 12.18). The resulting spatters of glowing lava cool in the air and hit the ground as solid lava cinders.

Cinder cones

The lava cinders form a cone around the vent called a **cinder cone**. Cinder cones are a common form of volcano. They are often found on the flanks of both shield volcanoes and composite volcanoes (see the next page). Cinder cones may also form in the caldera of dormant volcanoes. Cinder cones are structurally weak because they are simply a pile of rock bits.

Volcanoes with high silica magma

Composite volcanoes

Most coastal volcanoes are associated with subduction zones. The magma and lava of these volcanoes is thick and sticky because it is silica-rich. Over time, layers of this thick lava and ash build a tall cone called a **composite volcano** (Figure 12.19).

Dissolved gas in sticky magma

When silica-rich magma is low in dissolved gas, the lava comes out like toothpaste and form volcanic glass, called obsidian. But if the silica-rich magma contains high levels of dissolved gas, pressure usually builds inside the volcano. The lava of shield volcanoes is so runny that dissolved gas simply bubbles out. But silica-rich magma is too sticky. Before a composite volcano eruption, the magma may be under so much gas pressure that the composite volcano cone bulges (middle image, Figure 12.19).

Pumice and ash

When a composite volcano cone bulges like this, either the eruption will subside and the magma will return down the conduit, or the cone will explode. The cone may explode near the vent, throwing a column of gas and lava bits high into the atmosphere. The lava bits puff up and rip apart as the dissolved gas expands inside each bit. This puffing up action produces two forms of rock: pumice and ash. *Pumice* is a rock with lots of holes. Pumice has a low density because of its holes (which were made by air bubbles) and will float in water. *Ash* is smaller particles of rock, like fine sand. Because ash is so fine, it drifts with the wind and may settle over a very wide area.

Explosive eruptions

Pyroclastic flows

When a column of exploding material collapses, it races down the side of a composite volcano as a **pyroclastic flow**. The speed (more than a 80 km/h), force, and heat (200–700 °C) of the pyroclastic flow make it extremely destructive.

Lava bombs

Large pieces of glowing lava may be thrown far from the base of the composite volcano. These pieces, each one called a **lava bomb**, can be the size of watermelons. Sometimes the composite volcano explodes again, further down its side, adding more material to the expanding lava explosion.

Lahars

Mount Saint Helens erupted in Washington State in 1980. This was a classic silica-rich, gas-rich composite volcano eruption. Magma pressure formed a large bulge on the side of the mountain. The eruption was triggered when a portion of the bulge slid off. This created a weakness in the cone. An enormous explosion blew off a huge part of the side of the mountain. The combination of landslide, explosion, and pyroclastic flow killed 57 people. If water is present as snow and ice on the volcano, a mudflow called a **lahar** may accompany an eruption like this (Figure 12.20). The mudflows in the Mount Saint Helens' eruption destroyed forests and property and added to the death toll.

Volcanoes at divergent boundaries

Mid-ocean ridge volcanoes

A mid-ocean ridge forms at divergent boundaries, where two plates are pulling apart (Figure 12.21). As the plates move apart, mantle material below is drawn toward Earth's surface. The rock of the mantle is hot and flexible, but still solid. This rock is solid because of the great pressure of the material above it. But the pressure decreases as the rock rises. What affect will this have on the rising rock material? As you have just learned, the lower pressure also lowers the melting temperature of the rock. The rock melts and becomes magma that erupts underwater at the midocean ridge.

Basaltic magma

The magma at a mid-ocean ridge (associated with oceanic plates) is melted basalt. Basalt is a silica-poor, dark-colored rock. Basaltic magma is runny because of its low silica content. When runny basaltic lava oozes out at a mid-ocean ridge, it immediately hits cold seawater. The seawater cools the lava, forming a crust. But soon the crust cracks and another blob of basalt magma oozes out. This cycle repeats over and over, forming lava that looks like a pile of pillows. Geologists occasionally find pillow lava on land. This indicates that there was once a mid-ocean ridge under an ancient ocean at that location.

Volcanoes at convergent boundaries

The Ring of Fire

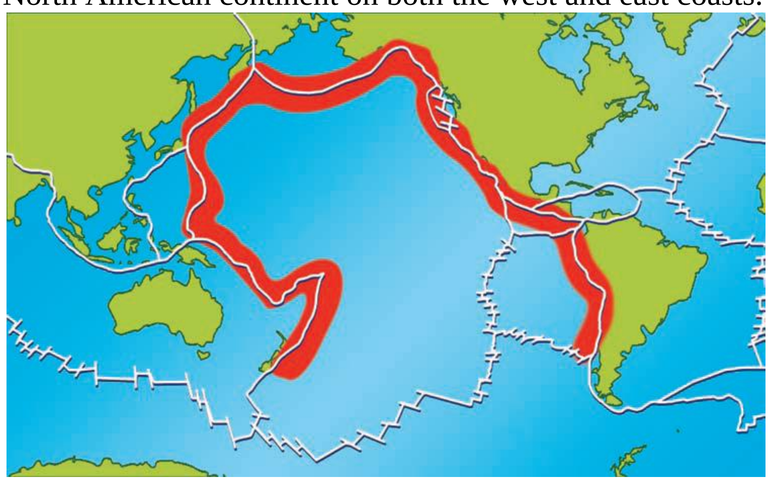
Most volcanoes are located along convergent plate boundaries. About half of the active surface volcanoes on Earth occur along the shores of the Pacific Ocean in a region called the **Ring of Fire**. Mount St. Helens is a volcano within the Ring of Fire. The Ring of Fire lies just above where the Pacific Plate is subducting under other surrounding plates.

Volcanic island arcs

A **volcanic island arc** is a string of volcanic islands that forms at a convergent plate boundary. The island of Japan and neighboring islands—all part of the Ring of Fire—are an island arc at the subduction zone where three plates come together (Figure 12.22).

How continents grow

In time, plate movements at a subduction zone bring islands and continents together. In this way, continents grow larger! Scientists can detect where island arcs have increased the size of the North American continent on both the west and east coasts.



Volcanoes on continents at convergent boundaries

Water

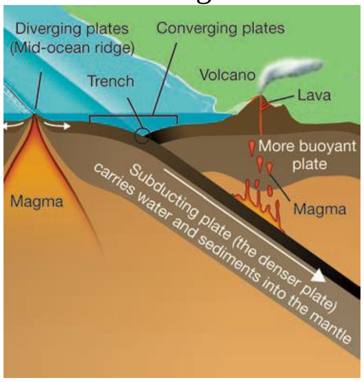
At subduction zones, water and sediments are carried downward as one plate sinks below the edge of another plate. The water and sediments combine with the hot mantle rock. As you have learned, water lowers the melting point of the mantle rock, so it melts, forming less-dense magma. The magma rises and eventually melts through the overlying plate, forming a volcano near the edge of the overlying plate (Figure 12.23).

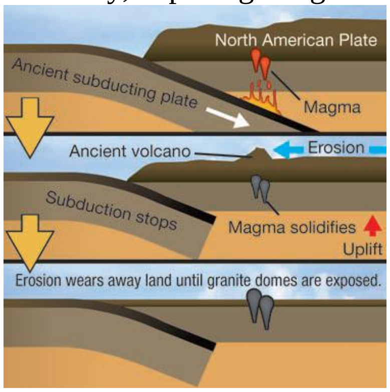
Silica-rich magma

The magma associated with subduction zones is silica-rich. Silicarich magma is light in color, thick, sticky, and less dense than basalt magma. When cooled, the silica-rich magma forms granite and other similar rocks. The surface of continents is made mostly of granite and andesite. Granite is not as dense as the basalt of the ocean floor. This is why continental plates float high on the mantle and provide us with dry land.

Granite domes

Yosemite National Park in California is famous for its granite domes. These domes formed when silica-rich magma rose to the surface at a subduction zone. When subduction stopped, the flow of magma stopped too (Figure 12.24). The magma below the surface cooled where it was. The surrounding land later eroded away, exposing the granite domes.





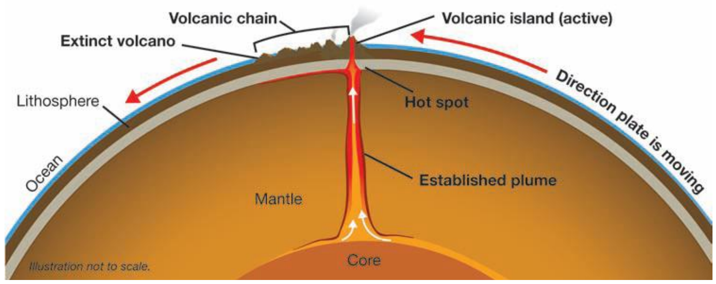
Volcanic islands away from plate boundaries

Volcanic island chains

You have learned that volcanic island arcs form at subduction zones. They also form in the middle of oceanic plates. The magma of these islands begins much deeper in the lower mantle. Deep mantle material flows slowly to the surface in a narrow mantle plume. The plume that feeds a volcanic island doesn't move because it is fixed in the lower mantle. But the plate over the plume does move! The area of the plate that is situated over the mantle plume is called a **hot spot**. Once the area of the plate has moved off the hot spot, the volcano will become extinct. But the mantle plume and hot spot are still active. Soon a new volcano will form beside the old one. In this way, a **volcanic island chain** is formed (Figure 12.25).

Silica-poor magma

The magma that forms a volcanic island chain is runny and silicapoor. These volcanoes have milder eruptions. As both island arcs and island chains are built, the lava that erupts underwater is cooled by the seawater it encounters. In this way, the lava hardens and builds up, eventually creating an island.



Using island chains to measure the motion of a plate

The Hawaiian Islands

The Hawaiian Islands are an example of a volcanic island chain. The biggest island, Hawaii, is over the hot spot now and has active volcanoes. Hawaii has been on top of this hot spot for the last 800,000 years. The islands to the northwest of Hawaii are older. Their volcanoes are either dormant or extinct.

Island chains and the speed of plates

By studying the direction, age, and length of a volcanic island chain, scientists can determine the direction and speed that a plate is moving. The Hawaiian Island chain shows us that the Pacific Plate is moving to the northwest at nearly 9 centimeters per year.

Adding to a volcanic island

To the southeast of the Hawaiian Island chain, the mantle plume under Hawaii is building a new volcano—Loihi. Loihi is an undersea volcano. When enough lava builds up so that Loihi is above sea level, it will extend the eastern border of Hawaii!

12.2 Section Review

1. What is the difference between magma and lava?

2. What is the difference between a dormant volcano and an active volcano?

3. A solid rock begins to melt:
a. under what conditions of temperature and pressure?

b. under what conditions of temperature and water content?

4. If you could increase the silica content of lava, would the lava get more sticky or less sticky?

5. What two ingredients in magma affect the type of explosion and shape of a volcano?

6. Describe what a high-gas, high-silica eruption is like. Then, describe a low-gas, low-silica eruption.

7. Answer *continental plate* or *oceanic plate* in response to these questions.
a. Where is runny lava found?

b. Where is thick and sticky lava found?

8. What causes the region called the Ring of Fire?

9. Name a difference between an island chain and an island arc.

10.When volcanic island chains are formed, what moves?

11.What kind of geologic formation is Loihi? Is it a part of the Hawaiian Island Chain? Explain your answer.

12.How have scientists figured out that the Pacific Plate is moving at about 9 centimeters per year?