Nature destroys - and pollutes - segments of itself, sporadically and violently, with man often a major victim in these upheavals. Earthquakes, volcanic eruptions, tidal waves, floods, epidemics are examples.

Glenn Seaborg
Introduction

- Most of the world's active volcanoes are located around the margin of the Pacific Ocean.
- Most active U.S. volcanoes are located in Alaska along the northern boundary of the Pacific Plate.
- Hawaiian volcanoes are located in the interior of the Pacific Plate.
- Magma composition and eruption style differ between volcanoes on plate margins and from the plate interior.

Volcanic activity includes more than just the eruption of volcanoes. In this chapter we will consider:
- The controls on the type of igneous eruption (fissure vs. volcano)
- Why some volcanoes are made up of lava and others of volcanic debris.
- Why some volcanoes are mild mannered and others are violent.
- The characteristics of igneous features formed below Earth's surface.
- The products of volcanic eruptions.

Most of the world's 1,500 potentially active volcanoes are located along convergent plate boundaries around the Pacific Ocean in the "Ring of Fire" (Fig. 1). The VolcanoWorld website ([http://volcano.und.nodak.edu/](http://volcano.und.nodak.edu/)) provides information on currently erupting volcanoes. Volcanic eruptions may be mild or violent and eruption style is dependent upon magma viscosity - the resistance to flow.

![Figure 1. Selected volcanoes that are currently active, recently active, or historically active. Note that most are located along plate boundaries.](image-url)
The U.S. has 52 volcanoes that have erupted in the past 200 years and 44 of those are in Alaska. The others are in the Cascade Range (Washington, Oregon, northern California), or on the islands of Hawaii. The Hawaiian Islands represent an exception to the rule that Pacific volcanoes are located along the boundary of the oceanic plate. Volcanoes located within the interiors of plates are typically the result of volcanic activity above a hot spot in the mantle. The dissimilar locations (plate interior vs. plate boundary) reflect different plate tectonic origins and distinct magma compositions that result in contrasting eruptive histories for each type of volcano.

On May 18, 1980, Mt. St. Helens, Washington, generated the most destructive volcanic eruption in U.S. history. The event provided scientists with a possible foretaste of what will happen if other volcanoes in the Cascade Range erupt in the future. Often the explosion itself is not the major cause of destruction or loss of life. Hazards associated with volcanic eruptions, such as lahars (volcanic mudflows) or pyroclastic flows, can travel great distances from the volcano itself, often affecting areas considered relatively secure from destruction. Hazards associated with eruptions are described using Mt. St. Helens as a case study in the elements of volcanic eruptions section.

The steep-sided, classic triangular shape of Cascade or Alaskan volcanoes contrasts with the flatter, broad cones of Hawaiian volcanoes (Fig. 2). The contrast in shape is a reflection of different components that are in turn related to distinct geologic histories. Volcano types and other landforms that may arise from volcanic activity such as dramatic calderas are described in the volcanoes and volcanic landforms section of the chapter (Fig. 3).
Finally, we recognize that not all magma reaches the surface and that plutonic igneous rocks may form in association with volcanic activity as **igneous intrusions** (Fig. 3). These features will be exposed at Earth's surface through a combination of uplift and erosion creating such spectacular features as Yosemite Valley in Yosemite National Park, California.

**Magma Viscosity**

- Molten rock below Earth's surface is magma; on Earth's surface it is called lava.
- The character of volcanic eruptions are largely controlled by the viscosity of the magma.
- Low viscosity fluids flow more easily than high-viscosity fluids.
- Composition controls magma viscosity.
- Magma with low-silica content has low viscosity and magma with high-silica content has high viscosity.
- Volcanic gases escape more easily from low-viscosity magmas.
- Volcanic eruptions are more violent when high-viscosity magmas are involved.

Volcanic activity occurs when magma, molten rock below Earth’s surface, rises to the surface through pipes and fissures (fractures) in Earth’s crust. The character of the resulting eruption is dependent upon the **viscosity** - the resistance to flow - of the magma. When magma reaches Earth's surface it is termed lava. High-viscosity lavas flow slowly and typically cover small areas. In contrast, low-viscosity magmas can flow more rapidly and may form lava flows that cover thousands of square kilometers (Fig. 4).

![Figure 4. Simple illustrations of the contrast in flow distance for low- and high-viscosity lavas.](image)
We use materials in our daily lives that exhibit a range of viscosity (Fig. 5). Water has low viscosity (it flows easily) whereas syrup and honey have greater viscosity. We can reduce viscosity by heating material (warm syrup flows more easily than cold syrup), or increase viscosity by decreasing the temperature.

Chemical content (composition) and temperature influence magma viscosity. The amount of silica (SiO₂: silicon and oxygen) present is especially significant. Viscosity increases with increasing silica content. Three types of magma, basalt, andesite, and rhyolite, are recognized on the basis of their composition. These magmas solidify to form rocks of the same name.

<table>
<thead>
<tr>
<th>Magma Type</th>
<th>Silica Content (% weight)</th>
<th>Magma Temperature</th>
<th>Viscosity Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basalt</td>
<td>Less than 53</td>
<td>1,100-1,250°C</td>
<td>Low</td>
</tr>
<tr>
<td>Andesite</td>
<td>53-68</td>
<td>800-1,100°C</td>
<td>Intermediate</td>
</tr>
<tr>
<td>Rhyolite</td>
<td>More than 68</td>
<td>700-850°C</td>
<td>High</td>
</tr>
</tbody>
</table>

Volcanic gases (water vapor, sulfur dioxide, carbon dioxide, hydrogen sulfide) help drive eruptions. Low-viscosity magmas allow gases to escape easily whereas gas pressures can build up in high-viscosity magmas, resulting in violent eruptions.

Try an experiment to prove this to yourself. Take two liquids of contrasting viscosity, water and a milk shake work well, and blow through a straw into each. The water will bubble readily without much effort but it will require a lot of lungpower to get the milk shake to bubble. Actually, the milk shake is more likely to splatter than bubble so make sure you are a few feet away from other people if you try this. The thicker the milk shake the more violent the result.
Magma Source vs. Magma Composition

So viscosity, and hence the violence of eruptions, is determined by composition, but what controls composition? Volcanic activity is linked to the plate tectonic cycle with mild eruptions occurring in plate interiors and along oceanic ridges, and more violent eruptions associated with convergent plate boundaries. The linkage between eruption style and the plate tectonic cycle is governed by the melting process.

Igneous rocks are composed of a variety of minerals (see the section on igneous rocks in the chapter, Rocks & Minerals). Silica (SiO2) is a key component of these minerals and the silica content of the rocks varies depending upon the constituent minerals. High-silica rocks (granite, rhyolite) are dominated by silica-rich minerals such as quartz and feldspar. Basalt and gabbro contain minerals with a lower silica content (olivine, pyroxene, and amphibole). However, even these rocks contain feldspar and their silica content rarely dips below 50% (by weight). The silica-rich minerals have a lower melting temperature than silica-poor minerals. Consequently, when physical conditions favor melting, the first minerals to melt will form a magma that is more silica-rich than the parent rock. This limited melting, involving only some minerals, is termed partial melting (Fig. 6).

![Figure 6. Relationship between parent rock (magma source) and magma type. Note: Each magma type contains more silica than its parent magma.](image)

The low-silica, low-viscosity basalt magmas that are characteristic of the Hawaiian Islands and the oceanic crust are derived from a mantle source that is even more deficient in silica (Fig. 7). Peridotite, a common mantle rock, is dominated by olivine and pyroxene, and lacks the feldspar common in basalts. Partial melting of peridotite yields a more silica-rich melt that crystallizes to form basalt (olivine, pyroxene, feldspar). Basaltic magmas also come to the surface on land where a continent overlies a deep mantle magma source (hot spot) or where a continent is splitting apart along a rift zone.
Magma is generated along convergent plate boundaries where oceanic lithosphere descends into the hot mantle at **subduction zones** (Fig. 7). The descending plate contains **oceanic crust** of basaltic composition but also includes some overlying **sediment mixed with sea water**. Partial melting of this mixture generates an **andesitic magma**. The increase in silica content results in a more viscous magma and a more violent eruption style. Consequently, volcanoes on plates overlying subduction zones (e.g., Mt. St. Helens, Washington; Mt. Pinatubo, Philippines) yield some of the most spectacular and dangerous volcanic eruptions.

**Think about it . . .**
Examine the map of Decade Volcanoes at the end of the chapter and answer questions about the type of magma associated with them based on their locations relative to plate boundaries.

**Rhyolite** is the third, and most silica-rich, magma type but it is also the least common of the three. The high-silica content of rhyolite requires the **partial melting of continental crust** that has an average composition similar to andesite. The relatively high-silica content results in a highly viscous magma that is relatively immobile and may solidify within the crust to form a plutonic igneous rock (granite). Rhyolite is common at Yellowstone National Park, Wyoming, which lies above a hot spot in the mantle (Fig. 7). The rising basaltic magma provided the heat source to melt surrounding continental crust and generate rhyolite that is present throughout the park, often in association with basalt.
Mt. St. Helens

- The 1980 eruption of Mt. St. Helens was the most destructive volcanic eruption in U.S. history.
- Mt. St. Helens eruptions occur at intervals of 100 to 200 years.
- Small earthquakes and minor steam eruptions occurred in the two months before the major eruption.
- Swelling of the north flank of the volcano created a bulge because of the rise of magma within the volcano.
- The major eruption occurred as a lateral blast that followed a moderate earthquake that triggered a massive landslide.
- Nearly 400 meters (1,300 feet) were removed from the volcano by the eruption.

On May 18, 1980, the eruption of Mt. St. Helens created the most destructive volcanic eruption in U.S. history. The event resulted in 57 deaths and approximately $1 billion damages.

Mt. St. Helens is just one of several major volcanoes that make up the Cascade Range (Washington, Oregon, California). Major cities such as Seattle (Washington) and Portland (Oregon), with populations of over one million people, are located less than 100 km (63 miles) from these volcanoes (Fig. 8). Fortunately such cities are typically too far away to be affected by most geologic hazards and are upwind from the nearest volcanoes. However, many smaller cities (Spokane, Boise) are in the downwind path of Cascade volcano eruptions.

Figure 8. Map illustrating location of Mt. St. Helens and other Cascade volcanoes. Modified from a map by Lynn Topinka (1998) at USGS Cascade Volcano Observatory.
Prior Activity

Geologists who study volcanoes (volcanologists) determined that Mt. St. Helens had experienced eruptions at intervals of 100 to 200 years since the fifteenth century. Lewis and Clark recorded an eruption during their expedition (1804-1806).

The volcano began to show signs of life in March 1980, after a dormant period of 123 years. Teams of scientists began to study changes in the volcano in an effort to determine if an eruption was imminent. Scientists identified three events that occurred in the months prior to the major eruption that indicated magma was moving upward beneath the volcano.

Earthquakes
Thousands of small earthquakes were recorded. One hundred and seventy four with magnitudes greater than 2.6 occurred in a two-day period in late March. The largest shocks (magnitude 4-5) were felt by those living near the volcano. The tremors generated small avalanches on the snow-covered upper slopes of the volcano. Scientists interpreted the earthquakes to mean that volcanic gases and magma were moving within the volcano. Small earthquakes continue to occur beneath the volcano.

Minor Eruptions
The first flurry of seismic activity was followed by small eruptions of ash, steam, and volcanic gases. These events represented the first eruptions in the conterminous U.S. in 63 years. Other steam-driven eruptions followed but no magma was involved. These explosions generated a summit crater.

The Bulge
The most obvious sign that magma was moving toward the surface was the growth of a bulge on the north flank of the volcanic cone. Earthquake activity was concentrated directly beneath the bulge. The bulge was growing at a rate of nearly 2 meters per day just a few weeks before the final eruption and caused the north flank to rise by approximately 150 meters from its original elevation.

The May 18 Eruption
Despite the attention of hundreds of scientists, the eruption of Mt. St. Helens on May 18, 1980, came as a big surprise. There

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**World's deadliest volcanic eruptions**

1. Tambora, Indonesia
   1815: 92,000 died, mostly due to starvation following the eruption

2. Krakatau, Indonesia
   36,000 dead; cause - tsunami

3. Mt. Pelee, Martinique
   30,000 killed by pyroclastic flows

4. Nevado del Ruiz, Colombia
   25,000 buried when mudflows engulfed town of Armero

5. Unzen, Japan
   15,000 died when the volcano collapsed and from associated tsunami
was no clear signal of the eruption and several geologists perished as a result.

The eruption began with a magnitude 5.1 earthquake below the volcano. This triggered a massive landslide (the largest in recorded history) of the north flank of the volcano that was followed by an explosive lateral blast. When the landslide released pressure on the bulge, the north side of the volcano was blasted off. Finally, volcanic debris was blasted vertically into the atmosphere and within 10 minutes the debris from the eruption reached an altitude of 16 kilometers (10 miles).

The Aftermath

A comparison of pictures of the volcano before and after the eruption reveals that the mountain lost about 1,300 feet in elevation (Fig. 9). The landscape to the north of the volcano was converted to a monochromatic wasteland blanketed in gray ash. (For more on the details of the eruption, see the next section, Elements of Volcanic Eruptions).

Think about it . . .
Assume that the future eruption of other Cascade Range volcanoes will be similar to the eruption of Mt. St. Helens. Identify potential methods that you could use to monitor volcanic activity in an effort to try to predict the next eruption. What volcanic features or activities would you monitor and how would you do it? What would you look for to separate minor activity from dangerous behavior? Remember, you don’t want to panic nearby residents unless you are sure a big eruption is on the way.
Elements of Volcanic Eruptions

- The eruption of Mt. St. Helens exhibited many of the typical features of eruptions from active volcanoes.
- Pyroclastic flows, dense mixtures of hot gases and ash, raced down the flanks of the volcano.
- Mudflows that combine ash with water in stream channels are known as lahars.
- The lateral blast knocked down mature trees up to 27 km from the volcano.
- Measurable layers of volcanic ash were deposited as far east as the Dakotas, Nebraska, and Colorado.
- The intermediate- to high-viscosity magma associated with the volcano yielded only modest volumes of lava that formed a lava dome in the volcanic crater.

The effects of the Mt. St. Helens eruption were immediately experienced adjacent to the volcano and were soon felt in states hundreds of miles away. Hazards associated with the eruption included pyroclastic flows, lahars (mudflows), ash fall, and the lateral blast (Fig. 10). Lava posed little hazard because it was produced in only modest quantities as a result of the relatively viscous magma associated with the eruption.

Figure 10. Impact of eruption immediately adjacent to Mt. St. Helens. The volcano’s crater is illustrated in the bottom half of the map. With the exception of some lahars, all devastation occurred to the northern side of the volcano, consistent with the northward-directed lateral blast. Map simplified from an original map at the USGS/Cascades Volcano Observatory site.
The lateral blast was directed to the north and all local damage associated with the eruption (with the exception of a few mudflows) was on the north face of the mountain. Structures nearby the volcano were blown over by the force of the lateral blast or carried away by mudflows, whereas, some structures downwind collapsed under the weight of volcanic ash.

The principal products of the eruption, with the exception of the lateral blast, are typical of most stratovolcano eruptions.

**Pyroclastic Flows**

Pyroclastic flows are mixtures of hot gases and ash, cinders that form a dense cloud that races down the volcano slope incinerating all in their path (Fig. 11). Pyroclastic flows (also known as nuee ardente or ash flows) reach speeds of 100 km/hr and temperatures of 400°C. The flows transport pumice blocks the size of children.

![Figure 11. Pyroclastic flow descends flank of Mt. St. Helens. Modified from an original image by P.W. Lipman, USGS, taken on August 7, 1980](image)

**Lahars**

Lahars are mudflows, largely confined to stream channels, formed when fine-grained pyroclastic debris (ash) mixes with water from snowmelt or streams. Flow velocity was typically

![Figure 12. Lahar deposits along Muddy River, Mt. St. Helens. Arrows indicate level of mudflow on trees adjacent to stream. Circled person for scale. Image modified from an original photograph by Lyn Topinka, USGS CVO.](image)
16 to 40 km/hr (10-25 mph). Lahars can destroy large structures (bridges) and carry large loads of debris. The lahars of May 18 destroyed over 200 homes and 300 km (220 miles) of roads. The flows reached a depth of 20 meters (66 feet) and occupied 220 km (135 miles) of stream channels (Fig. 12). Debris was swept downstream into the Columbia River reducing channel depth by two-thirds and disrupting river traffic.

**Lateral Blast**
Volcanic blasts, driven by gas-rich viscous magmas, are common from Mt. St. Helen's type volcanoes. Most blasts are directed vertically but low-angle lateral blasts can devastate large areas immediately adjacent to volcanoes. The force of the lateral blast, traveling at speeds of over 1,000 km/hr, knocked down trees on the surrounding national forest lands as far as 27 km (19 miles) from the crater (Figs. 10, 13). The blast removed or destroyed any objects within 12 km of the volcano (direct blast zone or tree-removal zone), knocked down trees between 12 to 27 km from the crater (channelized blast zone or tree-down zone), and singed trees in the outermost seared zone.

**Ash Fall**
Volcanic ash and other deposits, collectively termed pyroclastic debris or tephra, were blasted several miles into the atmosphere and spread around the world. Larger particles (lapilli, volcanic bombs) were deposited in thicker deposits, closer to the volcano (Fig. 14). The column of ash from the initial eruption reached an elevation of 20 km (13 miles) within 10 minutes and did not cease until the following morning. Ash was carried downwind (eastward) at a velocity of 100 km/hr (63 mph) and had reached Spokane, eastern Washington, by noon.
Lava
Lava was present in only minor volumes in association with the Mt. St. Helens eruption (Fig. 15). The low-viscosity basalt lava flows that are common from Hawaiian volcanoes can typically travel distances of 50 km from their source. In contrast, the intermediate-viscosity lava of Mt. St. Helens did not travel far and formed a lava dome within the volcano’s crater. The lava dome increased in size during the following decade, reaching an elevation of more than 300 meters and a basal width of over 1 km.

Think about it . . .
Review the description of the volcanic history of Mt. Shasta at the end of the chapter and use the map of the surrounding area to identify potential volcanic hazards for the area surrounding the volcano.

Volcanoes & Volcanic Landforms

- Volcanoes are divided into three classes (shield volcanoes, stratovolcanoes, and cinder cone volcanoes) on the basis of their shape and composition.
• Calderas are large craters that formed when a stratovolcano or shield volcano collapsed into a shallow, empty magma chamber below the volcano.
• Low-viscosity lavas that reach the surface through fissure eruptions rather than from a volcanic cone may accumulate to form lava plateaus.
• Water circulating near hot magma can result in the formation of several different features such as geysers, hot springs, fumeroles, and mud volcanoes.

The most common types of volcanic landforms are volcanoes but features such as geysers, lava plateaus, and calderas may also form as a result of volcanic eruptions. Volcanoes are separated into three basic types, shield volcanoes, stratovolcanoes (composite cone volcanoes), and cinder cone volcanoes.

Volcanoes

Shield Volcanoes
The Hawaiian Islands are composed of shield volcanoes with broad gently sloping sides (Fig. 16) built up from thousands of fluid, low-viscosity basalt lava flows. Shield volcanoes form when low-viscosity lavas are produced from a vent during mild eruptions. The lavas flow for long distances (tens of kilometers) and form extensive thin sheets (Fig. 17). The sheets of lava build up over time to form the distinctive shape of shield volcanoes.
**Stratovolcanoes**
The majority of the world's active volcanoes are steep-sided, symmetrical stratovolcanoes (or composite cones; Fig. 18). These volcanoes have a violent style of eruption that results in pyroclastic debris (tephra) being blasted several kilometers into the atmosphere. The volcanic cones are composed of tephra, pyroclastic flow deposits, and lavas.

Most of our familiar images of imposing volcanoes represent stratovolcanoes but they are modest in size in comparison to the Hawaiian shield volcanoes (Fig. 19).

**Cinder Cone Volcanoes**
Cinder cone (or tephra) volcanoes are the smallest and simplest type of volcano, rarely exceeding 400 meters in height (Fig. 20). They are composed of coarse pyroclastic debris that falls to earth around a volcanic vent following an eruption. Cinder

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**Figure 18. Mt. Adams, Washington, a stratovolcano in the Cascade Range. Modified from an original image by Lynn Topinka, USGS/CVO.**

**Figure 19. The approximate profiles of a Hawaiian shield volcano and a stratovolcano. Much of the shield volcano's base lies below sea level. Continental shield volcanoes are typically smaller than their oceanic relatives. Diagram modified from an original image, USGS Cascades Volcano Observatory.**

**Figure 20. Sunset Crater, northern Arizona. Sunset crater volcano was formed less than one thousand years ago.**
cones are readily eroded and often occur on the slopes of larger shield volcanoes or stratovolcanoes.

**Think about it . . .**
Use the Venn diagram at the end of the chapter to compare and contrast the characteristics of shield volcanoes and stratovolcanoes. Choose from the list of features to complete the diagram.

Volcanic Landforms

Other volcanic landforms are generated when volcanoes collapse to form **calderas** or when lava reaches Earth's surface through a linear fissure rather than a conical vent, to form a **lava plateau**. Finally, the interaction of water with a magma source may form a series of hydrothermal features including **geysers** and **hot springs**.

**Calderas**
Calderas are large craters that formed when a stratovolcano or shield volcano collapsed into a shallow, empty magma chamber below the volcano (Fig. 21). Calderas are tens of kilometers across. An elliptical caldera approximately 80 km (50 miles) long and 50 km (31 miles) wide underlies Yellowstone National Park, Wyoming. For comparison, the width of the crater in Mt. St. Helens is less than 2 km.

![Figure 21. Crater Lake, Oregon, occupies a caldera formed when ancient Mt. Mazama collapsed. Modified from an original image by W.E. Scott, USGS.](image)

**Lava Plateau**
Low-viscosity lavas that reach the surface through fissure eruptions rather than from a volcanic cone may accumulate to form lava plateaus made up of many nearly horizontal layers of solidified basaltic lava (Fig. 22). The Columbia River plateau is characterized by multiple lava flows that cover up to 40,000
square kilometers in area. Such large volumes of mobile lavas are sometimes termed **flood basalts**.

**Geysers, Hot Springs, Fumeroles, Mud Volcanoes**

Water circulating near hot magma can result in the formation of several different features. **Hot springs** form when heated waters rise to the surface. If water is heated under pressure with volcanic gases it may erupt violently to form a **geyser** (Fig. 23). **Fumeroles** form when gases escape in the absence of water. **Mud volcanoes** form when rocks are converted to soupy clays by heated waters from hot springs.
Igneous Intrusions

- Igneous rocks that solidify below Earth's surface form igneous intrusions or plutons.
- A volcanic neck forms when the interior of a volcano is left standing after the surrounding volcano is removed by erosion.
- Sills and dikes are sheetlike intrusions that are concordant (sill) or discordant (dike) with existing layers in the rock.
- Batholiths are the largest form of plutons and are often found in the core of mountain belts such as the Sierra Nevada Mountains of California.

Igneous rocks that cool below Earth's surface are termed plutonic (or intrusive) igneous rocks. The features they form are plutons (or intrusions). These features remain hidden from view until erosion removes the overlying rocks. The characteristics of the intrusions are largely controlled by the volume of magma involved and the character of the surrounding rocks. Magma moving within Earth's crust will often follow the path of least resistance such as fractures (or faults) or the surfaces between beds in sedimentary rocks. Some of the types of igneous intrusions are illustrated below.

Volcanic Neck
Magma may solidify within a volcano on its way to the surface. The plutonic rocks formed are typically more resistant to erosion than the surrounding volcano. Erosion may remove the volcano leaving behind a feature called a volcanic neck (Fig. 24).

Figure 24. Devils Tower, Wyoming, once the core of an ancient volcano. Devils Tower is approximately 300 meters (990 feet) high. President Theodore Roosevelt proclaimed Devils Tower the first U.S. National Monument in 1906.
Dike, Sill
Magma that solidifies within fractures or cracks in the earth's crust forms sheetlike or tabular intrusions (Fig. 25). If the intrusions cut across (discordant) preexisting features they are termed dikes. A dike may form a wall-like feature on the surface because it is typically more resistant to erosion than surrounding rocks. Intrusions that are oriented parallel (concordant) to preexisting features (e.g. beds) are termed sills.

Batholith
Large bodies of magma that cool and solidify underground are termed batholiths. These intrusions may cover large areas (hundreds to thousands of square kilometers). Such large masses of resistant rocks typically form mountains when exposed on the surface. The Sierra Nevada Mountains, California, and Black Hills, South Dakota (Fig. 26), are two examples of such features.
Summary

1. Where are volcanoes found?
Volcanoes can be found all over the world but most are concentrated along plate boundaries. The majority of the world's active volcanoes are located along convergent plate boundaries, especially around the Pacific Ocean. Most active U.S. volcanoes are located in Alaska or in the Cascade Range of Washington, Oregon, and California. Volcanoes form from magma generated by the melting of plates descending into subduction zones.

2. Why are there volcanoes in Hawaii?
The state of Hawaii is made up almost exclusively of volcanoes yet it is not located along a plate boundary. Hawaii is located above a hot spot in the mantle. Magma rising from the hot spot forms a line of volcanoes (Hawaiian island chain) as the overlying plate passes over the hot spot.

3. How do Hawaiian and Cascade (and Alaska) volcanoes differ?
Hawaiian volcanoes differ from Alaskan and Cascade volcanoes in their shape and style of eruption. Hawaiian volcanoes have broad gently sloping sides built up from lava produced during relatively mild eruptions. In contrast, Cascade and Alaskan volcanoes, are typically steep-sided and have a more violent style of eruption.

4. Why is magma viscosity significant in volcanic eruptions?
Volcanic gases help drive eruptions. Low-viscosity magmas allow gases to escape easily whereas gas pressures can build up in high-viscosity magmas, resulting in violent eruptions.

5. What factors control viscosity in magma?
Chemical content (composition) and temperature influence magma viscosity. The amount of silica (SiO₂: silicon and oxygen) present is especially significant. The greater the silica content, the more viscous the magma and the more explosive the volcanic eruption.

6. How did geologists know that Mt. St. Helens was likely to erupt?
Scientists identified three events that occurred in the months prior to the major eruption that indicated magma was moving upward beneath the volcano: (a) Thousands of small earthquakes were recorded; (b) there were numerous small
eruptions; (c) a large bulge began to grow on the north flank of the volcano.

7. What was the sequence of events associated with the eruption?
The eruption began with a magnitude 5.1 earthquake below the volcano. This triggered a massive landslide of the north flank of the volcano, followed by an explosive lateral blast. When the landslide released pressure on the bulge, the north side of the volcano was blasted off. Finally, volcanic debris was blasted vertically into the atmosphere.

8. What were the principal products of the eruption?
The principal products of the eruption were pyroclastic flows, lahar, ash fall deposits, and the lateral blast. Lava, often associated with volcanoes, was present in only small quantities at Mt. St. Helens because of the viscous nature of the magma.

9. What is a pyroclastic flow?
Pyroclastic flows are mixtures of hot gases and ash, cinders that form a dense cloud that races down the volcano slope incinerating all in their path. Pyroclastic flows are also known as ash flows or nuee ardente.

10. What is a lahar?
Lahars are mudflows, largely confined to stream channels, formed when fine-grained pyroclastic debris (ash) mixes with water from snowmelt or streams.

11. How do the different types of volcanoes differ in size?
Volcanoes are divided into three classes (shield volcanoes, stratovolcanoes, and cinder cone volcanoes) on the basis of their shape and composition. Shield volcanoes are the largest volcanoes with elevations of up to 9 km (~30,000 feet) and widths of over 100 km at their base. In contrast the largest stratovolcanoes rarely exceed 4 to 5 km in elevation and are much narrower at their base (~10 km). Cinder cone volcanoes are an order of magnitude smaller than stratovolcanoes.

12. How do the different types of volcanoes differ in composition?
Shield volcanoes are composed of thousands of thin basalt lava flows. Stratovolcanoes are made up of alternating layers of layers of lava and pyroclastic debris. Cinder cone volcanoes are made up of coarse pyroclastic debris.
13. What is a caldera?  
Calderas are large craters, tens of kilometers across, formed when a stratovolcano or shield volcano collapsed into a shallow, empty magma chamber below the volcano.

14. How are lava plateaus formed?  
Low-viscosity lavas that reach the surface through fissures or cracks may accumulate to form lava plateaus made up of many nearly horizontal layers of solidified lava (typically basalt).

15. Under what conditions do geysers, hot springs, and mud volcanoes form?  
Water circulating near hot magma can result in the formation of several different features. Hot springs form when heated waters rise to the surface. If water is heated under pressure with volcanic gases it may erupt violently to form a geyser. Fumeroles form when gases escape in the absence of water. Mud volcanoes form when rocks are converted to soupy clays by heated waters from hot springs.

16. What are plutons?  
Igneous rocks that cool below Earth's surface form features termed plutons (or intrusions).

17. What are the most common types of igneous intrusions?  
The characteristics of the intrusions are largely controlled by the volume of magma involved and the character of the surrounding rocks. Magma that solidifies within the conduit of a volcano may form a volcanic neck. Magma that solidifies within fractures or cracks in Earth's crust forms sheetlike or tabular intrusions. Intrusions that are concordant with structures within Earth are sills, plutons that are discordant are dikes. Large masses of magma that cool and solidify underground are termed batholiths.
Decade Volcanoes by Type of Magma

The Decade Volcano initiative is part of a United Nations program aimed at better utilizing science and emergency management to reduce the severity of natural disasters. The Decade Volcanoes are the focus of coordinated earth-science studies and land-use planning to learn the best ways to reduce the risks to life and property from volcano-related hazards.

Answer the questions below using the volcanoes illustrated on the map. It may be useful to review a map of plate boundaries before attempting to answer the questions.

1. Underline volcanoes in red if they formed by partial melting of oceanic lithosphere and circle volcanoes in blue that formed at least partly from the partial melting of mantle rocks.

2. Name a volcano that generates low-viscosity magma. ________________________

3. Which volcano is likely to have both basalt and rhyolite as products of its eruption?
   ____________________________

4. Name a stratovolcano not associated with the melting of the Pacific Plate.
   ____________________________

5. Name a shield volcano. ____________________________

6. Name a volcano that formed over a hot spot that isn’t in the Pacific Ocean.
   ____________________________
Volcanic Hazards Associated with Mt. Shasta, California

Read the description of the eruption history of Mt. Shasta given below and answer the questions that follow. Divide your group into two smaller subgroups. The first subgroup will be responsible for identifying potential volcanic hazards for the area surrounding the volcano. The second subgroup will be responsible for suggesting ways to monitor volcanic activity in an effort to try to predict the next major eruption.

Mt. Shasta Volcanic History

Mount Shasta in northern California, is a stratovolcano consisting of overlapping cones centered at four main vents. The volcano was constructed during the last several hundred thousand years. Each of the cone-building periods produced andesite lava flows and pyroclastic flows, mainly at the central vents, as well as numerous lahars on and beyond the flanks of the volcano. Mount Shasta has erupted on the average at least once per 800 years during the past 10,000 years, about once per 300 years during the past 3,500 years, and about once per 250 years during the past 750 years. The last known eruption occurred about 200 years ago and may have occurred in 1786 A.D.

Eruptions during the last 10,000 years produced lava flows and domes on and around the flanks of Mount Shasta. Lava flows issued from vents near the summit and from flank vents as far as 9 km away, and individual flows are as long as 13 km. Only about 33% of past lava flows reached more than 10 km from the summit and none reached as far as 20 km.

Some pyroclastic flows originating at the summit vent and at the Shastina vent extended more than 20 km. Pyroclastic flows from the Black Butte vent extended about 10 km southwestward.

Eruptions at the Mt. Shasta summit and Shastina vents produced many lahars, about 20% of which reached more than 20 km from the summit of Mount Shasta, and spread out around the base of
the volcano. Larger lahars and floods extended beyond the base of the volcano and entered the McCloud and Sacramento Rivers.

Ash has been erupted at Mount Shasta many times during the last 10,000 years and the deposits mantle the ground surface within about 25 km of the summit.

No known debris avalanches have occurred at Mount Shasta, but a catastrophic debris avalanche occurred between about 300,000 and 360,000 years ago. The debris avalanche flowed more than 64 km through the Shasta valley, covers more than 675 km$^2$, and has a volume that exceeds 45 km$^3$.

![Map of volcanic regions in the Pacific Northwest](image)

Potential volcanic hazards

Review the description of the volcanic history of Mt. Shasta and identify potential volcanic hazards for the area surrounding Mt. Shasta. Remember that the eruption styles and products of future events will be similar to historical eruptions.
1. Show the possible extent of selected hazards on the map of Mt. Shasta and vicinity and describe the distribution of potential hazards on a separate sheet of paper.

2. Are the cities of Weed, Mt. Shasta City, McCloud, and Dunsmuir going to face the same types of hazards?
Venn Diagram: Shield Volcanoes vs. Stratovolcanoes

Use the Venn diagram, below, to compare and contrast the similarities and differences between shield volcanoes and stratovolcanoes. Print this page and write features unique to either group in the larger areas of the left and right circles; note features that they share in the overlap area in the center of the image.

Place the numbers corresponding to the list of characteristics below in the most suitable locations on the diagram.

1. Form at convergent plate boundaries
2. Have a triangular shape in profile
3. Example: Mt. Hood, Oregon
4. Mild eruptions
5. Main product - lava
6. Intermediate-silica magma
7. Form above hot spots or at divergent plate boundaries
8. Andesite
9. Explosive eruptions
10. Basalt
11. May form chains of oceanic islands
12. Example: Mauna Loa, Hawaii
13. Form mountains
14. Low-silica magma
15. Main product - pyroclastic debris
16. Limestone