Eruption of Mt. Pinatubo on June 12, 1991. This wasn’t even “the big one.” (USGS)
Learning Objectives

Your goals in studying this chapter are to:

• Understand exactly what an earthquake is and the related terminology.
• Understand the types of faults and seismic waves
• Understand how earthquakes are measured.
• Understand the kinds of damage earthquakes can cause.
• Understand earthquake mitigation measures, including basic principles of seismic engineering.
• Understand earthquake risk in the United States.
• Understand the limitations of earthquake prediction.
• Understand earthquake preparedness.
Volcanoes destroy and volcanoes create. The catastrophic eruption of Mount St. Helens on May 18, 1980, made clear the awesome destructive power of a volcano. Yet, over a time span longer than human memory and record, volcanoes have played a key role in forming and modifying the planet upon which we live. More than 80 percent of the Earth's surface—above and below sea level—is of volcanic origin. Gaseous emissions from volcanic vents over hundreds of millions of years formed the Earth's earliest oceans and atmosphere, which supplied the ingredients vital to evolve and sustain life. Over geologic eons, countless volcanic eruptions have produced mountains, plateaus, and plains, which subsequent erosion and weathering have sculpted into majestic landscapes and formed fertile soils.

Ironically, these volcanic soils and inviting terranes have attracted, and continue to attract, people to live on the flanks of volcanoes. As population density increases in regions of active or potentially active volcanoes, mankind must become increasingly aware of the hazards and learn not to "crowd" the volcanoes. People living in the shadow of volcanoes must live in harmony with them and expect, and should plan for, periodic violent unleashings of their pent-up energy.

The word volcano comes from the little island of Vulcano in the Mediterranean Sea north of Sicily. Centuries ago, the people living in this area believed that Vulcano was the chimney of the forge of Vulcan—the blacksmith of the Roman gods. They thought that the hot lava fragments and clouds of dust erupting from Vulcano came from Vulcan's forge as he beat out thunderbolts for Jupiter, king of the gods, and weapons for Mars, the god of war. In Polynesia the people attributed eruptive activity to the beautiful but wrathful Pele, Goddess of Volcanoes, whenever she was angry or spiteful. Today we know that volcanic eruptions are not supernatural, but can be studied and interpreted by scientists.
Volcanic Hazards

Volcanic hazards consist of more than the obvious ones associated with an eruption (lava flows, pyroclastic flows, bombs, and ash fallout). Volcanoes are inherently unstable because of the nonuniform way volcanic materials are deposited on them to construct the volcano. In addition, some materials like ash fall and cinders are soft, and move downhill easily. If that were not enough, many volcanoes have molten or very hot rocks inside of them that bake and corrode the volcano from the inside out. Groundwater heated by the magma or hot rock (hydrothermal water) can alter volcanic rock into soft materials, making it weak and unstable. That makes any steep volcano hazardous whether or not it is actively erupting. Add deep snow or a wet climate, and the hazards increase dramatically.

The features and hazards summarized in this diagram are explained in the following pages.
Eruption Columns and Clouds
An explosive eruption blasts solid and molten rock fragments (tephra) and volcanic gases into the air with tremendous force. The largest rock fragments (bombs) usually fall back to the ground within 2 miles of the vent. Small fragments (less than about 0.1 inch across) of volcanic glass, minerals, and rock (ash) rise high into the air, forming a huge, billowing eruption column. Eruption columns can grow rapidly and reach more than 12 miles above a volcano in less than 30 minutes, forming an eruption cloud. The volcanic ash in the cloud can pose a serious hazard to aviation. During the past 15 years, about 80 commercial jets have been damaged by inadvertently flying into ash clouds, and several have nearly crashed because of engine failure. Large eruption clouds can extend hundreds of miles downwind, resulting in ash fall over enormous areas; the wind carries the smallest ash particles the farthest. Ash from the May 18, 1980, eruption of Mount St. Helens, Washington, fell over an area of 22,000 square miles in the Western United States. Heavy ash fall can collapse buildings, and even minor ash fall can dam age crops, electronics, and machinery.

Volcanic Gases
Volcanoes emit gases during eruptions. Even when a volcano is not erupting, cracks in the ground allow gases to reach the surface through small openings called fumaroles. More than 90% of all gas emitted by volcanoes is water vapor (steam), most of which is heated ground water (underground water from rain- fall and streams). Other common volcanic gases are carbon dioxide, sulfur dioxide, hydrogen sulfide, hydrogen, and fluorine. Sulfur dioxide gas can react with water droplets in the atmosphere to create acid rain, which causes corrosion and harms vegetation. Carbon dioxide is heavier than air and can be trapped in low areas in concentrations that are deadly to people and animals. Fluorine, which in high concentrations is toxic, can be adsorbed onto volcanic ash particles that later fall to the ground. The fluorine on the particles can poison livestock grazing on ash-coated grass and also contaminate domestic water supplies.

Cataclysmic eruptions, such as the June 15, 1991, eruption of Mount Pinatubo (Philip- pines), inject huge amounts of sulfur dioxide gas into the stratosphere, where it combines with water to form an aerosol (mist) of sulfuric acid. By reflecting solar radiation, such aerosols can lower the Earth’s average surface temperature for extended periods of time by several degrees Fahrenheit (°F). These sulfuric acid aerosols also contribute to the destruction of the ozone layer by altering chlorine and nitrogen compounds in the upper atmosphere.

Lava Flows and Domes
Molten rock (magma) that pours or oozes onto the Earth’s surface is called lava and forms lava flows. The higher a lava’s content of silica (silicon dioxide, SiO₂), the less easily it flows. For example, low-silica basalt lava can form fast-moving (10 to 30 miles per hour) streams or can spread out in broad thin sheets as much as several miles wide. Since 1983, Kilauea Volcano on the Island of Hawaii has erupted basalt lava flows that have destroyed nearly 200 houses and severed the nearby coastal highway. In contrast, flows of higher-silica andesite and dacite lava tend to be thick and sluggish, traveling only short distances from a vent. Dacite and rhyolite lavas often squeeze out of a vent to form irregular mounds called lava domes. Between 1980 and 1986, a dacite lava dome at Mount St. Helens grew to about 1,000 feet high and 3,500 feet across.
**Pyroclastic Flows**
High-speed avalanches of hot ash, rock fragments, and gas can move down the sides of a volcano during explosive eruptions or when the steep side of a growing lava dome collapses and breaks apart. These pyroclastic flows can be as hot as 1,500˚F and move at speeds of 100 to 150 miles per hour. Such flows tend to follow valleys and are capable of knocking down and burning everything in their paths. Lower-density pyroclastic flows, called pyroclastic surges, can easily overflow ridges hundreds of feet high. The climactic eruption of Mount St. Helens on May 18, 1980, generated a series of explosions that formed a huge pyroclastic surge. This so-called “lateral blast” destroyed an area of 230 square miles. Trees 6 feet in diameter were mowed down like blades of grass as far as 15 miles from the volcano.

**Volcano Landslides**
A landslide or debris avalanche is a rapid downhill movement of rocky material, snow, and (or) ice. Volcano landslides range in size from small movements of loose debris on the surface of a volcano to massive collapses of the entire summit or sides of a volcano. Steep volcanoes are susceptible to landslides because they are built up partly of layers of loose volcanic rock fragments. Some rocks on volcanoes have also been altered to soft, slippery clay minerals by circulating hot, acidic ground water. Landslides on volcano slopes are triggered when eruptions, heavy rainfall, or large earthquakes cause these materials to break free and move downhill. At least five large landslides have swept down the slopes of Mount Rainier, Washington, during the past 6,000 years. The largest volcano landslide in historical time occurred at the start of the May 18, 1980, Mount St. Helens eruption.

**Lahars**
Mudflows or debris flows composed mostly of volcanic materials on the flanks of a volcano are called lahars. These flows of mud, rock, and water can rush down valleys and stream channels at speeds of 20 to 40 miles per hour and can travel more than 50 miles. Some lahars contain so much rock debris (60 to 90% by weight) that they look like fast-moving rivers of wet concrete. Close to their source, these flows are powerful enough to rip up and carry trees, houses, and huge boulders miles downstream. Farther downstream they entomb everything in their path in mud.

Historically, lahars have been one of the deadliest volcano hazards. They can occur both during an eruption and when a volcano is quiet. The water that creates lahars can come from melting snow and ice (especially water from a glacier melted by a pyroclastic flow or surge), intense rainfall, or the break-out of a summit crater lake. Large lahars are a potential hazard to many communities downstream from glacier-clad volcanoes, such as Mount Rainier.

You can learn more about lahars at [http://volcanoes.usgs.gov/hazards/lahar/](http://volcanoes.usgs.gov/hazards/lahar/)
Search [YouTube.com](https://www.youtube.com) for “lahar” – there are a lot of exciting videos!
A rocky, muddy lahar filling a river bed.

This lahar destroyed the city of Armero, Colombia in 1985, killing 20,000 people.

A tree stump in the Electron mudflow (lahar), which began as an avalanche of hydrothermally altered rock high on Mount Rainier’s west flank near Sunset Amphitheater, but its onset cannot be correlated with volcanism. The lahar was highly fluid and flowed 100 km (60 mi) downstream to the Puget Sound lowland. When it entered the Puget Sound lowland in the community of Electron, it was 30 m (98 ft) deep. The Electron Mudflow reminds us of the possibility that, occasionally, lahars may have non-eruption origins and thus may occur with little conventional volcanic warning.
Examples of Volcanic Hazards

Mt. Etna (above) towers 10,991 feet (3350 m) above the city of Catania (population approx. 1 million). The people of Sicily have been living with this volcano since the Greeks and Romans settled the island. Catania itself has been over-run by lava flows eighteen times. The lava flow at right destroyed much of Catania and changed its coastline in 1669. This medieval castle’s thick walls protected it from the 8 meter-thick lava, but it was no longer beach-front property when the lava moved the shoreline by nearly a kilometer. (BYUI photos)
On August 24, A.D. 79, Vesuvius Volcano suddenly exploded and destroyed the Roman cities of Pompeii and Herculaneum. Although Vesuvius had shown stirrings of life when a succession of earthquakes in A.D. 63 caused some damage, it had been quiet for hundreds of years and was considered "extinct." Its surface and crater were green and covered with vegetation, so the eruption was totally unexpected. Yet within a few hours, hot volcanic ash and dust buried the two cities so thoroughly that their ruins were not uncovered for nearly 1700 years, when the discovery of an outer wall in 1748 started a period that developed the science of modern archeology. Vesuvius has continued its activity intermittently ever since A.D 79 with numerous minor eruptions and several major eruptions occurring in 1631, 1794, 1872, 1906, and in 1944 in the midst of the Italian campaign of World War II. [Videos of 1944 eruption]

In the United States on March 27, 1980, Mount St. Helens volcano in the Cascade Range, southwestern Washington, reawakened after more than a century of dormancy and provided a dramatic and tragic reminder that there are active volcanoes in the "lower 48" States as well as in Hawaii and Alaska. The catastrophic eruption of Mount St. Helens on May 18, 1980, and related mudflows and flooding caused significant loss of life (57 dead or missing) and property damage lover $1.2 billion). Mount St. Helens has remained intermittently active ever since, including an episode of lava dome building from 2004 - 2008. [Videos of 1980 eruption

You can also simply search YouTube.com for “St. Helens eruption” to find these and more videos.
Herculaneum was buried with Pompeii by pyroclastic flows from Mt. Vesuvius in August, 79 A.D. The ancient Roman port town now lies a mile inland and up to 90 feet underground. The structure at the bottom of the photo was at the sea shore. The roofs in this photo are modern. (BYUI)
Eruption Basics

Volcanoes are built by the accumulation of their own eruptive products. **Magma** is molten rock underground. **Lava** is molten rock that erupts onto the ground surface. **Bombs** are wind-shaped rocks that form when lava is thrown into the air and is shaped by the wind. **Tephra** includes everything that travels through the air in an eruption, including **ash** (sand-sized particles), **dust**, **bombs**, and **rock fragments** (cold rocks). A volcano forms at the opening or **vent** through which the molten rock and associated gases are expelled. The vent connects with reservoirs of molten rock below the surface of the Earth.

Molten rock is lighter than the surrounding solid rock, much like hot air is lighter than cold. Driven by this buoyancy and gas pressure, magma forces its way upward and may ultimately break through zones of weaknesses in the Earth's crust. If magma makes it to the surface, an eruption begins, and the molten rock may pour from the vent as non-explosive lava flows, or it may shoot violently into the air as dense clouds of lava fragments. Larger fragments fall back around the vent, and accumulations of fall-back fragments may form a **cinder cone**. Some of the finer tephra may be carried by the wind to fall to the ground many miles away. The finest ash particles may be ejected miles up into the atmosphere and carried many times around the world by stratospheric winds before settling out.

A lava fountain eruption forming a cinder cone. (USGS)

Cutaway diagram of a cinder cone. (NPS)
Tephra deposited by Mount St. Helens. (USGS)

Outcrop 9 km from St. Helens with pre-1980 tephra (USGS). Tephra set S overlies glacial gravel and consists of coarse, pale layers (Sg and So) overlying ash-size deposits. Set J is made up of one lapilli bed and is separated from set S by a thick, oxidized ash-rich deposit. Set Y consists of lapilli-and-bomb layers interbedded with ash. Set P is characterized by pale, thin layers including a flowage deposit. Set B is relatively dark and consists of thin layers. Set W, about 100 cm thick, consists chiefly of lapilli and bombs. Photograph taken in 1970.

Volcanic bombs erupted as blobs of lava, and were ejected at high velocities into the air, where they were shaped by the wind. They harden before hitting the ground, preserving their shapes. Bombs can be as large as trucks! (USGS)
Originating many tens of miles beneath the ground, the ascending magma commonly contains some crystals, fragments of surrounding (unmelted) rocks, and dissolved gases, but it is primarily a liquid composed principally of oxygen, silicon, aluminum, iron, magnesium, calcium, sodium, potassium, titanium, and manganese. Magmas also contain many other chemical elements in trace quantities. Upon cooling, the liquid magma may precipitate crystals of various minerals until solidification is complete to form an igneous rock. Magma that cools underground produces intrusive (or plutonic) rocks, which are characterized by a coarsely crystalline texture. Volcanic rocks are characterized by fine-grained texture, glassy texture, pyroclastic texture (consisting of shattered minerals, glass, pumice, and ash), or vesicular texture (containing bubbles formed by gases).

Tuff is a rock composed of tephra that has been more or less consolidated. It is made of rock, glass, and mineral fragments in a volcanic ash matrix. Tuffs commonly are composed of much shattered volcanic rock glass--chilled magma blown into the air and then deposited. If volcanic particles fall to the ground at a very high temperature, they may fuse together, forming a welded tuff. Tuff is common around Yellowstone and the Cascades volcanoes.
It’s All About The Gas

All magmas contain dissolved gases, and as they rise to the surface to erupt, the confining pressures are reduced and the dissolved gases are liberated either quietly or explosively. If the lava is a thin fluid (low viscosity), the gases may escape easily. But if the lava is thick and pasty (high viscosity), the gases will not move freely, but will build up tremendous pressure, and ultimately escape by exploding the magma. Gases in lava may be compared with the gas in a bottle of a carbonated soft drink. If you put your thumb over the top of the bottle and shake it vigorously, the gas separates from the liquid and forms bubbles. When you remove your thumb abruptly, there is a miniature explosion of gas and liquid. The gases in lava behave in somewhat the same way. Their sudden expansion causes the terrible explosions that throw out great masses of solid rock as well as lava, dust, and ash. Gases drive explosive eruptions – no gas, no explosion. Factors that increase the viscosity of the magma can also contribute to the explosivity of an eruption. Cooler magmas and those with high silica content (rhyolite in particular, but also andesite) tend to erupt more explosively. Basalt is usually low viscosity, so that gases cause fountains, and large explosive eruptions are more rare.

The separation of gas from lava may produce rock froth called pumice. Some of this froth is so light because of the many gas bubbles that it floats on water. In many eruptions, the froth is shattered explosively into small fragments that are hurled high into the air in the form of volcanic cinders (red or black), volcanic ash (commonly tan or gray), and volcanic dust.

During the 1959 eruption of Kilauea Iki, fountaining lava and volcanic debris completely blocked several of the roads in the Hawaii Volcanoes National Park. It created the lava lake seen here and the cinder cone to the left of the fountain. (USGS)