VOLCANOES

We may receive all the heat we need on the Earth's surface from sunlight, but if you dig a hole just a few feet deep, you might notice that the surrounding soil is much cooler. This happens because much of the sediment is insulated from the sun's energy. But, if you could dig miles and miles into the crust, you would find that the temperature of the rock would increase!

image
Figure 4.1. This temperature vs depth plot shows how temperature increases with depth. The rate of change is called a Geothermal Gradient. By: Bkilli1, CC BY-SA 3.0, Wikimedia Commons.
This increase in temperature with depth in the Earth's crust is called the geothermal gradient. We can expect temperatures to increase about 25°C for each kilometer of depth. This sounds like a significant increase in heat, but once we pass the 100 km mark, temperatures really take off!

As we learned in the second chapter, the Earth's iron core is wickedly hot! Such heat powers plate tectonics, and when combined with other factors, it can lead to partial melting in the upper mantle. This melted, molten rock occasionally rises to the Earth's surface and when it does, watch out!

A volcano will form above a chamber or plume of magma. There is a wide variety of volcanoes, and some are more explosive than others. Molten lava is far from the only hazard; volcanic eruptions can cause massive damage with ashfall, pyroclastic flows, toxic gases, and deadly landslides. There are even a few volcanoes considered so dangerous that we call them "supervolcanoes", and they have the potential to impact society drastically for generations.

Although volcanoes are hazardous, they are a continuous boon for the global economy. The precious minerals and useful rocks formed by volcanic processes have benefited civilization for thousands of years. In the modern economy, we use volcanism as a source of alternative energy and igneous rocks in trades ranging from construction to cosmetics.

Learning Objectives

Describe the size, shape, and eruption style of volcanoes and how they form.
Identify the major volcanic hazards and their effects on humans and property.
Explain how scientists monitor volcanoes, and where are volcanoes more likely to be found.
Explain how volcanic processes benefit society.

4.1 Molten Materials
CHARLENE ESTRADA

Is it Magma or is it Lava?

You may have heard both magma and lava used to refer to molten rock. This can confuse, especially since both terms apply to hot, melted rock. So what's the difference, anyway? It comes down to the location. Magma is hot, molten rock that exists beneath the Earth's surface. It can be found in the crust right below a volcano or within the mantle. For a volcano to erupt, it must have a source of magma.

Parts of a volcano. An active volcano always has a magma chamber beneath the cone.
Figure 4.1.1. Parts of a volcano. An active volcano always has a magma chamber beneath the cone.
Lava, on the other hand, is only observed at the surface following a volcanic eruption. It will have the same composition as the magma from which it originated. Besides erupting only at the surface, lava cools quickly because it is exposed to the comparatively cold Earth's atmosphere (or sometimes water!), and we see different igneous rock textures as a result. Igneous rocks from magma that solidified at depth are coarse-grained or intrusive because they cool slowly, but those from lava are fine-grained, or extrusive.

Lava fountain
Figure 4.1.2. Lava is the eruption or flow of molten material above ground.
Melting Solid Rock. How does magma form?

Figure 4.1.3. Notice the spheres on the left of this figure. Molten rock that appears on the mantle or crust is called magma. Molten rock that appears on the atmosphere is called lava, and it reaches the surface through volcanic processes. "Magmatism and Volcanism" By Woudloper, CC BY-SA 3.0.
Magma and lava contain three components—melt, solids, and volatiles (dissolved gases). The liquid part, called melt, is made of ions from molten minerals.

All you need to melt a solid rock is heat, right? Wrong! It may be counterintuitive, but most geological processes that melt rock do not involve increasing the temperature. Most lava at volcanoes is around 700 to 1300°C, which is the typical temperature of our upper mantle. However, our mantle as a whole is solid, so something else is required to cause rock to melt. That "something else" can be a sudden decrease in pressure or introducing liquid water, which will lower the melting point of rocks in the mantle. The two main mechanisms through which rocks melt are decompression melting and flux melting.

Decompression Melting
Our mantle is solid, but under high temperatures and pressures, it flows over very long timescales in a process known as convection. Convection forms circular cells of movement for the rock within the mantle, and sometimes leads to the upwelling of hot mantle material at divergent plate boundaries and hot spots.

Rock is a poor heat conductor, so as rock in the mantle rises with upwelling or convection, its temperature does not significantly change. Nevertheless, when that rock rises, the pressure of the rock decreases. This happens because the depth decreases, meaning that the weight of the column of rock above it decreases. It is the decrease in lithostatic pressure that causes the rock to melt. This process of the rock melting due to a sudden change in pressure is called decompression melting, and it typically occurs at hot spots and divergent boundaries, such as the Mid-Atlantic Ridge [1].

At a divergent boundary, where two plates move apart, the crust above molten material in the magma thins, causing less overriding pressure. Some of the mantle material begins to melt as magma and rise to the thinning rift to create new crust.

Figure 4.1.4. A divergent boundary between two rifting tectonic plates. As these plates move away, the lithostatic pressure decreases and the mantle melts. The magma rises to the rift as new crust, in the seafloor spreading center.

Flux Melting

image

Figure 4.1.5. In a subduction zone, melting occurs in the sinking plate. Water, trapped in minerals, is released at depth. The addition of water melts the rock (rising diapirs in the image). Notice the location of magma and volcanoes on the over-riding plate. "Subduction" By K. D. Schroeder CC-BY-SA 4.0

At subduction zones along the Earth's lithosphere, the descending slab is always made of oceanic lithosphere. This slab contains some hydrated minerals that, when exposed to elevated temperatures and pressures during subduction, will become released as volatile gases such as water vapor.

These volatile gases rise and interact with the overlying plate in the subduction zone. The addition of the volatiles does not change the pressure or temperature of the rock, but it does lower a property called the melting point. The decrease in melting point with those added volatiles suddenly makes it possible for the rocks in the subduction zone to melt at the same pressures and temperatures they have been experiencing, which is why we observe volcanoes at this type of plate boundary. Magmas producing the volcanoes of the Ring of Fire, associated with the subduction zones bordering the Pacific Ocean, are a result of flux melting [1].

Magma Composition

In 1980, Mount St. Helens blew up in the costliest and deadliest volcanic eruption in United States history. The eruption killed 57 people, destroyed 250 homes, and swept away 47 bridges. Mount St. Helens today still has minor earthquakes and eruptions and now has a horseshoe-shaped crater with a lava dome inside. The dome is made of pb_glossary id="1812″]viscous[/pb_glossary] lava that oozes into place [1].

Video 4.1.1 Geologists from the US Geological Survey explained the main eruption event as well as the signs that announced it and the aftermath (7:00).

Volcanoes do not always erupt in the same way. Each volcanic eruption is unique, differing in magnitude, style, and composition of the erupted material. One key to what makes the eruption unique is the chemical composition of the magma that feeds a volcano, which determines (1) the eruption style, (2) the type of volcanic cone that forms, and (3) the composition of rocks that are found at the volcano.

The words that we use to describe the composition of igneous rocks (Ch. 3), also the ones we use to describe the composition of the magma. Mafic magmas are low in silica and have darker magnesium (Mg), and iron (Fe)-rich minerals, such as olivine and pyroxene. Felsicmagmas are higher in silica and have lighter-colored minerals such as quartz and orthoclase feldspar.

The higher the amount of silica in the magma, the higher its viscosity. Viscosity is a liquid's resistance to flow or movement within the Earth or on its surface. Viscosity determines what the magma will do. Mafic magma is not very viscous and will flow smoothly to the surface.

Video 4.1.2 Review the impacts of viscosity on magmas, lavas and the igneous rocks derived (4:57).

Volcanoes with a mafic composition will typically not have very explosive eruptions, but the lava will be fast moving. This mafic lava often moves down mountainsides and cools rapidly into unique textures that are either ropey called “Pahoehoe” or rough called “A'a“.

Pahoehoe lava flows are thin and ropey whereas aa is rough and blocky.
Figure 4.1.6. Mafic lava flows. Left: Close-up view of A'a forming during an eruption of Pacaya Volcano in Guatemala. Field of view, approximately 1 m across. Right: Rubbly reddish-brown A'a lava flow viewed from Chain of Craters Road, Hawai'i Volcanoes National Park. Pahoehoe is visible in lighter grey in the foreground.
Felsic magma is very viscous, and it does not flow smoothly. Most felsic magma will stay deeper in the crust and will cool to form intrusive igneous rocks such as granite and diorite. If felsic magma rises into a magma chamber, it may be too viscous to move, so it tends to get stuck.

However, intermediate magma is also highly viscous, and it contains dissolved volatile gases. These gases become trapped by the magma, and the magma chamber begins to build in pressure. When the magma finally can erupt as lava, it does so very violently and explosively, as we have seen at Mount St. Helens.

4.2 Volcano Shape
CHARLENE ESTRADA

Types of Volcanoes
There are all types of volcanoes on our planet: some are huge, some are no bigger than hills, some are explosive, and some are less so. There are several broad types of volcanoes based on their shape, eruption style, magma composition, and other aspects. However, all volcanoes are potentially deadly!

Figure 4.2.1. What image comes to mind when you think of a volcano? Does it look like the one in this figure? If so, you thought of a strato volcano, a.k.a composite volcano."Volcano Structure" By W. Crochot. CC BY SA 4.0.
Volcanoes have a cone-shaped structure that has been built over long periods of geologic time after multiple eruptions. At the very top of this cone is a crater. All active volcanoes sit atop a plume of magma called a magma chamber. The composition of this magma can vary from felsic to mafic depending on factors such as region, overlying crust composition, and tectonic setting.

When the magma chamber experiences too much pressure, it will erupt. The molten rock and volatile gases explode upward through a pipe-like column called a chimney. When the magma reaches the surface, it is called lava, even though the composition does not change.

Magma chambers, cones, craters, chimneys, and lava are features that are diagnostic of volcanoes. However, that is where the similarities end. Below, we will explore the different types of volcanoes on our planet.

Cinder Cones
Cross section of a cinder-cone with a central vent in the middle, fragments of rock along the rim, and a crater at the top.
Figure 4.2.2. Schematic of a typical cinder cone volcano.
Cinder cones are small volcanoes with steep sides, made of tephra and volcanic bombs ejected from a clear central vent. Cinders themselves are composed primarily of mafic lava with more volatile gases than average. Cinders are smaller pieces of tephra, or molten rock, that will erupt with lava from the volcano and rapidly cool and solidify in the air. Larger tephra rocks (over 2.5 inches) are called volcanic bombs, which are potentially deadly to anyone within range.

Cinder cone volcanoes do not last relatively long, but they are common in the United States and Mexico. Because they are usually mafic in composition, they produce extrusive igneous rock deposits such as scoria.

Lava Domes
A rounded dome of lava above a central volcanic crater
Figure 4.2.3. A rounded dome of lava above a central volcanic crater of Volcán Chaitén, Chile.
Lava Domes are fairly small structures made of felsic rocks that form within the collapsed craters of stratovolcanoes. These domes are made of extrusive rocks such as rhyolite, pumice, and obsidian that are piled around the vent. The dome-like structure is the result of the high-viscosity of the felsic to intermediate lava, which is too sticky to move long distances.

Lava domes have appeared in Mount St. Helens, Mammoth Mountain in California, and Chaiten in Chile (see Fig. 4.2.3).

Stratovolcanoes

Conical and steep volcano with bright orange lava flows
Figure 4.2.4. The Mayon volcano in the Philippines.
Mount St. Helens, Mount Vesuvius, Mount Fuji, Mount Pinatubo, Krakatoa— these infamous volcanoes belong to a frightening class of volcanoes that are historically known for their destruction and hazards. Stratovolcanoes (also called composite volcanoes) have steep sides and a symmetrical cone shape with an easily identifiable crater on top. These are called "composite" or "strato" because of the different layers of volcanic materials (such as ash) and lava that build up the volcano [1].

Stratovolcanoes can have magma that is anywhere from felsic to mafic in composition, although most of these volcanoes tend to be intermediate in composition. Stratovolcanoes usually form along subduction zones between oceanic-oceanic or continental-oceanic lithosphere. A good example of these volcanoes can be found along the Pacific Northwest. There, an ancient subduction zone used to exist between the North American plate and Farallon plate which formed the Cascade Mountain range and deadly stratovolcanoes including Mount Rainier and Mount St Helens. Check out the interactive model of Mt St Helens by clicking on Fig. 4.2.5.

Interactive Model of Mt St. Helens Landscape
Figure 4.2.5. Mount St Helens landscape. Click this image to go to an interactive model of the volcano and surrounding landscape by Sara Carena, CC BY-N-SA.

Shield Volcanoes

A large, shallow sloped volcano in the New Mexico desert.
Figure 4.2.6. The Sierra Grande shield volcano at Capulin Volcano National Monument, New Mexico.
The largest type of volcano is a shield volcano. These are characterized by very broad, shallow slopes, and small vents. The word "shield" refers to the shield-like shape of the volcano when it is viewed from the side. Shield volcanoes are sourced from low-viscosity mafic magma, and they typically have basaltic lava that has reached far distances along the volcanic slope. We typically observe shield volcanoes in areas where the upper mantle rises to meet the crust. These areas include hot spots, mid-ocean ridges, and continental rift zones.

image
Figure 4.2.7. "Hawaiian Islands" by NASA's Earth Observatory, Public Domain.
The mafic magma below shield volcanoes does not contain too many volatile gases; therefore, when shield volcanoes erupt, they are not very explosive. Instead, these volcanic eruptions are fairly small and predictable, which makes them less of a potential hazard than others. We can find a perfect example of shield volcanoes with the Hawaiian Islands at Mauna Loa and Kilauea (right). Click here to view an interactive model of Mauna Loa, the world's largest shield volcano!

Kilauea is the most active volcano in the world, although it does not cause many human fatalities. The eruption of Kilauea from fissures in Hawaii in 2018, however, produced lavas that did considerable damage to roads and structures [1].

BACKYARD GEOLOGY: HOUSE MOUNTAIN, SEDONA

Sedona, AZ is not just a resort town with rust-red rocks! About 15 million years ago, this region was volcanically active due to the migrating continental hot spot, which is responsible for the San Francisco Volcanic Field. This hot spot produced both mafic magmas and lavas and near Sedona, a large shield volcano formed that we now call "House Mountain". House mountain is pretty huge! This large shield volcano covers the area around 84 smaller volcano vents in an area of 180 square miles. While that is still much smaller than Mauna Loa (2,035 square miles!), that is still a pretty huge volcano [2]!

House Mountain shield volcano looms over desert Verde Valley in the distance.
Figure 4.2.8. View of House Mountain shield volcano near Sedona, AZ in the Verde Valley.
Calderas
image
Figure 4.2.9. "Crater Lake" CC BY SA 3.0
Calderas are large (up to 15 miles in diameter!), crater-like depressions that form after a volcano has collapsed after it has emptied much of its magma chamber. It takes a very explosive eruption to form a caldera, so it should come as no surprise that most calderas are found at volcanoes with highly viscous felsic and intermediate magma.

Because the caldera is a basin or depression, it often is filled in by water to become a crater-lake. The Yellowstone Caldera and Crater Lake, Oregon (above) is a notable example of this type of volcano. In the figure below, you can see a diagram of how a caldera forms at Crater Lake from the Mount Mazama stratovolcano [1]. This volcano has an explosive eruption that drains the magma chamber, and causes a collapse of the vent. That collapsed feature then fills with water.

Stages of caldera lake formation: 1. A felsic/intermedia eruption occurs. 2. The volcanic dome collapses under the violence of the eruption. 3. Steam exits the crater/depression over time and water precipitates. 4. A lake forms in the crater/depression of the volcano.
Figure 4.2.10. "Mount Mazama Eruption" by the United States Geologic Survey, Public Domain.
Flood Basalts
Map of Northern Russia showing the extent of the Siberian flood basalts, which influenced the Permian-Triassic Extinction in 252 Ma.
Figure 4.2.11. Map of Northern Russia showing the extent of the Siberian flood basalts (blue line), which influenced the Permian-Triassic Extinction in 252 Ma.
Flood basalts are an uncommon type of eruption, but they are by far the largest and longest. As the name suggests, Flood Basalts are large-scale eruptions of basaltic lava. We have not seen flood basalts throughout human history, but the evidence of flood basalt activity has been found in the geologic record. We currently estimate that once volcanism begins, flood basalts will erupt for up to 1-3 million years!

Some notable examples of flood basalts include the Deccan Traps that cover about one-third of India and the Siberian Traps, which can be found in Russia. We now think that flood basalt volcanism can be a key contributor in causing mass extinctions in our planet's history. For instance, the Siberian Traps, which were active about 252 million years ago, may have expelled greenhouse gases into the atmosphere in such large amounts that the entire planet's temperature could have rapidly increased by 5°C!

This process of rapid warming, in combination with other factors, may have caused the largest mass extinction the world ever experienced, the Permian-Triassic Mass Extinction.

Super Volcanoes
"Super-volcanic" eruptions can impact the entire planet, and the life inhabiting it, for years. The eruption can exceed 100,000 atomic bombs! For those lucky enough to survive the initial blast, a massive amount of ash is also ejected into the atmosphere and will blanket land hundreds of kilometers away. The combination of toxic gases and ash will furthermore block out sunlight in the atmosphere and cause "volcanic winters" that last for years. Such a devastating eruption has not yet occurred in modern human society…yet.

Schematic of the Yellowstone Caldera, fed by a hotspot.
Figure 4.2.12. Schematic cross section of the Yellowstone Caldera.
The Yellowstone Hot Spot is an active caldera-type volcano that is capable of a super-volcanic eruption. Although this is a hot spot volcano, it differs greatly from the shield volcanoes of Hawaii! This is because Yellowstone is located on the continental plate of North America. This very thick plate produces felsic to intermediate magma, which will erupt violently.

image
Figure 4.2.13. "Yellowstone Relief Map" by the United States Geologic Survey is licensed under Public Domain.
The Yellowstone caldera already erupted three times in the recent past: at 2.1, 1.3, and 0.64 million years ago [1]. Each eruption created large rhyolite lava flows and pyroclastic clouds of ash that solidified into tuff. These extra-large eruptions rapidly emptied the magma chamber, causing the roof to collapse and form a caldera. These eruptions left three calderas, and most of the roads and hotels of Yellowstone National Park are within the caldera [1].

4.3 Deadly Hazards
CHARLENE ESTRADA

Volcanic Hazards
Volcanoes are responsible for a large number of deaths, but lava is not the only danger associated with these hazards. Mount Vesuvius (Naples, Italy) is infamous for its violent explosion thousands of years ago in 79 AD when a pyroclastic flow travelled over the Roman countryside and engulfed the cities of Pompeii and Herculaneum [1]. It was not until the 18th century that we uncovered the shocking remains of these towns beneath over 10 feet of ash and the casts of people preserved within it.

Cast of a sitting victim of the Vesuvius eruption, Pompeii 79 AD
Figure 4.3.1. Cast of a sitting victim of the Vesuvius eruption, Pompeii 79 AD.
We know more about volcanic hazards over the past century because they have been better monitored and documented. We have seen enormously violent explosions, effusive lava, fast pyroclastic flows, ash, landslides, toxic gases, and more!

Pyroclastic Flows
The most dangerous type of volcanic hazard are pyroclastic flows. These flows are a mix of lava blocks, pumice, ash, and hot gases between 400 to 1,300°F! The turbulent cloud of ash and gas races down the steep flanks at high speeds at an average of 60 mph (much faster than people can run) into the valleys where farmlands grow and cities thrive [1].

image
Figure 4.3.2. “Pyroclastic Flow at Mayon Volcano” by the United States Geologic Survey, Public Domain.
Pyroclastic flows can often be expected of stratovolcanoes that contain felsic or intermediate magma. This magma is silica-rich and contains volatile gases that make it highly viscous. Therefore, these volcanoes often have very violent eruptions that are accompanied by a pyroclastic flow.

There are numerous examples of deadly pyroclastic flows. In 2014, the Mount Ontake pyroclastic flow in Japan killed 47 people. The flow was caused by magma heating groundwater into steam, which then rapidly ejected with ash and volcanic bombs. Some were killed by inhalation of toxic gases and hot ash, while volcanic bombs struck others [1]. In 1902, on the Caribbean Island Martinique, Mount Pelee erupted with a violent pyroclastic flow that destroyed the entire town of St. Pierre and killing 28,000 people in moments [3].

Lahars
Video 4.3.1 What are lahars and how are lahars formed? How does the composition influence the lahar behavior? (3:34)

A lahar is an Indonesian word for a mudflow that is a mixture of water, ash, rock fragments, and other debris that moves down the mountainside of a volcano (or other nearby mountains covered with fresh ash). They form from the rapid melting of snow or glaciers on volcanoes or sometimes in combination with a new eruption and heavy thunderstorm, as seen at Mt. Pinatubo.

Lahars move like a slurry of concrete, but they can move extremely fast at speeds up to 50 mph. Part of the reason they are so deadly is that they are slurry-like; they easily capture materials in their wake and they can travel very long distances like a flash flood [1].

During the 1980 Mount St. Helens eruption, lahars reached 17-miles (27 km) down the North Fork of the Toutle River. Another scenario played out when a lahar from the volcano Nevado del Ruiz, Colombia, buried a town in 1985 and killed about 25,000 people [1].

image
Figure. 4.3.3. “Lahar off Mount St. Helens” by the United States Geologic Survey Public Domain.
Tephra and Ash
A building lies in ruins under the weight of ash from the eruption of Mount Pinatubo, a volcano which came to life in June 1991 for the first time in over 600 years.
Figure 4.3.4. A building is crushed under the weight of ash from the eruption of Mount Pinatubo, a volcano which came to life in June 1991 for the first time in over 600 years.
Volcanoes—mainly stratovolcanoes—eject substantial amounts of tephra and ash [1].

Tephra is heavier than ash, so it will fall closer to the volcano’s crater and vent. Large masses of tephra sometimes erupt from volcanoes and can pose deadly hazards to anyone nearby. These are called volcanic bombs [1].

image
Figure 4.3.5. “Ash Plume from Mount Cleveland” by NASA’s Earth Observatory is licensed under Public Domain.
Ash is much finer, but it is dangerous. It can travel much longer distances away from the volcano, and that can cause more widespread issues in nearby towns and cities. A build-up of ash can collapse the roof of a building or home, and the microscopic minerals within ash will cause respiratory illnesses such as silicosis. Inhaling ash is extremely hazardous because much of it contains microscopic volcanic glass particles [4]. Imagine inhaling tiny shards of glass!

Ash will also interfere with transportation services farther away from an eruption. For example, the 2010 Eyjafjallajökull volcanic eruption in Iceland created a gigantic ash cloud that caused a significant air travel disruption in northern Europe. No one was hurt, but the cost to the world economy was estimated in the billions of dollars [3].

Volcanic Gases
Magma contains dissolved volatile gases. As magma rises toward the surface, the pressure that keeps it in the magma chamber will start to decrease, which allows those gases to escape. Think of this process like twisting the cap of a soda bottle; the first thing to rise and escape in that initial hissing noise is gas! [1]

Volcanic gases react with the atmosphere in various ways; the conve...
Figure 4.3.6. Volcanic gases react with the atmosphere in various ways; the conversion of sulfur dioxide (SO_2) to sulfuric acid (H_2SO_4) has the most significant impact on climate. (Public domain, USGS Volcanic Hazards Program)

The types of gases that are commonly released from volcanoes include greenhouse gases such as carbon dioxide (CO2), sulfur dioxide (SO2), hydrogen sulfide (H2S), methane (CH4), and water vapor (H2O). There are also toxic and acidic gases present at volcanoes such as HF, HBr, and HCl. After gigantic volcanic explosions, some volcanic gases such as sulfur dioxide will become sulfate aerosols in the atmosphere. These aerosol particles block sunlight coming toward Earth's surface and cause the planet to become cooler [5].

The volcanic gases can be both toxic and suffocating, and these gases sometimes are released from a volcano without an accompanying eruption. Gases were released from the Oku Volcanic Plain in Lake Nyos, Cameroon, and the carbon dioxide suffocated almost 2,000 people in 1986 [1].

4.4 Monitoring Volcanoes
CHARLENE ESTRADA

The Science of Predicting Volcanic Eruptions
Upper part of the image is a lake of bright lava in the bottom. On the bottom, a woman wearing yellow coat and a helmet smiles looking at the camera. She seems be perched on a slope.
Figure 4.4.1. Volcanologists get as close as they can to study volcanoes. But monitoring volcanoes from a space is less risky and could be even more impactful. Jani Radebaugh, CC BY-SA 4.0
Scorching temperatures, toxic gases, and let's not forget the volcanic bombs! Monitoring volcanoes is an extremely dangerous job, and it comes as no surprise that volcanology routinely appears among the top ten deadliest professions in the world! Nevertheless, as seen in video 4.4.1, scientists take risks to monitor volcanoes because it may reduce the chance of a potential eruption taking a populated region by surprise.

Video 4.4.1. Every volcanic eruption is an opportunity to learn about Earth's interior and to refine our prediction models (1:16).

[Video Description: Images of molten lava at active volcanic craters. Text: "Volcanoes are SO HOT right now. SO HOT that globally around 40 volcanoes erupt each month. Clip of hydrothermal vent. "Along with hundreds more erupting on the seafloor." Video of lava. "EACH MONTH. And every eruption is an opportunity to learn about what's happening deep, deep within the Earth." Video of white volcanic gases. "In addition to lava and ash, these portals to the deep emit gases. Water, carbon and sulfur from within Earth provide valuable clues about how our planet works. Collecting these gases might look cool, but it's the HOTTEST job in science." Video of Jeep driving down the road. "By 2019, the Deep Carbon Observatory will TRIPLE the number of continuous volcanic gas monitoring stations worldwide, collecting real-time data in some of the most remote places on Earth." World map of earthquakes, eruptions, and gas emissions. "When pieced together, this information helps reveal the story of deep carbon.

Measuring these gases may even help us forecast future volcanic eruptions, and that's not just a bunch of HOT AIR." Video of erupting stratovolcano by a town.]

It is difficult to predict whether or when a volcano will erupt, but scientists closely monitor a volcano over time to look for changes that could show geologic activity. Scientists will measure characteristics such as seismic activity surrounding the volcano, the deformation of the cone, gas emissions, and past history of volcanic eruptions [1,6]. These measurements will lead scientists to advise officials to take decisive action that can lead to evacuations, and hopefully, the prevention of a catastrophe.

Monitoring techniques shown include remote sensing, camera imaging, earthquake detection, surveying ground tilt and GPS, and gas monitoring.
Figure 4.4.2. The wide array of available monitoring techniques that scientists use to characterize and predict volcanic eruptions.
History of Volcanic Activity
How active is a volcano? Scientists compile historical records from cities, towns, and villages surrounding a volcano to learn when, over the course of written history, it last erupted. Geologists can also examine the cooled lava fields along the slopes of a volcano, and even date some of the recently deposited ash and rock to determine when it was last ejected from the vent.

Video 4.4.2. What can scientists see in a particle of ash? Geologists, John Wolff and Michael Rowe, discuss the use of geochemistry to aid in the prediction of volcanic eruptions. Their work centers on geologic activity in the Cascade Range, where a powerful subduction zone off the coast of North America produces constant volcanic activity in the area (3:44). Source: Washington State University, CC BY.

One way to classify volcanoes is by their activity: erupting, dormant, active, and extinct. An erupting volcano, as the name suggests, is currently erupting. A volcano that is not erupting, but remains connected to a magma chamber that might erupt, is called dormant. If a volcano has erupted just once in the past 10,000 years, scientists consider it to be active, even if it is in a period of dormancy or currently erupting. The only "safe" volcano is an extinct volcano, which means that we do not expect it to erupt in the foreseeable future. Nonetheless, even extinct volcanoes may surprise scientists and they are still prone to mass wasting events.

Scientists usually focus their monitoring efforts on active volcanoes, especially those that might affect populated areas. By documenting the eruption history of active volcanoes, scientists could construct a broad timeframe in which it is reasonable to expect an eruption.

Earthquakes

When magma moves beneath an active volcano, it can shake the ground nearby. The sudden shaking releases energy in the form of seismic waves, that is, it produces seismic movements or earthquakes.

A good indicator of a volcano that is just about to erupt is a series or “swarm” of earthquakes. Scientists measure these with instruments called seismographs, which capture the seismic waves released by the movement of the volcanic slope [7].

Swarms of Earthquakes, recorded as Seismograms, caused by Volcanic Activity

Figure 4.4.3. Swarms of earthquakes, recorded as seismograms, caused by volcanic activity.

Ground Deformation

In addition to producing earthquakes, the movement of magma under a volcano can also bulge the flanks of the mountainside. The deformation of the ground along the volcanic slope might not very apparent to the naked eye. Scientists use instruments called tiltmeters, which precisely measure the angle of a volcano’s slope. When that slope starts to deform, due to pressure from the underlying melted rock and gas, it will change the slope angle of the volcano [8]. The tiltmeter is a sensitive instrument that can detect infinitesimal changes. The deformation process could even cause mass wasting events.

Mount St Helens' northern peak is bulged outward in 1980 before its massive eruption

Figure 4.4.4. Before its eruption in 1980, the top of Mount St Helens appeared to be bulging. Today, well after its eruption, this area has collapsed or caved-in!

Some scientists now use the modern technique of remote sensing to detect subtle changes in the volcano’s shape and slope. Scientists use modern drones and satellites to track slight changes in elevation and temperature in areas that are inaccessible to scientists. Some of these technologies include Light Detection and Ranging (LiDAR), Global Positioning System stations (GPS), and Interferometric Synthetic Aperture Radar (InSAR). Figure 4.4.4 shows the working principle for inSAR.

Image shows how inSAR works: A Satellite passes over an area at least 2-3 times to record information about how the ground changes during volcanic activity.

Figure 4.4.5. How does inSAR work? A satellite passes over an area and makes a map of the relative elevation. When the satellite passes over the same place multiple times again, it will notice differences in elevation brought about by volcanic activity.

Gas Emissions

Some active volcanoes release gases before magma. These gases include sulfur dioxide (SO2), carbon dioxide (CO2), water vapor (H2O), and hydrochloric acid (HCl). Scientists will detect these gases near the vent of the volcano or sample them and later analyze the gas concentration with sophisticated instruments, called spectrometers. The increase in the concentration of certain gases may indicate an imminent eruption [9].

Large gas monitoring station with solar panels at Mount St. Helens with a geologists sitting on top of it for scale.
Figure 4.4.6. A gas monitoring station placed at Mount St. Helens can collect water vapor, carbon dioxide, sulfur dioxide, and hydrogen sulfide.

4.5 Where are the Volcanoes?
CHARLENE ESTRADA

Distribution of Volcanic Activity
There are between 1400 and 1500 active volcanoes on our planet right now, and they are unevenly distributed throughout Earth's surface. Some volcanoes cluster in specific regions. The Ring of Fire is an infamous area loosely spanning the border between continents and the Pacific Ocean (Fig. 4.5.3). This region spans about 40,000 kilometers and it has significantly more volcanic and seismic activity compared to other places on the planet.

The USGS Volcano Hazards Program shows both monitored and unmonitored volcanoes in the United States. Along the Western Coast and Hawaii are 161 active volcanoes, some of which may erupt in the near future. CLICK THIS IMAGE TO GO SEE THE CURRENT STATUS OF THESE VOLCANOES!
Figure 4.5.1. Screenshot from the USGS Volcano Hazards Program (2021). Monitored and unmonitored volcanoes in the United States are mapped along with real-time status. Along the Western Coast and Hawai'i are 161 active volcanoes, some of which may erupt soon. Notice the legend on the bottom right. What does an orange triangle with an eye mean? Click on this image to see the current status of these volcanoes.
Why are so many volcanoes bunched together? Tectonic processes form most volcanoes such as subduction at convergent boundaries or rifting at divergent boundaries. Therefore, the distribution of volcanoes naturally coincides with plate boundaries. This connection between volcanism and plate boundaries is called interplate volcanism. There are some volcanoes, however, that occur very far away from plate boundaries. They are typically the result of hot spot volcanism, which can occur on both continental and oceanic lithosphere.

Below, we will explore some of the broad geologic environments that result in volcanism and the types of volcanoes we might expect from each.

Mid-Oceanic Ridges
New lithosphere is continuously being formed at divergent boundaries. As two tectonic plates spread apart, the magma from the asthenosphere will rise to the surface and form brand new oceanic crust made of basalt and gabbro. The Mid-Atlantic Ridge exemplifies this process, and it is Earth's longest mountain range! There are two sets of divergent boundaries at the Mid-Atlantic Ridge: the North American-Eurasian plate boundary to the north and the South American-African plate boundary to the south. Such a long spreading center along the ocean floor is responsible for the majority of Earth's volcanism, but because it is deep underwater, it poses little to no risk to society.

image

Figure 4.5.2. Map of the mid-ocean ridge system (yellow-green) in the Earth's oceans. The Mid-Atlantic Ridge is on the right, transversing the globe south to north. "Mid-Ocean Ridge System", National Oceanic and Atmospheric Administration, Public Domain.

Continental Rifts

The lithosphere spreads in mid-ocean ridges and in the continents! Although the continental lithosphere can be up to 100 km thick, divergent tectonic forces can break it apart. As a result, the continental crust will thin over time, and the lower layers of the crust and the mantle will rise because they are buoyant. These uprising rocks in the lower lithosphere and mantle undergo decompression melting (section 4.1) and basaltic magma will erupt from newly created volcanoes. The spread-apart regions on continents are called continental rift valleys. Most continental rift valleys form at divergent boundaries where ocean basins have not yet opened. These places are sites of continental break-up, and we can see this process occurring today at the East African rift.

Convergent Boundaries

image

Figure 4.5.3. The Pacific Ring of Fire is the area highlighted in red. Notice the location of trenches. Public Domain.

Recall from Ch. 2 that in convergent boundaries between two oceanic plates or between an oceanic and continental plates, the denser oceanic lithosphere sinks toward the mantle. Within the subduction zone, magma will form due to flux melting (Section 4.1).

The magma generated at the subduction zone is derived from the mantle and thus shares the same chemical composition; it is mafic. However, if this mafic magma rises toward a continental plate, which is felsic, it will melt it partially. The new melt added to the magma will change the original magma composition, and it will become intermediate or even felsic, when more continental crust gets melted into it. The result is a very viscous magma that will produce stratovolcanoes. Stratovolcanoes typically form at convergent boundaries. The Pacific Ring of Fire, a continuous subduction zone, receives its name due to the abundance of with these explosive volcanoes.

A description of the Pacific Ring of Fire along western North America is below (Fig. 4.5.3):

Subduction at the middle American trench creates volcanoes in Central America.

The San Andreas fault is a transform boundary.

Subduction of the Juan de Fuca plate beneath the North American plate creates the Cascade volcanoes like Mount St. Helens, Mount Rainier, Mount Hood, and more.

Subduction of the Pacific plate beneath the North American plate in the north creates the long chain of the Aleutian Islands volcanoes near Alaska.

Hot Spots

Figure 4.5.4. A simplified cross-section of Hawaiʻi Island and the Hawaiian hot spot (NPS Graphic) "Hawaiian Hot Spot". Public Domain.
A volcanic "hotspot" is an area in the mantle from which heat rises as a thermal plume from deep in the Earth. High heat and lower pressure at the base of the lithosphere (tectonic plate) facilitates melting of the rock. This melt, called magma, rises through cracks and erupts to form volcanoes. As the tectonic plate moves over the stationary hot spot, the volcanoes are rafted away and new ones form in their place. This results in chains of volcanoes, such as the Hawaiian Islands (Video 4.5.1, from IRIS and Fig. 4.5.4). These islands are usually just "the tip of the iceberg" as they are often very large shield volcanoes that lie under the water (Fig. 4.5.4). Shield volcanoes form by low-viscosity, mafic magma.

Video 4.5.1 Hotspot track animation. Observe the movement of the oceanic plate while the thermal plume remains in place.

Video Player

00:00
00:06

Some hot spots form beneath the continental lithosphere. Although the partially melted mantle composition is ultramafic at depth, as it rises to the surface and mixes with the materials in within the continental crust, it becomes mafic, then intermediate. In some areas, it might even become felsic. This mixing of molten materials is a recipe for potential disaster! As the magma becomes more silica-rich, it also becomes more viscous with volatile gases, which make for a very explosive eruption. In the United States, there is one active continental hot spot volcano we are currently monitoring: the Yellowstone Caldera (above), which is likely to have a super-volcanic eruption in the next 100,000 years.

Figure 4.5.5. Hot material rises from deep within Earth's mantle and melts, forming basalt magma at the base of the crust. The rising magma encounters silica-rich continental crust on its journey upward forms a rhyolite magma chamber only 5 to 10 miles (8 to 16 kilometers) beneath Yellowstone National Park. National Park Service, Public Domain.

4.6 Surviving a Volcanic Eruption

CHARLENE ESTRADA

As frightening as some volcanic eruptions can be, people survive them. You should never rely solely on luck, the knowledge of others, or city policy to survive an eruption; if you live in an area that is prone to this deadly hazard, there are plenty of precautions you can take to ensure that the odds are in your favor when you, your family, or your friends are affected by a volcanic eruption.

Volcanic Hazard Zones

After reading all that you have, you may wonder why anyone in their right mind would live near an active volcano! The reasons are complex, and after millions upon billions of dollars have been invested in building a town with emotional and spiritual significance for its residents, relocating from a hazardous area is rarely ever an option. Instead, it is useful to determine the likelihood that certain areas around the volcano will experience hazards like lava flows, lahars, pyroclastic flows, and more should the worse happen.

Geologists do not just closely monitor volcanoes to predict when they will erupt. They also create hazard maps around the volcano that is accessible to the public, as shown in the example of Hawaii (Fig. 4.6.1).

Lava-flow hazard zones map, Island of Hawaiʻi, where the most hazardous areas are directly around the crater of Mauna Loa or downslope of the volcano. See Full Map for co...
Figure 4.6.1. Lava-flow hazard zones map, Island of Hawaii. USGS. Public Domain.
These volcanic hazard maps mark the regions that should evacuate if a volcanic eruption is imminent. If you happen to visit a place with an active volcano such as Hawaii, or have family living in such an area, it is a good idea to check whether they live in an area that would be most threatened by volcanic activity. In general, any community or city that is downslope from the volcano should pay careful attention to announcements about that volcano and potential evacuation orders [11].

Have A Plan

A sign posted in Alaska that says: "Volcanic eruption preparedness gear. Are you prepared? Get your 72 hour kit ready for action today
Figure 4.6.2. Sign advertising emergency kits for volcanoes in Anchorage, AK (USA), where there is significant volcanic activity.
Never allow yourself to be unprepared for a potential disaster. This statement is correct of any situation; volcanoes, earthquakes, landslides, flooding, etc. Although your community should have a plan to mitigate the damage from a natural hazard at the city and state level, those policies are not a substitute for how you will react to a spontaneous disaster. If you live in a region affected by volcanoes, make sure that you do the following:

Research the layout of your community and the geologic risks to it. Figure out a safe place that is likely to be less affected by a volcanic eruption and its hazards that you can quickly relocate to.
Communicate the risks of a volcanic eruption to your family. Work together with them to come up with an emergency plan that each member will carry out should an eruption unexpectedly happen.
Factor in unknowns such as family members getting separated or traffic blockages into your plan. Make sure everyone knows the way to your safe meeting place.

Put together an Emergency Kit that contains at least a 3-day supply of food and water for everyone. Volcanoes, in particular, spew ash that is dangerous if inhaled. Make sure you add N95 face masks to this kit for you and your family members! [12]
BUILDING AN EMERGENCY PREPAREDNESS KIT

A standard emergency preparedness kit shown by the Red Cross that contains first aid supplies, water, personal protective gear and a flashlight.
Figure 4.6.3. A standard emergency kit illustrated by the Red Cross.
Having an emergency preparedness kit ready in your home is a great first step toward surviving any potential disaster. They may look really expensive at stores or online (such as the basic kit pictured above), but you can put together a really effective kit by yourself that may keep you and your loved ones safe!

How Build Your Own Kit

Look for the basics around your home before you buy costly equipment. Just make sure that equipment still works before you put it together in your kit! Make sure you have the following:

Non-perishable food that does not require fuel sources (i.e. microwave/oven) that can last up to 72 hours per person. Think food bars and canned food! Don't forget a can opener!
1 Gallon of water for each person to last every day of the emergency. This amount should be about 3 gallons per person to last 72 hours.
A flashlight with extra batteries.
A radio! Many updates come on radio and they are more reliable if cell towers come down. There are also hand-crank powered radios that can be useful in a pinch!
Personal protective equipment: face masks, goggles, and gloves will keep you safe and free from contamination and disease.
Emergency cash: consider an emergency that knocks out the power grid and affects basic utilities, including the ability to pay electronically.
Toilet paper and other sanitation products
If applicable: Personal medications, pet food, solar chargers, flares, whistle, hand tools
When in doubt, go to https://ready.gov/kit/ for advice!

During the Eruption
Be sure that you are periodically monitoring updates from your local scientists on whether your volcano is becoming active. If there is some unrest, you will hear about it early, and have some time to prepare and perhaps evacuate!

If you are right near or on the volcano…
Hopefully, this won't apply to you! However, if you are in the worst-case scenario of hiking a volcanic summit when it erupts, you can STILL protect yourself.

Move away from the volcano as quickly as you can!

Do NOT walk into any low-lying areas such as washes, ditches, valleys, etc. These are places that are prone to lava flows or lahars.
Carefully read the signage posted by the forestry service as you go. You might be able to receive the life-saving information that a certain route is blocked off or closed! [13]
A hiker finds higher ground to avoid lava
Figure 4.6.4. Illustration of hiker finding higher ground to survive a volcanic eruption.
If you are downslope of the volcano…
This situation often applies to residents in the valley surrounding a volcano who have refused to evacuate or an area that has not sent out evacuation orders.

Do NOT drive! The ash falling from volcanoes can clog engines and ruin infrastructure. Driving during an eruption should be your last resort.
Seal your windows and doors. If your area is not affected by lahars and lava flows, it still might be affected by falling ash. Prevent it from getting into your home by taping off your windows and doors and shut off your HVAC system (or limit it as much as possible!).
Avoid the lowest relief areas, such as valleys, channels, washes, ditches, etc. These are the places where lahars and/or lava flows are likely to be, and therefore the most hazardous!
Listen for announcements by officials and scientists about potential lahar warnings, lava flows, and other hazards. They will also let you know when it is safe to go outside or move. Using a radio for this is the most reliable method as cell phone towers and the internet will be unreliable. [13]
Two men listening for updates on a radio.
Figure 4.6.5. People listening for updates on the radio during a volcanic eruption event.
After the Eruption
Do NOT approach cooling lava! It may look black and safe, but lava is insanely hot at temperatures over 1000°C. Appearances are deceiving, and sometimes lava is only cooled at the very surface.
Avoid all areas around a potential lahar zone! These flows take a long time to solidify and they may occur repeatedly.
Avoid cleaning your roof of ash–allow professionals to do this, and certainly do not attempt it until the ash has finished falling. If there is a significant amount of ash on your roof (multiple feet), consider evacuating for safety as the weight of ash can cause collapses.
If you have breathing problems, continue to wear a mask to keep your airways safe from the unconsolidated ash deposits.
Keep monitoring your area for announcements and potential secondary hazards that could make the eruption effects worse, such as rainstorms. [14]
A man wearing goggles and a mask carefully cleans volcanic ash off a windshield.
Figure 4.6.6. Care and protective measures must be taken even when cleaning small amount of volcanic ash from buildings and cars.
4.7 Thriving Near Volcanoes
CHARLENE ESTRADA

“Every act of creation is, first of all, an act of destruction.” -Pablo Picasso

Volcanic eruptions are deadly; molten lava destroys the surrounding land and vegetation, and unpredictable lahars will bury other regions downslope of the volcano. Even if a community is fortunate to survive a violent eruption accompanied with these and other hazards such as ash, toxic gases, and pyroclastic flows, these hazards can still cause fatalities, the death of livestock, and the immeasurable destruction of infrastructure such as buildings, homes, and farmlands.

As terrible as a volcanic eruption may be for our society, we also must acknowledge that without volcanism, life as we know it may never have begun on Earth! Volcanic activity is not limited to eruptions of lava, gases, or ash. Most active volcanoes are continuous sources of heat and chemicals. For our earliest ancestor on the planet (which was likely bacteria), which sought its energy from heat or chemicals, areas of volcanic activity were a gold mine!

An underwater, dark rock formation surrounded by small sea life. At the center, hot water is erupted out into the cold sea along with black minerals, which looks like black smoke.
Figure 4.7.1. A “black-smoker” type hydrothermal vent. The black particles expelled underwater are metal solids made of elements such as iron, lead, copper, silver, and gold. These types of hydrothermal vents are powered by volcanic activity associated with divergent boundaries.
Literal gold mines are also sourced from volcanic activity, as are many other metals. Humans have had a long history of using igneous rocks and precious minerals to build industries and economies. Below, we will explore how volcanoes have transformed life on our planet, and how we have learned to harness the benefits of volcanic activity.

Hydrothermal Vents
An intriguing consequence of volcanism at mid-ocean ridges are areas along the divergent boundary that heat the seawater. This water reaches temperatures up to 380°C (716°F!). At such hot temperatures, the water can dissolve metallic elements from the igneous rocks. When that water circulates up to the rest of the ocean, it carries a surprise: the water is dark black!

Cold seawater moves down the cracks in the seafloor, is superheated by magma, and strips rocks of metals. The water rises and precipitates the metals as black smoke as chimneys of ore.
Figure 4.7.2. Diagram of the movement of heat caused by volcanic activity at a hydrothermal vent.
These areas of very hot, mineral-rich water are called deep-sea hydrothermal vents. They are sites for economic and precious mineral deposition, but they are also areas where diverse ecosystems can thrive deep beyond the reach of sunlight. Hydrothermal vents that belch out dark plumes of minerals along with hot water are usually called “black smokers”.

Scientists are very interested in hydrothermal vents because there is a strong indication that some of the earliest lifeforms on Earth preferred very high temperatures of over 80°C. We do not know much about the very first life on Earth, except that it had to be very similar to a single celled bacterium, and that it did not have the capability to make its energy through photosynthesis. Some scientists suggest that the first life on Earth lived close to a hydrothermal vent, where it could keep warm and make its energy through an alternative method of eating the chemicals that are released through this volcanic process.

Hot Springs and Geysers
Water and high temperature rock do not just encounter one another deep in the ocean at mid-oceanic ridges. This process also regularly occurs on land. Volcanic activity keeps rock beneath our surface very hot; therefore, when water meets this rock at depth, it too becomes super heated. This overly hot water will find a way to rise to the surface, often through cracks in the layers of rock, and the end result is often exciting! We will observe that hot water shoot upward from underground as a geyser.

Video 4.7.1. A large geyser, known as Old Faithful, continuously erupts hot water and steam up around 130 feet into the air, goes back down into the ground, and then erupts more to the cheers of surrounding tourists at Yellowstone National Park. (2:22)

Perhaps the most famous geyser in the United States is Old Faithful, at Yellowstone National Park. This region is affected by hot spot volcanism, and the geyser itself predictably erupts about 17 times each day [15].

A hot spring describes hot or warm water that has quietly pooled at the surface. As you might expect from the presence of Old Faithful, there are thousands of hot springs at Yellowstone! Like hydrothermal vents, hot springs provide a wealth of chemical and heat energy for microbes to thrive, which can lead to a wide range of differently colored springs, such as the Grand Prismatic Spring in Yellowstone.

An aerial view of Grand Prismatic Spring, which is steaming and bright blue and ringed by rainbow colors of reds, oranges, and yellows caused.
Figure 4.7.3. Grand Prismatic Spring in Yellowstone National Park is a hot spring with a colorful border that is caused by bacteria that are attracted to the hot water.
Most hot springs are known in the media for their warm water that humans (and animals!) can soak in comfortably. Japan, which sits along a subduction zone with significant volcanic activity, has built a rich culture surrounding hot springs. Some hot springs contain unique concentrations of dissolved elements and minerals that have softened skin and (reportedly) relaxed tired muscles.

White "snow monkeys" are relaxing in the Jigokudani hot spring in snowy, Nagano Japan.
Figure 4.7.4. Snow monkeys, or Japanese Macaques, bathing in the hot springs of Nagano, Japan.
Nevertheless, if you encounter a hot spring, DO NOT step into it, unless it has been approved as safe for human use! A lot of hot springs are extremely acidic, or extremely alkaline, both will burn you. Others are boiling hot or contain toxic gases and chemicals. Nearly every year, there is a report of a tourist death or severe injury at Yellowstone National Park due to attempted

bathing in the hot springs. In some of these unfortunate circumstances, the bodies of these individuals are dissolved in the acidic, boiling water within a day.

A warning bulletin at Yellowstone national park depicts a frightened child stepping on a geyser after wandering off the pathway. These warnings are meant to dissuade tourists from wandering into the deadly hot springs.
Figure 4.7.5. A bulletin announcement for all national and international tourists to avoid stepping off the pathways at Yellowstone National Park.
BACKYARD GEOLOGY: HOT SPRINGS IN ARIZONA

There are many hot springs throughout the United States, and Arizona is no exception! Although most of our Northern Arizona volcanoes are extinct, hot springs can also be created by a high geothermal gradient. When that warm water rises, it can have the same therapeutic benefits as springs in Japan. Two popular destinations are Castle Hot Springs (60 miles from Phoenix) and Verde Hot Springs (100 miles away from Phoenix, Fig. 4.7.6). The hot springs in our state were traditionally believed by the Apache and Yavapai to hold healing properties [16], and should you experience an Arizona hot spring (maybe not in the summer) it will be easy to understand why!

Verde Hot Springs is a naturally-occurring deep spring of hot water people can bathe in off a hiking trail at Camp Verde near Prescott.
Figure 4.7.6. Verde Hot Springs is a narrow, but deep pool of naturally-occurring hot water that can be found off a hiking trail in Camp Verde near Prescott.
A Wealth of Resources
Most volcanic activity is great for business. Pompeii and Mount Vesuvius. The Hawaiian Islands. Arequipa and El Misti. Tokyo and Fuji-san. Historically, there have been many civilizations around volcanoes, and this was not bad luck or coincidence. When lava cools, it becomes igneous rock. When igneous rock is eventually weathered, it provides the land with fertile soil for agriculture.

Volcanoes also leave deposits of precious minerals such as gold, silver, copper, lead, zinc, iron, and nickel. Many of these are precipitated by the “black-smoker” hydrothermal vents. Volcanoes more commonly deposit igneous rocks such as granite that have been used as sturdy building materials.

A wall made of granite bricks cemented together
Figure 4.7.7. Granite is a popular building material in construction because the minerals that compose this rock naturally resist weathering from humid weather, rain, and snow. Granite is both hard and durable.
Some of the most amazing landscapes are near volcanoes because volcanic activity builds land and creates breathtaking scenery. The volcanoes themselves are economically vital for many regions because of the recreational activity and tourism they bring [1]. As terrifying as an eruption at Yellowstone may be, this region is one of the most frequented parks by international tourists in the United States!

Sunset Crater has a dedicated visitor center with a walkable path for tourists near the lava fields. Pictured here is an interactive exhibit for tourists at the visitor's center.
Figure 4.7.8. There are visitor centers and gift shops associated with volcanic sites like Sunset Crater.

Geothermal Energy

image

Figure 4.7.9. “Geothermal Energy” Creative Commons Attribution-ShareAlike 4.0 International.

Geothermal energy is becoming a rising alternative source of energy. “Geothermal” references the fact that heat is being sources from the Earth, or in this situation, volcanic activity at depth. Volcanic activity generates heat, which can be harnessed to create electricity [1]. In some regions, there is enough geothermal power to completely replace our more traditional methods of generating electricity such as burning fossil fuels, and this method does not produce additional greenhouse gases.

Which regions would benefit most from geothermal energy? Follow the volcanoes. Hawaii, particularly at the world’s most active volcano of Kilauea, is an excellent source of American geothermal energy. Iceland also significantly benefits from this natural resource since it sits along the Mid-Atlantic Ridge. Around 85% of the homes in that country are already powered by geothermal energy [17].

image

Fig. 4.7.10. “Nesjavellir Power Station in Southwest Iceland” is licensed under Public Domain.

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Media Assets

Fig. 4.1. Bkilli1. (2013, Oct 9). “Geothermal Gradient.” [Online Image]. Wikimedia Commons. https://commons.wikimedia.org/wiki/File:Temperature_schematic_of_inner_Earth.jpg CC BY-SA 3.0

The Geothermal Gradient within Earth.
4.1

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4.2
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