

# Volcanoes

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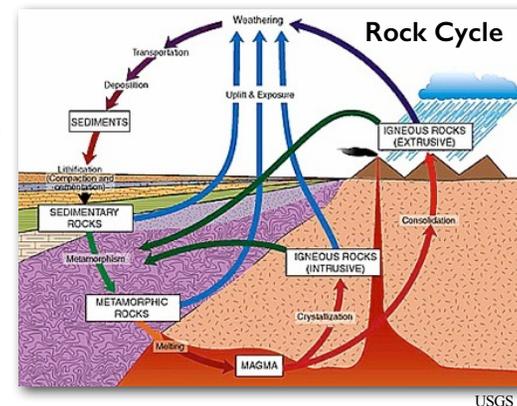


## Some Definitions

**Igneous** refers to processes and rocks involving or formed from molten rock. Igneous rocks are one of the three main rock types, the others being sedimentary and metamorphic rock. Igneous rocks are formed by the cooling and solidification of magma or lava

**Magma** is molten rock, and contains volatiles (gases such as water and CO<sub>2</sub>) and solids (crystals and rock fragments). Magma is found beneath the Earth's surface.

**Lava** is magma that has extruded onto the Earth's surface and is the volcanic equivalent of magma.



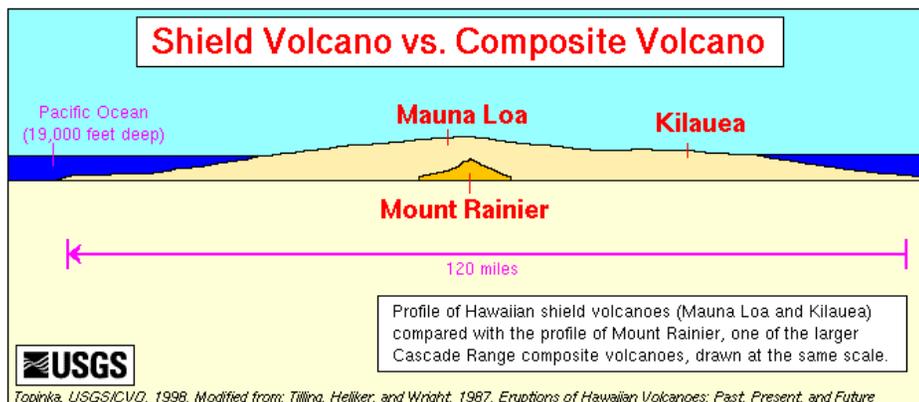
## I Types of Volcanoes

Successive eruptions build up mountainous accumulations of material forming a volcano.

There are 3 main types of volcanoes:

1. shield
2. composite
3. cinder cone

**They differ in size and composition.**



## Shield Volcanoes

**Shield volcanoes** form from the accumulation of very fluid basalt (mafic) flows. They can be very large and have a broad and slightly domed shape.

The Hawaiian islands are formed from *shield volcanoes*. Mauna Loa on the island of Hawaii is nearly 6 miles in height (see photo).

Kilauea has been continuously erupting since 1983.



Mauna Loa, Hawaii



Medicine Lake Volcano, CA

Good examples of *shield volcanoes* are found in the Hawaiian islands - Kilauea, Mauna Loa, Mauna Kea. Small shield volcanoes, such as Medicine Lake, are found in California.

USGS Photo by J. Sweeney/USGS

## Calderas

Eruption of a shield volcano is frequently followed by collapse of the summit region — forming a *caldera* (>1 km).

A *caldera* is a circular depression where the surface has slumped as lava has poured out from the magma chamber beneath.

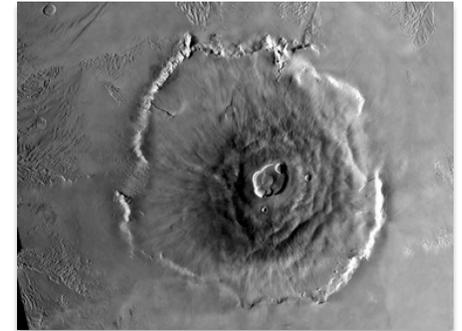


*Shield volcanoes* are found on other planets — Olympus Mons on Mars is the largest volcano found in the solar system.

Olympus Mons rises 24 km from its base and measures 550 km across.

By comparison, Earth's largest volcano, Mauna Loa in Hawaii, rises only 9 km high and measures 120 km across.

Note the caldera at the summit of Olympus Mons.



## Composite Volcanoes

*Composite Volcanoes* or *Stratovolcanoes* are large and commonly symmetric and are composed of alternating lava flows and pyroclastic deposits.

They are produced by relatively *viscous* lavas such as *andesite* (intermediate between mafic and felsic) and are usually associated with subduction zones.

The photo shows Mt. Rainier in Washington. These are the most violent types of volcanoes.

Examples of *composite volcanoes* include Mt. Fuji, Japan and the Cascade range in N. California, Oregon and Washington: Mt. Shasta, Mt. Hood, Mt. St. Helens, Mt. Rainier



Mt. Shasta and Mt. Lassen in California represent the southern extent of the Cascade range of volcanoes that result from subduction along the NW coast.

A smaller parasitic cone (Mt. Shastina) can be seen on the flank of Mt. Shasta.

Mt. Lassen is a remnant of a much larger volcano (Mt. Tehama) and is one of only two volcanoes to have historically erupted in the continental U.S.



This video shows the 1915 eruption of Mt. Lassen.

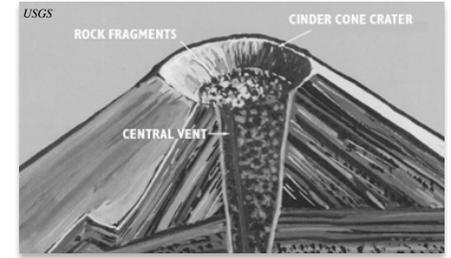
Commonly, the summit of the composite volcano may collapse at the end of a violent eruptive cycle — forming a *caldera*. Examples of calderas include Crater Lake (OR) (top) and Aniakchak Caldera (AK) (bottom).



## Cinder Cones

*Cinder cones* are small (<300 m), steep-sided (30-40°) and are composed of loose pyroclastic (literally *fire particle*) material. They represent a short volcanic episode from start to finish and commonly occur in groups (fields).

They are predominantly basaltic (mafic) in composition.



Cinder cones are common throughout California and the western U.S.

## II Plutonic Activity

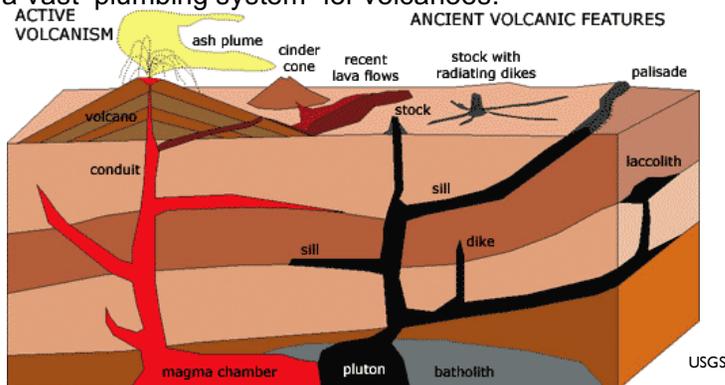
Volcanism is spectacular, but most magma is emplaced at depth in the crust.

There are two types of igneous activities:

- Volcanic
- Plutonic

Keep in mind that these two processes occur simultaneously and involve the same materials.

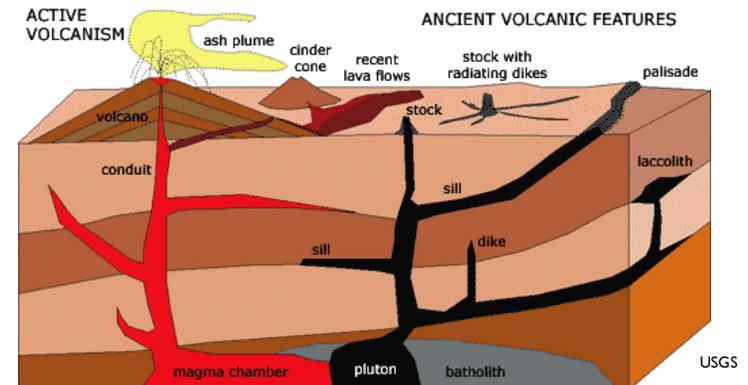
There is a vast "plumbing system" for volcanoes.



When magma is emplaced at depths and crystallizes, it forms a variety of plutonic bodies.

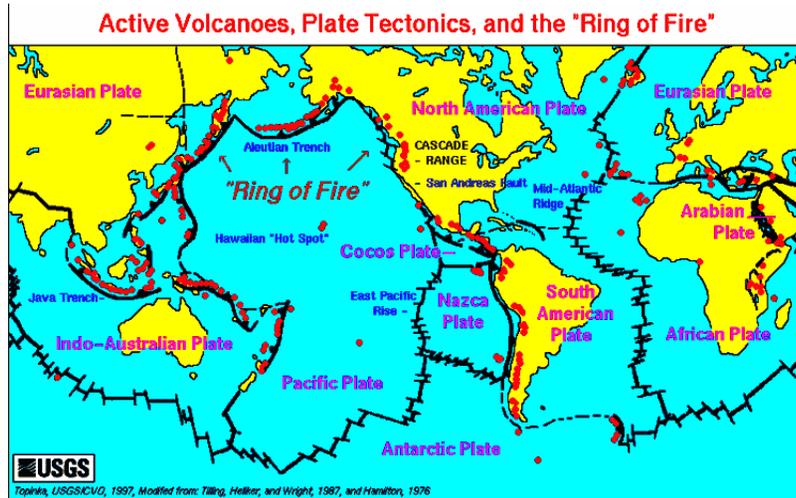
After volcanism has ceased, erosion of the surface may expose these buried plutonic bodies.

Thus, by investigating these features that are now at the surface, we are glimpsing at the "plumbing system" for an ancient volcanic system.



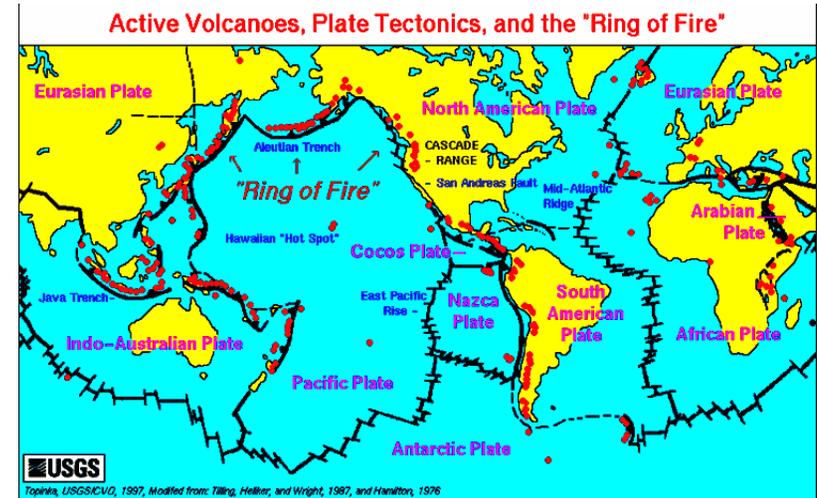
### III Plate Tectonics and Igneous Activity

Looking at a map of the global distribution of volcanoes, it is apparent that they occur in certain tectonic environments. Most occur along plate margins or boundaries. The figure below shows the distribution of some of the Earth's major volcanoes.

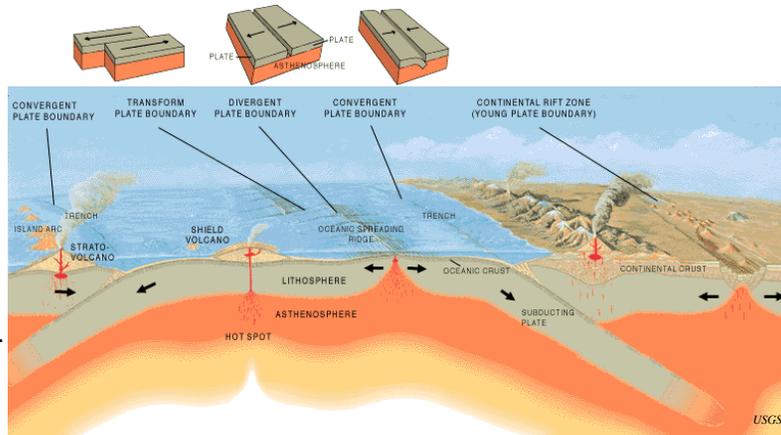


Volcanoes occur within three tectonic zones:

- convergent plate boundaries - *subduction*
- divergent plate boundaries - seafloor spreading at mid-ocean ridges
- interior of plates - hot spot volcanism (ex. Hawaii)



The figure shows the tectonic setting for each zone of volcanism.



Most volcanoes occur associated with subduction zones (convergent margin).

Seafloor spreading (divergent margin) is associated with a large amount of volcanic activity.

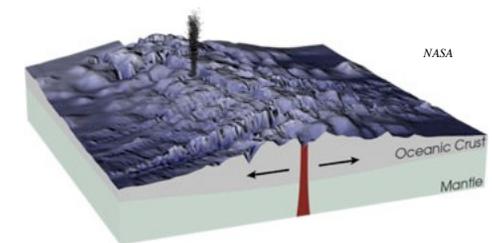
There are a few volcanoes (Hawaii) that occur in the middle of tectonic plates and are not associated with plate boundaries (hot spot volcanism).

### Igneous Activity at Spreading Centers

The greatest volume of volcanic rock on the Earth is produced along the oceanic ridge system.

As plates pull apart, the pressure of the underlying rocks is lessened. The reduced pressure results in partial melting of the mantle. Lava works its way up to form new basalt seafloor.

Submarine lava flows typically consist of *pillow lavas*.



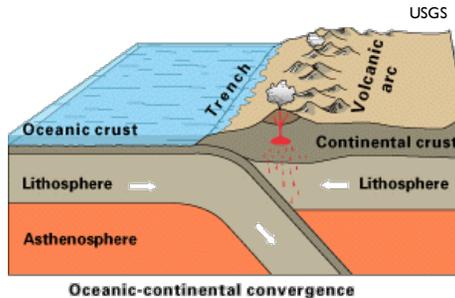
## Igneous Activity at Subduction Zones

As a seafloor slab sinks into the mantle at a subduction zone, melting of rock occurs in the mantle above the subducted plate.

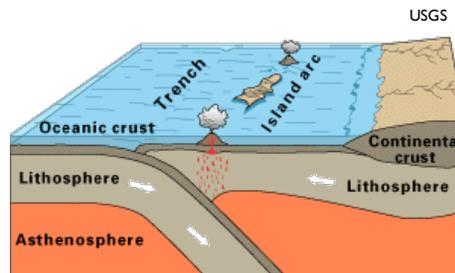
The magma rises through the crust where it may form volcanoes.

The subducted slab may dive under continental crust forming a **continental arc**. This is the origin of the Cascade and Andes volcanoes.

Likewise, the subducted slab may dive under another oceanic plate and form an **island arc**. This is the origin of Japan, the Philippines, and the Aleutian Islands.



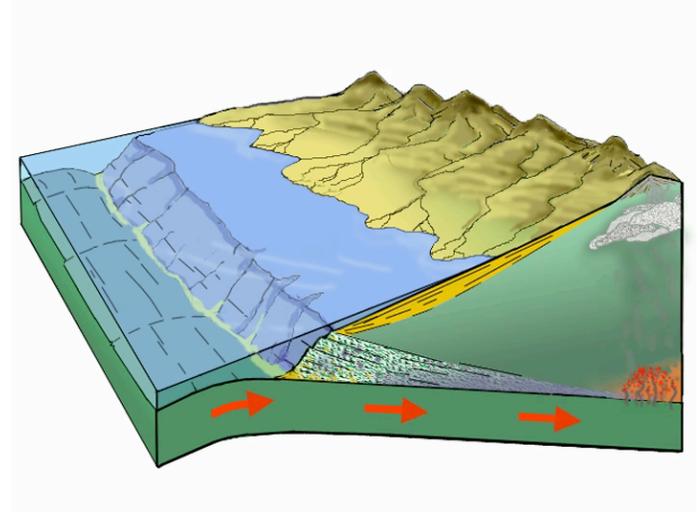
Oceanic-continental convergence



Oceanic-oceanic convergence

Magma is generated when water is driven out of the subducted plate. The buoyant water migrates upward where it causes partial melting of the mantle wedge. (Magma forms by melting in the mantle and not by melting of the subducted plate.)

The magma rises buoyantly through the crust. As it migrates upward through the crust, it changes composition (more later) and may accumulate in the upper crust in magma chambers.



Tanya Atwater, UCSB

The chemistry of the magma associated with stratovolcanoes is higher in silica and water than basalt. This causes these volcanoes (andesite) to be more explosive than basalt volcanoes and represents some of the most dangerous volcanoes in the world.



Mt. Pinatubo



Note the ring of volcanoes that circles the Pacific Ocean.

There are many subduction zones that border the Pacific and it is known as the **Ring of Fire**.

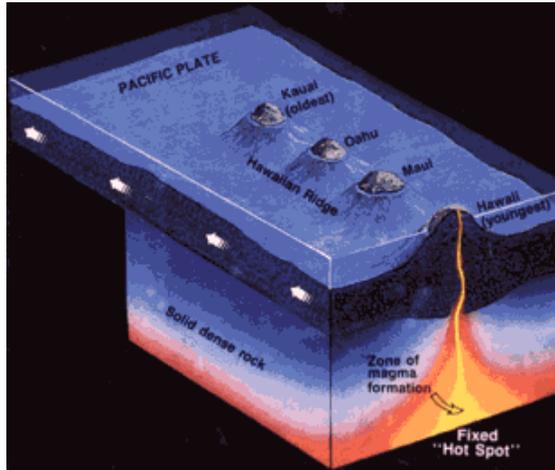
## Active Volcanoes, Plate Tectonics, and the "Ring of Fire"



## Intraplate Igneous Activity

Although most igneous activity occurs along plate boundaries, there are some regions of igneous activities that occur within oceanic and continental plates (ex. Hawaii and Yellowstone). The explanation for these intraplate volcanoes was not adequately explain until the development of the theory of plate tectonics.

There are plumes in the mantle where hot material is rising known as *mantle hot spots*. The *mantle hot spots* remain essentially stationary but when the crust moves over the hot spot, melting can occur resulting in volcanic activity.

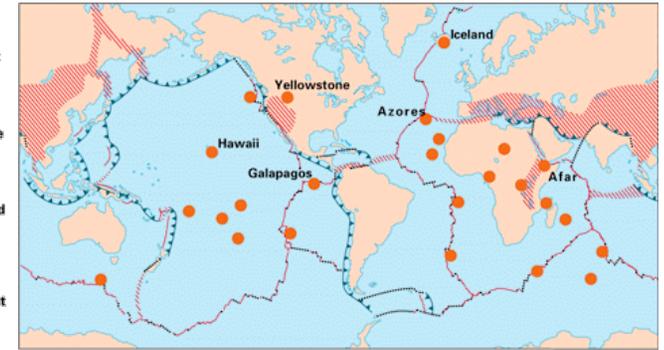


USGS

This figure shows the location of hot spots. Note that hot spots occur beneath oceanic and continental crust — Africa seems to be particularly abundant in hot spot.

Many of these hot spots are easy to identify as lines of seamounts and volcanoes on the map of the seafloor.

- EXPLANATION**
- Divergent plate boundaries— Where new crust is generated as the plates pull away from each other.
  - Convergent plate boundaries— Where crust is consumed in the Earth's interior as one plate dives under another.
  - Transform plate boundaries— Where crust is neither produced nor destroyed as plates slide horizontally past each other.
  - Plate boundary zones—Broad belts in which deformation is diffuse and boundaries are not well defined.
  - Selected prominent hotspots



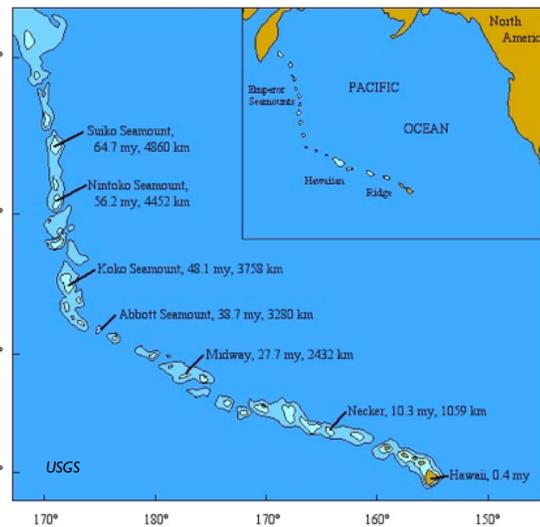
USGS

This figure shows the Hawaiian Islands and seamount chain and the Emperor seamount chain.

In addition, the age of each is listed.

Kilauea is currently erupting and is located directly over the hot spot. However, the further the island or seamount is from the hot spot, the older the age.

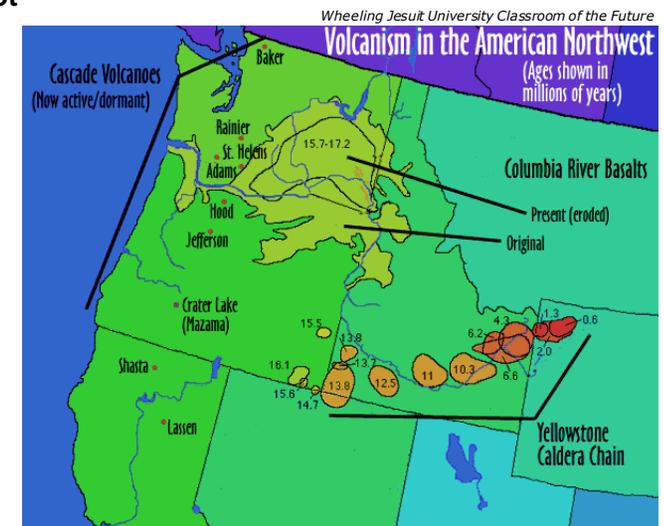
A new Hawaiian island/seamount, Loihi, is starting to form off the southeast coast of the Big Island.



These data are also excellent evidence in support of the theory of plate tectonics.

## Yellowstone Hotspot

As North America drifted southwest over the Yellowstone hotspot, the volcanism progressed northeast, beginning in northern Nevada 16.5 million years ago and reaching Yellowstone National Park 2 million years ago.

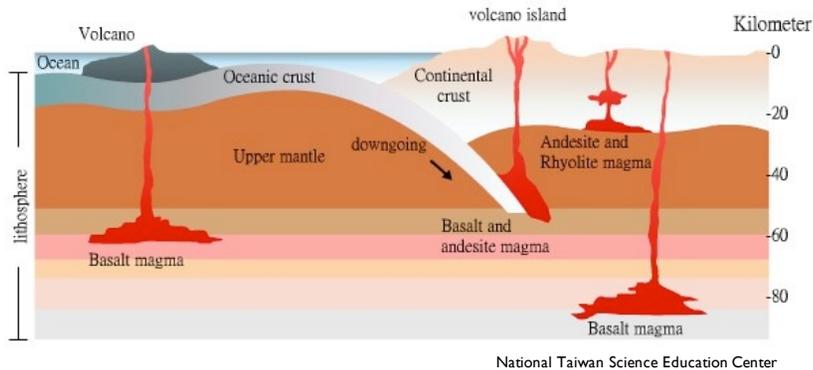


A series of ancient caldera complexes have been recognized on the Snake River Plain - a flood basalt region.

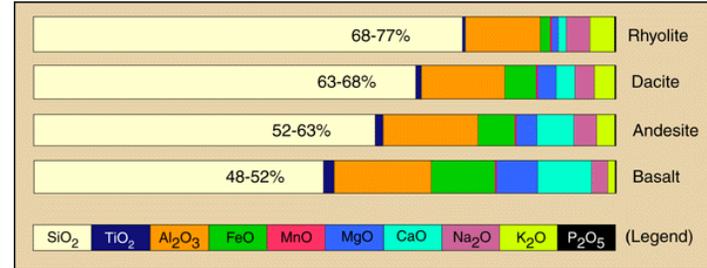
## IV Magma and Lava

Generally, magma formation begins in the upper mantle by a variety of different processes. Partial melting of the rocks of the upper mantle produce basalt (basalt is the most abundant rock on the Earth's surface – seafloor).

Melting in the lower crust is generally associated with uprising magma from the mantle. Magma may change its composition as it ascends through the crust by a variety of processes.



## Composition of Igneous Rocks



A survey of igneous rocks indicates that there are many different types with different chemical compositions. Generally, the composition of igneous rocks can be categorized by the SiO<sub>2</sub> content.

- **Felsic** composition rocks are rich in SiO<sub>2</sub> and other elements (K and Na). They are generally poor in Fe, Mg, and Ca.
- **Mafic** composition rocks are poor in SiO<sub>2</sub> and rich in Fe, Mg, and Ca.
- **Intermediate** compositions are 'intermediate' in composition between felsic and mafic.
- **Ultramafic** compositions are the lowest in SiO<sub>2</sub> and the richest in Fe, Mg, and Ca. Ultramafic magmas/lavas occurred in the distant past but do not occur today.

## Viscosity

The *viscosity* of lava is important because it affects how it behaves and is directly related to the violence of a volcanic eruption.

The *viscosity* of a fluid is its resistance to flow:

- low *viscosity* fluids are very fluid and mobile
- high *viscosity* fluids are very thick and sticky

Low viscosity lavas such as basalt can flow very easy over the surface of the earth and may form lava rivers and fountains.

High viscosity lavas such as andesite and rhyolite don't flow easily and usually form crumbly rocky lava flows that look like rock piles moving downhill. The viscous magma/lava can trap volcanic gases and commonly result in explosive eruptions. As an initially low viscosity basalt lava flow cools, it can also become very viscous.

Low viscosity basalt lava (Hawaii) and high viscosity andesite lava (Mount St. Helens).



## Factors Affecting Viscosity

1. **Temperature.** As the temperature decreases, the viscosity increases. Intermediate and felsic magmas/lavas are lower temperature than basalt. Lower temperature magmas are generally more explosive. The transition from low viscosity *pahoehoe* lava (basalt) to high viscosity *aa* lava (basalt) is do the cooling of the lava flow.

Basalt magma 1000-1200°C  
Andesite magma 800-1000°C  
Rhyolite magma 650-800°C

2. **Magma Composition.** Magmas that are richer in silica or quartz (SiO<sub>2</sub>) are generally more viscous and therefore more explosive. Temperature and composition are not really independent of one another.

3. **Degree of Crystallization.** A magma with significant crystallization of minerals is generally more viscous than a magma that is 100% molten.

The degree of crystallization is not independent of temperature and composition.



## Importance of Dissolved Gases

At depth in the Earth nearly all magmas contain dissolved gas. The gases in magma are mostly water vapor and CO<sub>2</sub>.

The amount of gas in a magma is also related to the chemical composition of the magma. Felsic magmas generally have higher gas contents than mafic magmas.

As the magma nears the surface, gases come out of solution and their volume may increase hundreds of times the original volume. This is similar to opening a bottle of pop.

Magmas contain 1 - 6 weight% gas.

The gas content strongly affects the mode of eruption — when the pressure is released during an eruption, the gases begin to escape and expand.

**Pyroclastic** material (ash, dust, bombs) are produced by the violent eruption of gas-laden viscous magmas.



## V Types of Lava Flows

The image shows a typical fountaining eruption at Kilauea in Hawaii.

The style of eruption (explosive or more fluid) depends on a number of factors including lava composition and volatile content.

Basaltic (mafic) lava flows are generally very fluid.



[USGS](#)

Generally, the *viscosity* of lava increases and the lava flow changes its character as it cools and degasses.

When basaltic lava first erupts, it is very fluid and flows like a *viscous* fluid.

This type of lava flow is known as **pahoehoe** and has a smooth to ropey surface.



[USGS](#)

The video shows a typical **aa** flow in Hawaii.

As the lava cools as it flows, its viscosity increases until the flow consists of rough, jagged blocks that push forward. This type of lava flow is known as **aa**.



[USGS](#)

Sometimes lava flows are *submarine* and occur on the ocean floor. The style of eruption is different than the *subaerial* flows.

As lava erupts underwater, it flows in lobate forms that pile on top of each other forming lava *pillows*.



NOAA

The photo on the right shows pillow basalts on the seafloor near Hawaii.



NOBF



AGU

The photo to the left shows pillow lavas that formed in a submarine environment. Pillow lavas are common in California.

The video/animation shows the May 18, 1980 eruption of Mt. St. Helens.

Preceding this major eruption, magma had moved upward into the volcano swelling its flanks. The unstable slopes had visible bulges from the inflation of magma.

When magma moves, it causes small earthquakes (harmonic tremors). In this movie, you can see a landslide (in slow motion) due to an harmonic tremor.

The large landslide resulted in the decompression of the magma inside the volcano and it explosively released its gas. This is similar to opening a shaken bottle of soda pop.

The explosive eruption sent tons of ash and debris into the air and blasted one flank of the mountain.



YouTube

The eruption of a composite volcano can result in the production of a very hot cloud of gas and ash (up to 700°C) that is heavier than air. As it moves out of the volcanic vent, it moves downslope at speeds of up to 80 km/hour.

This is known as an *ash flow* or *pyroclastic flow*.

These types of eruptions can move rapidly up to 10's of km from their source and are utterly devastating.



USGS



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