EENS 1110	Physical Geology
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Volcanoes and Volcanic Eruptions	

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Magmas and Lava

Since volcanic eruptions are caused by ***magma*** (a mixture of liquid rock, crystals, and dissolved gas) expelled onto the Earth's surface, we'll first review the characteristics of magma that we covered previously.

Three basic types of magma:

1. ***Mafic or Basaltic***-- SiO_2 45-55 wt%, high in Fe, Mg, Ca, low in K, Na
2. ***Intermediate or Andesitic***-- SiO_2 55-65 wt%, intermediate. in Fe, Mg, Ca, Na, K
3. ***Felsic or Rhyolitic***-- SiO_2 65-75%, low in Fe, Mg, Ca, high in K, Na.

Gases - At depth in the Earth nearly all magmas contain gas. Gas gives magmas their explosive character, because the gas expands as pressure is reduced.

- Mostly H_2O with some CO_2
- Minor amounts of Sulfur, Cl , and F
- Felsic magmas usually have higher gas contents than mafic magmas.

Temperature of Magmas

- Mafic/Basaltic - 1000-1200^{o}C
- Intermediate/Andesitic - 800-1000^{o}C
- Felsic/Rhyolitic - 650-800^{o}C.

Viscosity of Magmas

Viscosity is the resistance to flow (opposite of fluidity). Depends on composition, temperature, & gas content.

- Higher SiO_2 content magmas have higher viscosity than lower SiO_2 content magmas
- Lower Temperature magmas have higher viscosity than higher temperature magmas.

Thus, basaltic magmas tend to be fairly fluid (low viscosity), but their viscosity is still 10,000 to 100,0000 times more viscous than water. Rhyolitic magmas tend to have even higher viscosity, ranging between 1 million and 100 million times more viscous than water. (Note that solids, even though they appear solid have a viscosity, but it very high, measured as trillions time the viscosity of water). Viscosity is an important property in determining the eruptive behavior of magmas.

Summary Table						
Magma Type	Solidified Volcanic Rock	Solidified Plutonic Rock	Chemical Composition	Temperature	Viscosity	Gas Content
Mafic or Basaltic	Basalt	Gabbro	45-55 SiO_2 %, high in Fe, Mg, Ca, low in K, Na	1000 - 1200 ^oC	Low	Low
Intermediate or Andesitic	Andesite	Diorite	55-65 SiO_2 %, intermediate in Fe, Mg, Ca, Na, K	800 - 1000 ^oC	Intermediate	Intermediate
Felsic or Rhyolitic	Rhyolite	Granite	65-75 SiO_2 %, low in Fe, Mg, Ca, high in K, Na	650 - 800 ^oC	High	High

The Products of Volcanic Eruptions

Lava Flows

When magma reaches the surface of the earth, it is called lava. Since it its a liquid, it flows downhill in response to gravity as a lava flows. Different magma types behave differently as lava flows, depending on their temperature, viscosity, and gas content.

- *Pahoehoe Flows* - Basaltic lava flows with low viscosity start to cool when exposed to the low temperature of the atmosphere. This causes a surface skin to form, although it is still very hot and behaves in a plastic fashion, capable of deformation. Such lava flows that initially have a smooth surface are called pahoehoe flows. Initially the surface skin is smooth, but often inflates with molten lava and expands to form *pahoehoe toes* or rolls to form ropey pahoehoe. (See figure 9.3d in your text). Pahoehoe flows tend to be thin and, because of their low viscosity travel long distances from the vent.

- *A'A' Flows* - Higher viscosity basaltic and andesitic lavas also initially develop a smooth surface skin, but this is quickly broken up by flow of the molten lava within and by gases that continue to escape from the lava. This creates a rough, clinkery surface that is characteristic of an A'A' flow (see figure 9.3e in your text).

- *Lava Tubes* - Once the surface skin becomes solid, the lava can continue to flow beneath the surface in lava tubes. The surface skin insulates the hot liquid lava form further cooling. When the eruption ends, liquid lava often drains leaving an open cave (see figure 9.3 in your text).

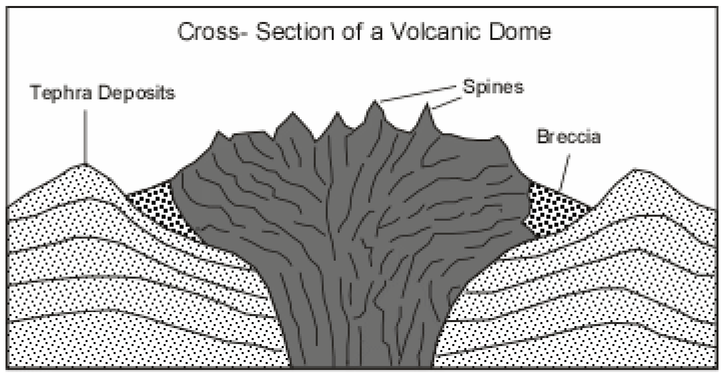
- *Pillow Lavas* - When lava erupts on the sea floor or other body of water, the surface skin forms rapidly, and, like with pahoehoe toes inflates with molten lava. Eventually these inflated balloons of magma drop off and stack up like a pile of pillows and are called pillow lavas. Ancient pillow lavas are readily recognizable because of their shape, their glassy margins and radial fractures that formed during cooling (see figure 9.4b in your text).

- *Columnar Jointing* - When thick basaltic or andesitic lavas cool, they contract. The contraction results in fractures and often times results in a type of jointing called columnar jointing. The columns are usually hexagonal in shape. This often happens when lavas pool in depressions or deep canyons (see figure 9.4a in your text).

- *Siliceous Lava Flows* - High viscosity andesitic and rhyolitic lava flows, because they can't flow very easily, form thick stubby flows that don't move far from the vent.

- *Lava Domes or Volcanic Domes* - result from the extrusion of highly viscous, gas poor andesitic and rhyolitic lava. Since the viscosity is so high, the lava does not flow away from the vent, but instead piles up over the vent. Blocks of nearly solid lava break off the outer surface of the dome and roll down its flanks to form a breccia around the margins of domes.

  The surface of volcanic domes are generally very rough, with numerous spines that have been pushed up by the magma from below.



Pyroclastic Material

If the magma has high gas content and high viscosity, the gas will expand in an explosive fashion and break the liquid into clots that fly through the air and cool along their path through the atmosphere. Alternatively it blast out solid pieces of rock that once formed the volcanic edifice. All of these fragments are referred to as ***Pyroclasts*** = hot, broken fragments. Loose assemblages of pyroclasts called ***tephra***. Depending on size, tephra can be classified as bombs. blocks, lapilli, or ash.

Tephra and Pyroclastic Rocks		
Average Particle Size (mm)	Unconsolidated Material (Tephra)	Pyroclastic Rock
>64	Bombs or Blocks	Agglomerate
2 - 64	Lapilli	Lapilli Tuff
<2	Ash	Ash Tuff

- ***Blocks*** are angular fragments that were solid when ejected.

- ***Bombs*** have an aerodynamic shape indicating they were liquid when ejected.

- Bombs and lapilli that consist mostly of gas bubbles (***vesicles***) result in a low density highly vesicular rock fragment called ***pumice***.

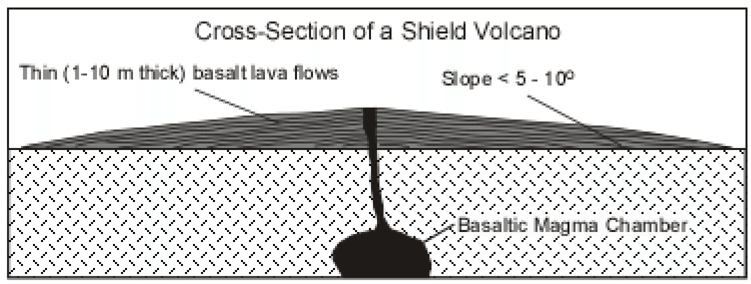
Rock formed by accumulation and cementation of tephra called a ***pyroclastic rock*** or tuff. Welding, compaction and deposition of other grains cause tephra (loose material) to be converted into pyroclastic rock.

Volcanic Landforms

Volcanic landforms are controlled by the geological processes that form them and act on them after they have formed. Thus, a given volcanic landform will be characteristic of the types of material it is made of, which in turn depends on the prior eruptive behavior of the volcano. Here we discuss the major volcanic landforms and how they are formed Most of this material will be discussed with reference to slides shown in class that illustrate the essential features of each volcanic landform.

Shield Volcanoes

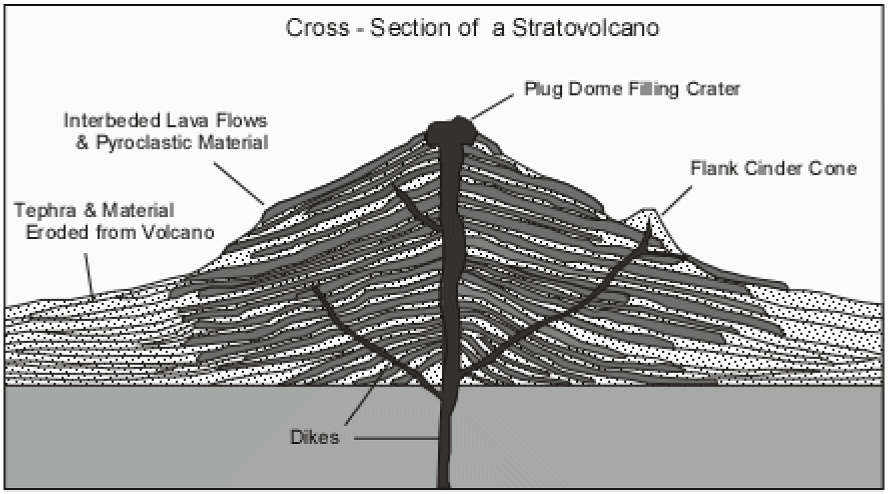
- A shield volcano is characterized by gentle upper slopes (about 5^{o}) and somewhat steeper lower slopes (about 10^{o}).



- Shield volcanoes are composed almost entirely of relatively thin lava flows built up over a central vent.
- Most shields were formed by low viscosity basaltic magma that flows easily down slope away from the summit vent.
- The low viscosity of the magma allows the lava to travel down slope on a gentle slope, but as it cools and its viscosity increases, its thickness builds up on the lower slopes giving a somewhat steeper lower slope.
- Most shield volcanoes have a roughly circular or oval shape in map view.
- Very little pyroclastic material is found within a shield volcano, except near the eruptive vents, where small amounts of pyroclastic material accumulate as a result of fire fountaining events.

Stratovolcanoes (also called **Composite Volcanoes**)

- Have steeper slopes than shield volcanoes, with slopes of 6 to 10^{o} low on the flanks to 30^{o} near the top.
- The steep slope near the summit is due partly to thick, short viscous lava flows that do not travel far down slope from the vent.



- The gentler slopes near the base are due to accumulations of material eroded from the volcano and to the accumulation of pyroclastic material.

- Stratovolcanoes show inter-layering of lava flows and pyroclastic material, which is why they are sometimes called composite volcanoes. Pyroclastic material can make up over 50% of the volume of a stratovolcano.

- Lavas and pyroclastics are usually andesitic to rhyolitic in composition.

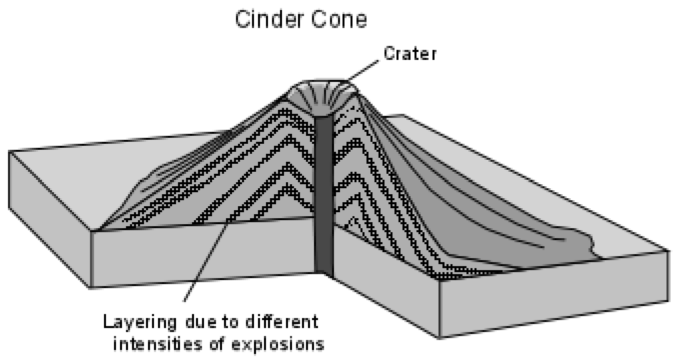
- Due to the higher viscosity of magmas erupted from these volcanoes, they are usually more explosive than shield volcanoes.

- Stratovolcanoes sometimes have a crater at the summit that is formed by explosive ejection of material from a central vent. Sometimes the craters have been filled in by lava flows or lava domes, sometimes they are filled with glacial ice, and less commonly they are filled with water.
- Long periods of repose (times of inactivity) lasting for hundreds to thousands of years, make this type of volcano particularly dangerous, since many times they have shown no historic activity, and people are reluctant to heed warnings about possible eruptions.

Cinder Cones

- Cinder cones are small volume cones consisting predominantly of ash and scoria that result from mildly explosive eruptions. They usually consist of basaltic to andesitic material.
- They are actually fall deposits that are built surrounding the eruptive vent.
- Slopes of the cones are controlled by the angle of repose (angle of stable slope for loose unconsolidated material) and are usually between about 25 and 35^{o}.

- They show an internal layered structure due to varying intensities of the explosions that deposit different sizes of pyroclastics.

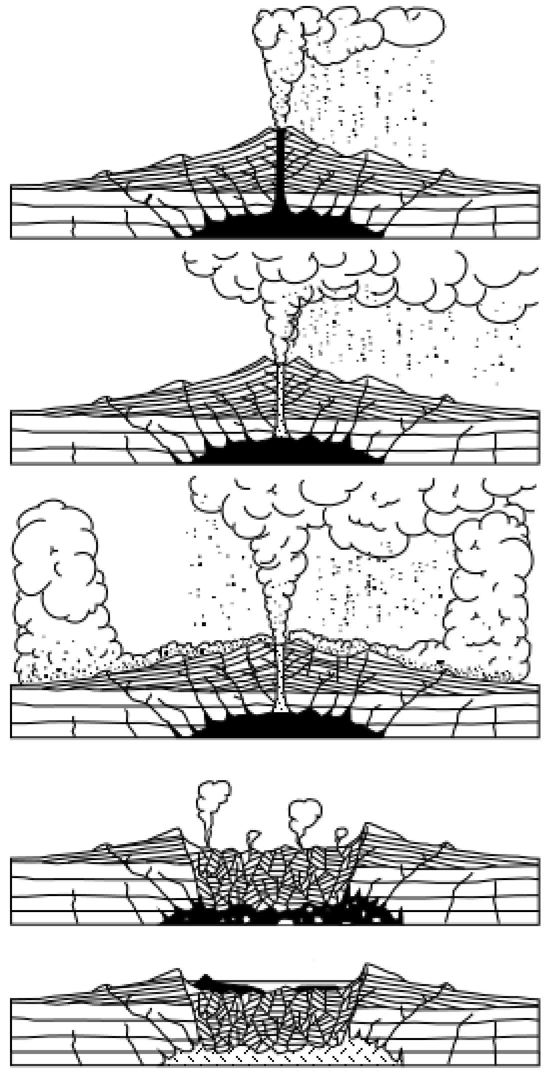


- On young cones, a depression at the top of the cone, called a crater, is evident, and represents the area above the vent from which material was explosively ejected. Craters are usually eroded away on older cones.
- If lava flows are emitted from tephra cones, they are usually emitted from vents on the flank or near the base of the cone during the later stages of eruption.
- Cinder and tephra cones usually occur around summit vents and flank vents of stratovolcanoes.
- An excellent example of cinder cone is Parícutin Volcano in Mexico. This volcano was born in a farmers corn field in 1943 and erupted for the next 9 years. Lava flows erupted from the base of the cone eventually covered two towns.

Craters and Calderas

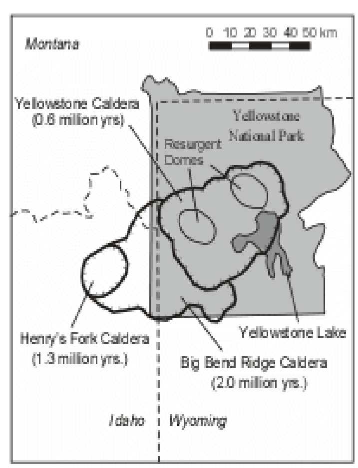
- Craters are circular depressions, usually less than 1 km in diameter, that form as a result of explosions that emit gases and ash.
- Calderas are much larger depressions, circular to elliptical in shape, with diameters ranging from 1 km to 50 km. Calderas form as a result of collapse of a volcanic structure. The collapse results from evacuation of the underlying magma chamber.
- Crater Lake Caldera in southern Oregon is an 8 km diameter caldera containing a lake The caldera formed about 6800 years ago as a result of the eruption of about 75 km^3 of rhyolite magma in the form of tephra, found as far away as Canada, accompanied by pyroclastic flows that left thick deposits of tuff on the flanks of the volcano. Subsequent eruptions have built a cinder cone on the floor of the caldera, which now forms an island called Wizard Island.

- In stratovolcanoes the collapse and formation of a caldera results from rapid evacuation of the underlying magma chamber by voluminous explosive eruptions that form extensive fall deposits and pyroclastic flows.
- On shield volcanoes, like in Hawaii, the evacuation of the magma chamber is a slow drawn out processes, wherein magma is withdrawn to erupt on from the rift zones on the flanks.
- Larger calderas have formed within the past million years in the western United States. These include Yellowstone Caldera in Wyoming, Long Valley Caldera in eastern California, and Valles Caldera in New Mexico.



After H. Williams, 1951

- The Yellowstone caldera is an important example, as it illustrates the amount of repose time that might be expected from large rhyolitic systems, and the devastating effect caldera forming eruptions can have on widespread areas.
  - Yellowstone Caldera which occupies most of Yellowstone National Park, is actually the third caldera to form in the area within the past 2 million years. The three calderas formed at 2.0 million years ago, 1.3 million years ago, and the latest at 600,000 years ago. Thus the repose time is on the average about 650,000 years.



  - Tephra fall deposits from the latest eruption are found in Louisiana and into the Gulf of Mexico, and covered much of the Western part of the United States.

- The eruption 600,000 years ago produced about 1000 km^3 of rhyolite (in comparison, the eruption of Mt. St. Helens in May of 1980 produced only 0.75 km^3.
- Magma still underlies Yellowstone caldera, as evidenced by the large number of hot springs and geysers in the area.

Volcanic Eruptions

In general, magmas that are generated deep within the Earth begin to rise because they are less dense than the surrounding solid rocks. As they rise they may encounter a depth or pressure where the dissolved gas no longer can be held in solution in the magma, and the gas begins to form a separate phase (i.e. it makes bubbles just like in a bottle of carbonated beverage when the pressure is reduced).

When a gas bubble forms, it will also continue to grow in size as pressure is reduced and more of the gas comes out of solution. In other words, the gas bubbles begin to expand. If the liquid part of the magma has a low viscosity, then the gas can expand relatively easily. When the magma reaches the Earth's surface, the gas bubble will simply burst, the gas will easily expand to atmospheric pressure, and a effusive or non-explosive eruption will occur, usually as a lava flow

If the liquid part of the magma has a high viscosity, then the gas will not be able to expand very easily, and thus, pressure will build up inside of the gas bubble(s). When this magma reaches the surface, the gas bubbles will have a high pressure inside, which will cause them to burst explosively on reaching atmospheric pressure. This will cause an explosive volcanic eruption and the production of pyroclastic material.

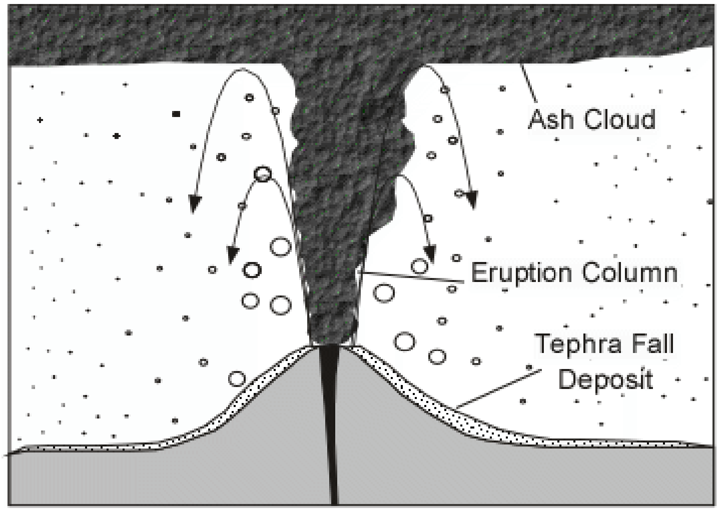
Effusive Eruptions

Effusive or Non explosive eruptions are favored by low gas content and low viscosity magmas (basaltic to andesitic magmas).

- If the viscosity is low, non-explosive eruptions usually begin with fire fountains due to release of dissolved gases.
- Lava flows are produced on the surface, and these run like liquids down slope, along the lowest areas they can find.
- If the magma emerges along a fracture, it results in a fissure eruption, often called a "curtain of fire"
- Lava flows produced by eruptions under water are called ***pillow lavas***.
- If the viscosity is high, but the gas content is low, then the lava will pile up over the vent to produce a ***lava dome*** or ***volcanic dome.***

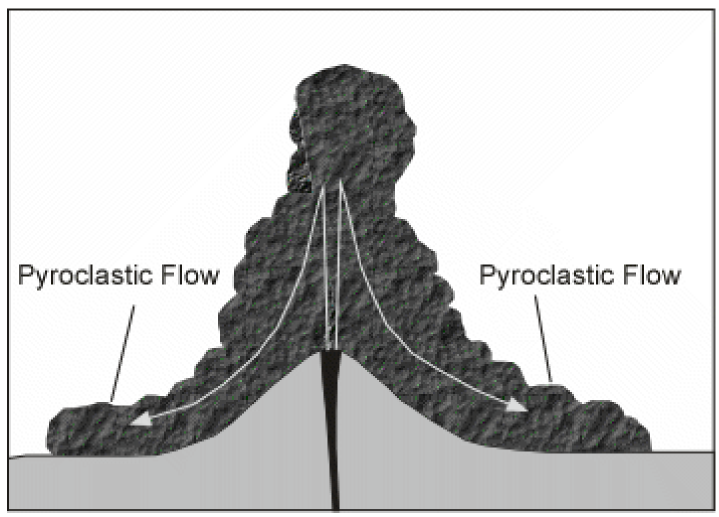
Explosive Eruptions

Explosive eruptions are favored by high gas content & high viscosity magmas (andesitic to rhyolitic magmas). The explosive bursting of bubbles fragments the magma into clots of liquid that cool as they fall through the air. These solid particles become pyroclasts or volcanic ash.



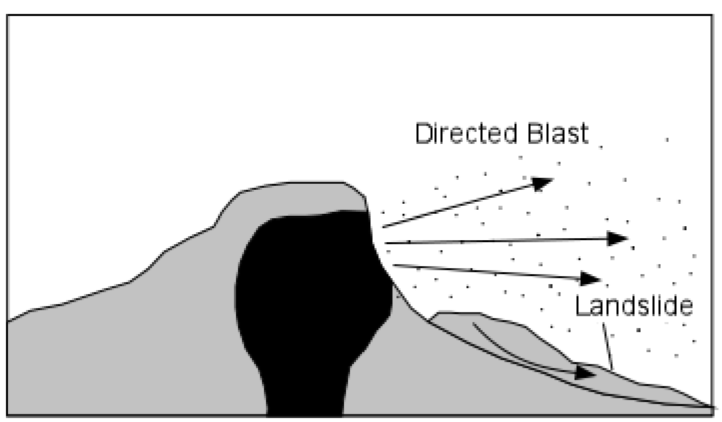
Clouds of gas and tephra that rise above a volcano produce an ***eruption column*** that can rise up to 45 km into the atmosphere. Eventually the tephra in the eruption column will be picked up by the wind, carried for some distance, and then fall back to the surface as a ***tephra fall*** or ***ash fall***. This type of eruption is called a ***Plinian eruption***.

If the pressure in the bubbles is low, the eruption will produce an eruption column only a few hundred meters high, and most of the pyroclastic material will fall to close to the vent to build a cinder cone. This type of eruption is called a ***Strombolian eruption***, and is considered mildly explosive.



If the eruption column collapses a ***pyroclastic flow*** will occur, wherein gas and tephra rush down the flanks of the volcano at high speed. This is the most dangerous type of volcanic eruption. The deposits that are produced are called ***ignimbrites*** if they contain pumice or ***pyroclastic flow deposits*** if they contain non-vesicular blocks.

A Plinian eruption and pyroclastic flow from Vesuvius volcano killed about 20,000 people in Pompeii in 79 CE.



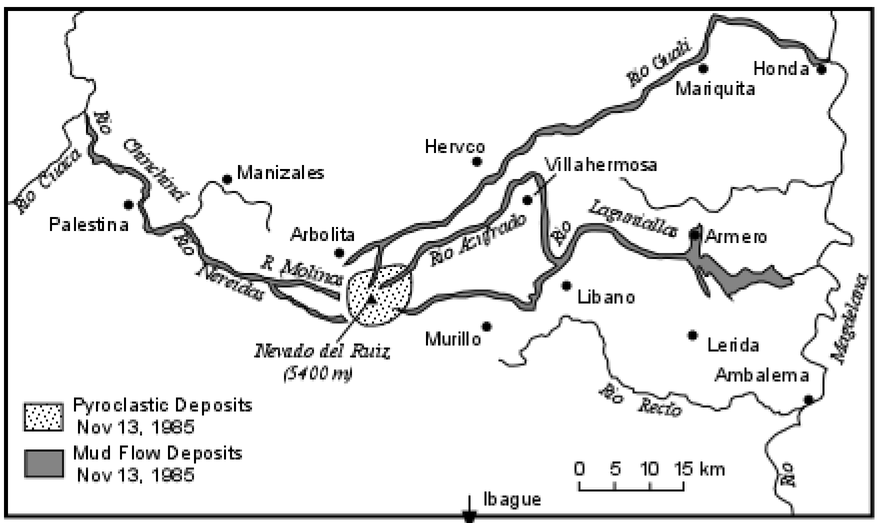
If the gas pressure inside the magma is directed outward instead of upward, a ***lateral blast*** can occur. When this occurs on the flanks of a lava dome, a pyroclastic flows called a ***glowing avalanche*** or ***nuée ardentes*** (in French) can also result. Directed blasts often result from sudden exposure of the magma by a landslide or collapse of a lava dome.

This happened at Mt. Pelée Volcano in Martinique in 1902 and killed about 30,000 people.

Lahars (Volcanic Mudflows)

A volcanic eruption usually leaves lots of loose unconsolidated fragmental debris. When this loose material mixes with water from rainfall, melting of snow or ice, or draining of a crater lake, a mudflow results. Volcanic mudflows are called ***lahars***. These can occur accompanying an eruption or occur long after an eruption. Lahars may be hot or cold and move at high velocity as they fill stream valleys that drain the volcano. At the base of the volcano, they spread out and cover wide areas. In general, they dev estate anything in their path, carrying away homes, buildings, bridges, and destroying roads, and killing livestock and people.

In 1985 a lahar produced by a mild eruption of Nevado de Ruiz volcano in Colombia wiped out the village of Armero, about 60 km away from the volcano and killed about 23,000 people.



After Francis, 1993

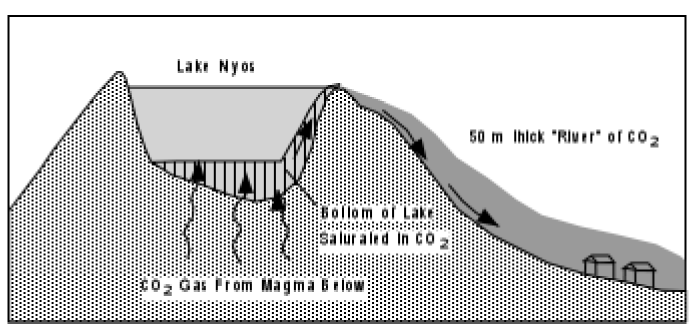
It is important to understand that lahars can occur accompanying an eruption, or can occur simply as the result of heavy rainfall or sudden snow melt, without an eruption.

Volcanic Gases

Although the predominant gas erupted from volcanoes is H_2O vapor, other gases are erupted can have disastrous effects on life. Poisonous gases like Hydrogen Chloride (HCl), Hydrogen Sulfide (H_2S), SO_2, Hydrogen Fluoride (HF), and Carbon Dioxide (CO_2). The Chlorine, Sulfur. and Fluorine gases can kill organisms by direct ingestion, or by absorption onto plants followed by ingestion by organisms.

In 1986 an CO_2 gas emission from Lake Nyos in Cameroon killed more than 1700 people and 3000 cattle.

The gases can also have an effect on the atmosphere and climate. Much of the water on the surface of the earth was produced by volcanoes throughout earth history.



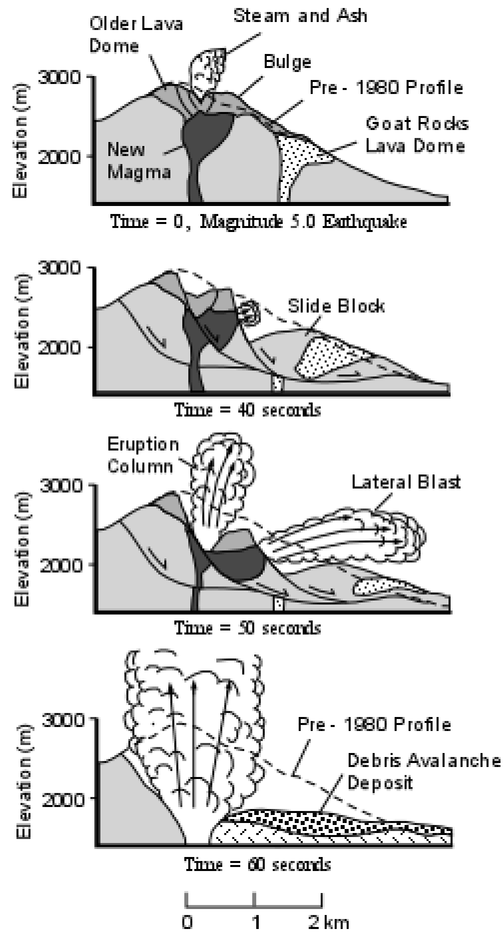
After Abbott, 1996

Sulfur gases in the atmosphere, along with volcanic ash, reflect incoming solar radiation back into space and have a cooling effect on the atmosphere, thus lowering average global temperatures. The effect lasts only as long as the gases and ash remain in the atmosphere, normally a few years at the most. CO_2 gas, produces the opposite effect. It is a greenhouse gas which absorbs solar radiation and causes a warming effect. Eruptions in the past that produced huge quantities of this gas may have been responsible for mass extinction events

The Eruption of Mount. St. Helens, 1980

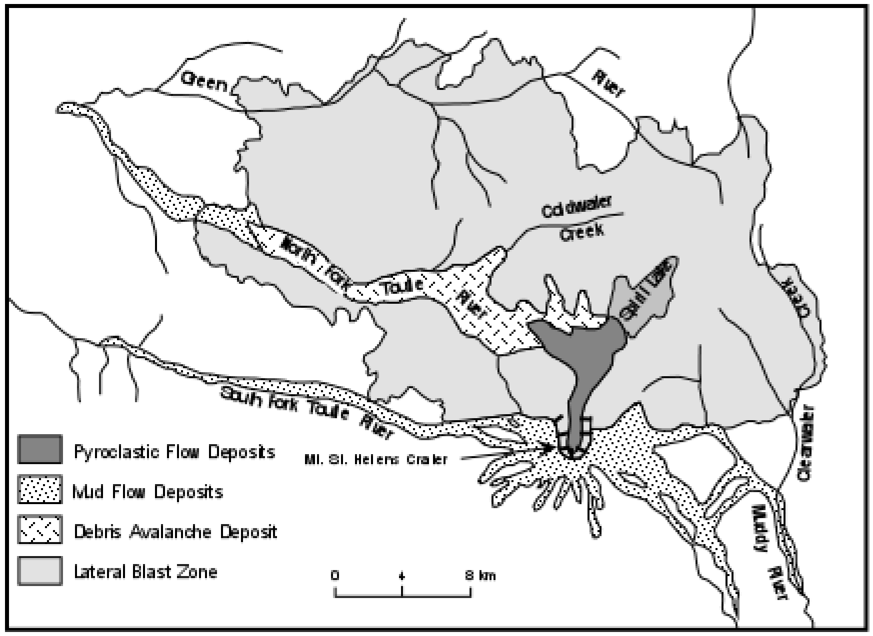
Prior to 1980, Mount St. Helens last erupted in 1857. On March 21, 1980 a 4.2 earthquake occurred beneath the volcano signaling the beginning of an eruption. Small eruptions took place through mid April and the summit of the mountain developed a new crater due to the explosions. By the end of April surveys showed that the north face of the mountain had begun to bulge upwards and outwards at rates up to 1 m per day. By May 12, the bulge had displaced parts of the northern part of the volcano a distance of about 150 m. Geologists now recognized that this bulge could soon develop into a landslide.

At 8:32 AM on May 18, 1980 a magnitude 5.0 earthquake occurred beneath Mt. St. Helens. This led to a violent eruption that took place over about the next minute. The earthquake triggered a large landslide that began to slide out to the north, initially as three large blocks.



As the first block, began to slide downward, the magma chamber beneath the volcano became exposed to atmospheric pressure. The gas inside the magma expanded rapidly, producing a lateral blast that moved outward toward the north. As the second slide block began to move downwards a vertical eruption column began to form above the volcano. The lateral blast rapidly overtook the slide block and roared through an area to the north of the mountain, knocking down all trees in its path and suffocating all living things, Within the next 10 seconds the third slide block moved out toward the north. The landslide thus became a debris avalanche and left a deposit extending about 20 km down the valley (see map below). The southern shores of Spirit Lake were displaced about 1 km northward and the level of the lake was raised about 40 m.

Within about the first minute of the eruption the summit of Mount St. Helens had been reduced by about 500 m. The magma however continued to erupt in a Plinian eruption column that reached up to 26 km into the atmosphere.



After Tilling, 1984

The eruption column collapsed several times to produce pyroclastic flows that moved into Spirit Lake and the upper reaches of the Toutle River Valley. This Plinian phase lasted about 9 hours and spread tephra in a plume to the east, darkening the area at midday to make it appear like night.

In all, 62 people lost their lives, either by being buried by the debris avalanche deposit, or suffocating by breathing the hot gases and dust of the blast.

Over the next several days melted snow combined with the new ash to produce lahars that roared down the North and South Forks of the Toutle River and drainages to the south of the volcano.

In general, the eruption had been much larger than most anticipated, but the fact that a hazards study had been carried out, that public officials were quick to act and evacuate the danger zone, and that the volcano was under constant monitoring, resulted in the minimization of loss of life to only 62 instead of a much larger number that could have been killed had not these efforts been in place.

Since the 1980 eruption, several volcanic domes have been emplaced in the crater and some have been blasted out. In the future, it is expected that new domes will continue to form, eventually building the volcano back to a form that will look more like it did prior to the 1980 eruption.

Predicting Volcanic Eruptions

Before discussing how we can predict volcanic eruptions, its important to get some terminology straight by defining some commonly used terms.

***Active Volcano* -** An active volcano to volcanologists is a volcano that has shown eruptive activity within recorded history. Thus an active volcano need not be in eruption to be considered active.

- Currently there are about 600 volcanoes on Earth considered to be active volcanoes.
- Each year 50 to 60 of volcanoes actually erupt.

Extinct Volcano **-** An extinct volcano is a volcano that has not shown any historic activity, is usually deeply eroded, and shows no signs of recent activity. How old must a volcano be to be considered extinct depends to a large degree on past activity.

Dormant Volcano **-** A dormant volcano (sleeping volcano) is somewhere between active and extinct. A dormant volcano is one that has not shown eruptive activity within recorded history, but shows geologic evidence of activity within the geologic recent past. Because the lifetime of a volcano may be on the order of a million years, dormant volcanoes can become active volcanoes all of sudden. These are perhaps the most dangerous volcanoes because people living in the vicinity of a dormant volcano may not understand the concept of geologic time, and there is no written record of activity. These people are sometimes difficult to convince when a dormant volcano shows signs of renewed activity.

Long - Term Forecasting and Volcanic Hazards Studies

- Studies of the geologic history of a volcano are generally necessary to make an assessment of the types of hazards posed by the volcano and the frequency at which these types of hazards have occurred in the past. The best way to determine the future behavior of a volcano is by studying its past behavior as revealed in the deposits produced by ancient eruptions. Because volcanoes have such long lifetimes relative to human recorded history, geologic studies are absolutely essential.

- Once this information is available, geologists can then make forecasts concerning what areas surrounding a volcano would be subject to the various kinds of activity should they occur in a future eruption, and also make forecasts about the long - term likelihood or probability of a volcanic eruption in the area.

- During such studies, geologists examine sequences of layered deposits and lava flows. Armed with knowledge about the characteristics of deposits left by various types of eruptions, the past behavior of a volcano can be determined.

- Using radiometric age dating of the deposits the past frequency of events can be determined.

- This information is then combined with knowledge about the present surface aspects of the volcano to make volcanic hazards maps which can aid other scientists, public officials, and the public at large to plan for evacuations, rescue and recovery in the event that short-term prediction suggests another eruption.
- Such hazards maps delineate zones of danger expected from the hazards discussed above: lava flows, pyroclastic flows, tephra falls, lahars, floods, etc.

Short - Term Prediction based on Volcanic Monitoring

Short - term prediction of volcanic eruptions involves monitoring the volcano to determine when magma is approaching the surface and monitoring for precursor events that often signal a forthcoming eruption.

- **Earthquakes** - As magma moves toward the surface it usually deforms and fractures rock to generate earthquakes. Thus an increase in earthquake activity immediately below the volcano is usually a sign that an eruption will occur.

- **Ground Deformation -** As magma moves into a volcano, the structure may inflate. This will cause deformation of the ground which can be monitored. Instruments like tilt meters measure changes in the angle of the Earth's surface. Other instruments track changes in distance between several points on the ground to monitor deformation.

- **Changes in Heat Flow -** Heat is everywhere flowing out of the surface of the Earth. As magma approaches the surface or as the temperature of groundwater increases, the amount of surface heat flow will increase. Although these changes may be small they be measured using infrared remote sensing.
- **Changes in Gas Compositions -** The composition of gases emitted from volcanic vents and fumaroles often changes just prior to an eruption. In general, increases in the proportions of hydrogen chloride (HCl) and sulfur dioxide (SO_2) are seen to increase relative to the proportion of water vapor.

In general, no single event can be used to predict a volcanic eruption, and thus many events are usually monitored so that taken in total, an eruption can often be predicted. Still, each volcano behaves somewhat differently, and until patterns are recognized for an individual volcano, predictions vary in their reliability. Furthermore, sometimes a volcano can erupt with no precursor events at all.

Volcanic Hazards

The main types of volcanic hazards have been discussed above, so here we only briefly discuss them. You should make sure you understand what each of these are, and what effects each type of hazard can have. We will not likely have time to discuss these again in detail, so the following material is mostly for review.

Primary Effects of Volcanism

- **Lava Flows** - lava flows are common in Hawaiian and Strombolian type of eruptions, the least explosive. Although they have been known to travel as fast as 64 km/hr, most are slower and give people time to move out of the way. Thus, in general, lava flows are most damaging to property, as they can destroy anything in their path.
- **Pyroclastic Flows** - Pyroclastic flows are one of the most dangerous aspects of volcanism. They cause death by suffocation and burning. They can travel so rapidly that few humans can escape.

- **Ash falls** - Although tephra falls blanket an area like snow, they are far more destructive because tephra deposits have a density more than twice that of snow and tephra deposits do not melt like snow an cause the collapse of roof. They and can affect areas far from the eruption. Tephra falls destroy vegetation, including crops, and can kill livestock that eat the ash covered vegetation. Tephra falls can cause loss of agricultural activity for years after an eruption.
- **Poisonous Gas Emissions** , as discussed above.

Secondary and Tertiary Effects of Volcanism

- Mudflows (Lahars) As discussed above, mudflows can both accompany an eruption and occur many years after an eruption. They are formed when water and loose ash deposits come together and begin to flow. The source of water can be derived by melting of snow or ice during the eruption, emptying of crater lakes during an eruption, or rainfall that takes place any time with no eruption.

- **Debris Avalanches, Landslides, and Debris Flows** - Volcanic mountains tend to become oversteepened as a result of the addition of new material over time as well due to inflation of the mountain as magma intrudes. Oversteepened slopes may become unstable, leading to a sudden slope failure that results in landslides, debris flows or debris avalanches. Debris avalanches, landslides, and debris flows do not necessarily occur accompanied by a volcanic eruption. There are documented cases of such occurrences where no new magma has been erupted.

- **Flooding** - Drainage systems can become blocked by deposition of pyroclastic flows and lava flows. Such blockage may create a temporary dam that could eventually fill with water and fail resulting in floods downstream from the natural dam. Volcanoes in cold climates can melt snow and glacial ice, rapidly releasing water into the drainage system and possibly causing floods. Jokaulhlaups occur when heating of a glacier results in rapid outburst of water from the melting glacier.
- **Tsunami** - Debris avalanche events, landslides, caldera collapse events, and pyroclastic flows entering a body of water may generate tsunami. During the 1883 eruption of Krakatau volcano, in the straits of Sunda between Java and Sumatra, several tsunami were generated by pyroclastic flows entering the sea and by collapse accompanying caldera formation. The tsunami killed about 36,400 people, some as far away from the volcano as 200 km.

- **Volcanic Earthquakes** - Earthquakes usually precede and accompany volcanic eruptions, as magma intrudes and moves within the volcano. Although most volcanic earthquakes are small, some are large enough to cause damage in the area immediately surrounding the volcano, and some are large enough to trigger landslides and debris avalanches, such as in the case of Mount St. Helens.

- **Atmospheric Effect**s- Fined grained ash and sulfur gases expelled into the atmosphere reflect solar radiations and cause cooling of the atmosphere. CO_2 released by volcanoes can cause warming of the atmosphere.

Volcanoes and Plate Tectonics

Global Distribution of Volcanoes

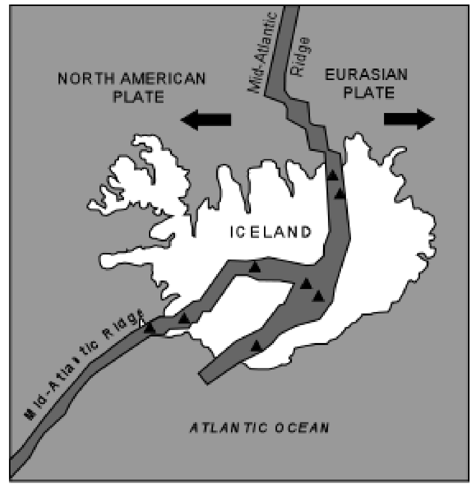
In the discussion we had on igneous rocks and how magmas form, we pointed out that since the upper parts of the Earth are solid, special conditions are necessary to form magmas. These special conditions do not exist everywhere beneath the surface, and thus volcanism does not occur everywhere. If we look at the global distribution of volcanoes we see that volcanism occurs four principal settings.

1. Along divergent plate boundaries, such as Oceanic Ridges or spreading centers.
2. In areas of continental extension (that may become divergent plate boundaries in the future).
3. Along converging plate boundaries where subduction is occurring.

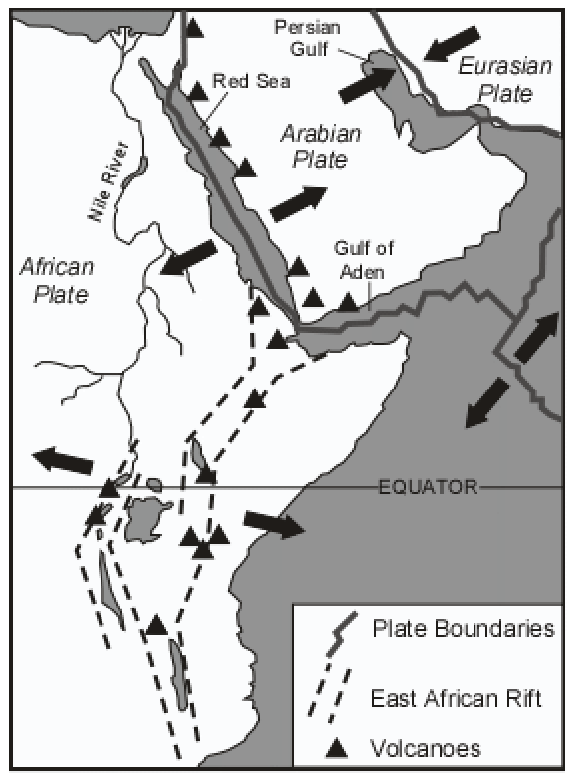
4. And, in areas called "hot spots" that are usually located in the interior of plates, away from the plate margins.

Since we discussed this in the lecture on igneous rocks, we only briefly review this material here.

- **Diverging Plate Margins**



Active volcanism is currently taking place along all of oceanic ridges, but most of this volcanism is submarine volcanism. One place where an oceanic ridge reaches above sea level is at Iceland, along the Mid-Atlantic Ridge. Here, most eruptions are basaltic in nature, but, many are explosive strombolian types or explosive phreatic or phreatomagmatic types. As seen in the map to the right, the Mid-Atlantic ridge runs directly through Iceland

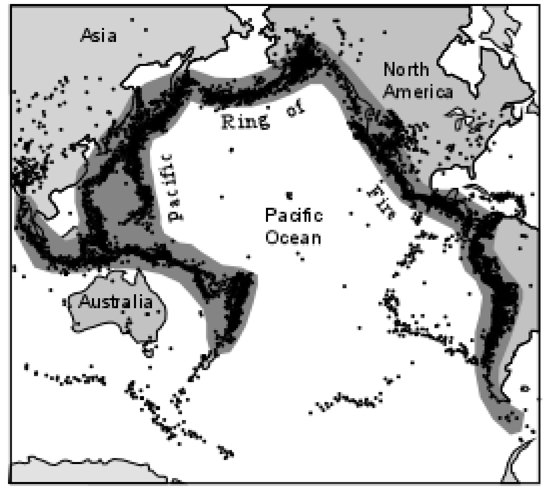


Volcanism also occurs in continental areas that are undergoing episodes of rifting. A classic example is the East African Rift Valley, where the African plate is being split. The extensional deformation occurs because the underlying mantle is rising from below and stretching the overlying continental crust. Upwelling mantle may melt to produce magmas, which then rise to the surface, often along normal faults produced by the extensional deformation. Basaltic and rhyolitic volcanism is common in these areas. In the same area, the crust has rifted apart along the Red Sea, and the Gulf of Aden to form new oceanic ridges. This may also be the fate of the East African Rift Valley at some time in the future.

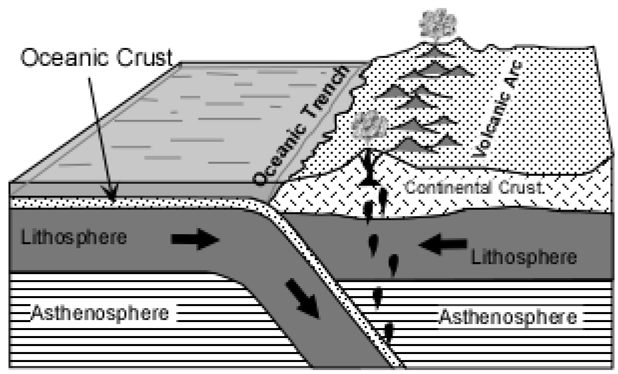
Other areas where extensional deformation is occurring within the crust is Basin and Range Province of the western U.S. (eastern California, Nevada, Utah, Idaho, western Wyoming and Arizona) and the Rio Grande Rift, New Mexico. These are also areas of recent basaltic and rhyolitic volcanism.

- **Converging Plate Margins**

All around the Pacific Ocean, is a zone often referred to as the Pacific Ring of Fire, where most of the world's most active and most dangerous volcanoes occur. The Ring of Fire occurs because most of the margins of the Pacific ocean coincide with converging margins along which subduction is occurring

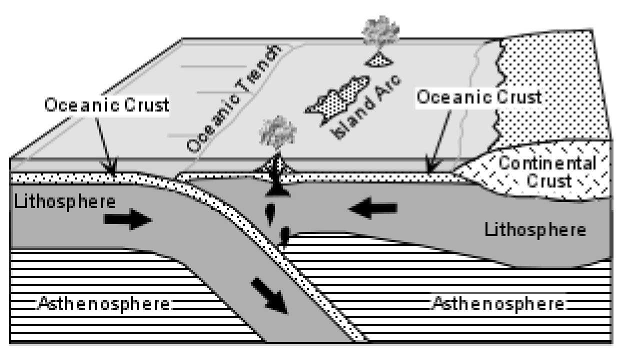


The convergent boundary along the coasts of South America, Central America, Mexico, the northwestern U.S. (Northern California, Oregon, & Washington), western Canada, and eastern Alaska, are boundaries along which oceanic lithosphere is being subducted beneath continental lithosphere. This has resulted in the formation of continental volcanic arcs that form the Andes Mountains, the Central American Volcanic Belt, the Mexican Volcanic Belt, the Cascade Range, and the Alaskan volcanic arc.



Ocean - Continent Convergence

The Aleutian Islands (west of Alaska), the Kurile-Kamchatka Arc, Japan, Philippine Islands, and Marianas Islands, New Zealand, and the Indonesian Islands, along the northern and western margins of the Pacific Ocean are zones where oceanic lithosphere is being subducted beneath oceanic lithosphere. These are all island arcs.



Ocean - Ocean Convergence

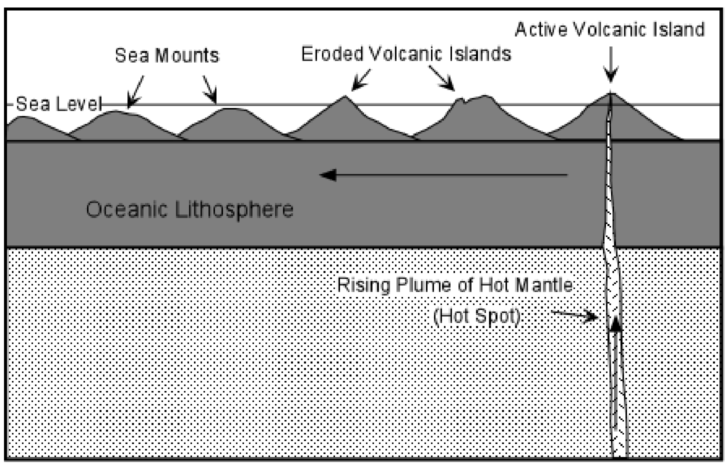
- As discussed previously, the magmas are likely generated by flux melting of the mantle overlying the subduction zone to produce basaltic magmas.
- Through magmatic differentiation, basaltic magmas change to andesitic and rhyolitic magma.

- Because these magmas are often gas rich and have all have relatively high

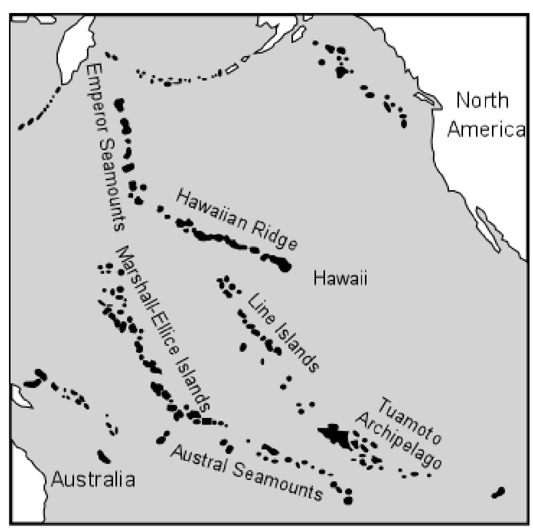
viscosity, eruptions in these areas tend to be violent, with common Strombolian, Plinian and Pelean eruptions.
  - Volcanic landforms tend to be cinder cones, stratovolcanoes, volcanic domes, and calderas.
  - Repose periods between eruptions tend to be hundreds to thousands of years, thus giving people living near these volcanoes a false sense of security.

- **Hot Spots**

  Volcanism also occurs in areas that are not associated with plate boundaries, in the interior of plates. These are most commonly associated with what is called a hot spot. Hot spots appear to result from plumes of hot mantle material upwelling toward the surface, independent of the convection cells though to cause plate motion. Hot spots tend to be fixed in position, with the plates moving over the top. As the rising plume of hot mantle moves upward it begins to melt to produce magmas. These magmas then rise to the surface producing a volcano. But, as the plate carrying the volcano moves away from the position over the hot spot, volcanism ceases and new volcano forms in the position now over the hot spot. This tends to produce chains of volcanoes or seamounts (former volcanic islands that have eroded below sea level).

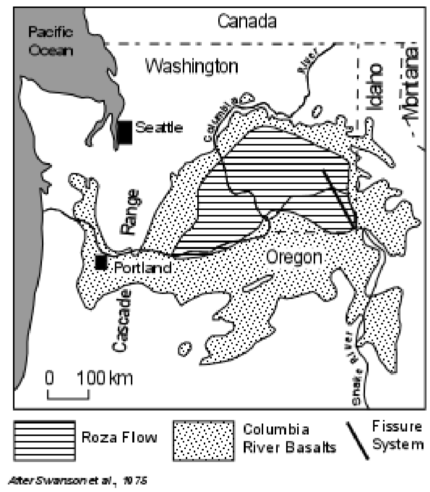


The Hawaiian Ridge is one such hot spot trace. Here the Big Island of Hawaii is currently over the hot spot, the other Hawaiian islands still stand above sea level, but volcanism has ceased. Northwest of the Hawaiian Islands, the volcanoes have eroded and are now seamounts.



Plateau Basalts or **Flood Basalts**

- Plateau or Flood basalts are extremely large volume outpourings of low viscosity basaltic magma from fissure vents. The basalts spread huge areas of relatively low slope and build up plateaus.
- Many of these outpourings appear to have occurred along a zone that eventually developed into a rift valley and later into a diverging plate boundary.
- In Oregon and Washington of the northwestern U.S., the Columbia River Basalts represent a series of lava flows all erupted within about 1 million years 12 million years ago. One of the basalt flows, the Roza flow, was erupted over a period of a few weeks traveled about 300 km and has a volume of about 1500 km^3.



Examples of questions on this material that could be asked on an exam

1. What are the major gases in magma? What are the minor gases in magma? Why is the amount of gas in magma important in relation to volcanic eruptions?
2. What chemical and physical characteristics of magma are most important in whether the magma erupts explosively or non-explosively?
3. Define the following terms (a) viscosity, (b) block, (c) bomb, (d) ash, (e) eruption column, (f) pyroclastic flow, (g) lateral blast
4. Compare and contrast the different types of volcanic eruptions
5. Define the following and state what kind of magma characteristically erupts from each: (a) shield volcano, (b) stratovolcano, (c) cinder cone, (d) lava dome.
6. What is a caldera and how do calderas form?
7. What kind of volcanic landforms would you expect to find in each of the following tectonic settings (a) diverging plate boundary, (b) converging plate boundary, (c) hot spot
8. Give examples of volcanoes that occur at (a) hot spots, (b) diverging plate boundaries, and (c) converging plate boundaries.

9. What are the main volcanic hazards? Which of these have the greatest potential to cause damage at large distances from the volcano?
10. Define an active volcano, a dormant volcano, and an extinct volcano?
11. What is the best indicator of the future behavior of a volcano and how is thus determined?
12. What types of monitoring is necessary for short term prediction of volcanic eruptions?

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