

**GEOSCIENCE
AUSTRALIA**

VOLCANOES

Teacher Notes

Gary B. Lewis

Original Notes and activities

&

Christine V. McLelland

US Content

Record No.GA 1995/24

US Edition 2003 developed in partnership with



**THE GEOLOGICAL SOCIETY
OF AMERICA**

GEOSCIENCE AUSTRALIA

Chief Executive Officer: Dr Neil Williams

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AGSO Record No. 1995/24

ISSN: 1039 – 0073

ISBN: 0 642 22340 8

Developed and Written by: Gary B. Lewis

Scientific Advice: R. W. (Wally) Johnson

Other Education titles in this Series include:

Plate Tectonics – Teacher Notes and Student Activities

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National Science Education Standards

Volcanoes Teacher Notes, Student Activities, and Diagrams meet the following National Science Education Standards:

Content Standard D – Earth and Space Science

Grades 5-8

- Structure of the Earth system
- Earth's history

Grades 9-12

- Energy in the Earth system
- Origin and evolution of the Earth system

Content Standard F – Science in Personal and Social Perspectives

Grades 5-8

- Natural hazards
- Risk and benefits
- Science and technology in society

Grades 9-12

- Natural and human-induced hazards
- Geochemical cycles
- Science and technology in local, national, and global challenges

Volcanoes

Vulcan was the one of three children of the Roman gods, Jupiter and Juno. As well as a number of minor divine attributes, Vulcan was the blacksmith of the gods – the god of fire. It is no wonder that the ancient Romans gave his name to a small island, Vulcano, off the coast of Sicily where at night they saw the lights of his fires and heard the sound of his forge. Today, the term volcano evokes scenes of running molten rocks, huge towering eruption clouds, explosions, ash and destruction.

The study of volcanoes, or volcanology, aims to understand the importance of the Earth's volcanic activity: What does it tell us about the structure of our planet? What risk does it pose to our lives? What economic benefits can we obtain from its power?

This booklet aims to give you the background knowledge to enable you to share some of the wonder of volcanology with your students.

1. Definition

A volcano is a vent or chimney and its surrounding accumulations of volcanic material, which connects a pool of molten rock material (magma) below the Earth's surface with the surface.

Volcanoes are often classified by their recent history of activity as *active*, *dormant* or *extinct*. These terms mean:

Active

An active volcano is any volcano that shows some form of current volcanic activity, such as the eruption of lava, release of gas or seismic activity.

The table below lists a small number of active volcanoes that have caused fatalities over the last millennium.

Dormant

A dormant volcano is any volcano which has not erupted for a long time but which could do so again.

Extinct

An extinct volcano is any volcano that will never erupt again. These volcanoes may now only be the remnants of lava flows or the central volcanic pipe.

Some Active Volcanoes

Volcano	Country	Year	Estimated Casualties
Merapi	Indonesia	1006	1,000
Etna	Italy	1169	15,000
Kelut	Indonesia	1586	10,000
Vesuvius	Italy	1631	18,000
Etna	Italy	1669	10,000
Merapi	Indonesia	1672	300
Unzen	Japan	1792	15,000
Mayon	Philippines	1814	1,200
Tambora	Indonesia	1815	92,000
Krakatau	Indonesia	1883	36,000
Mont Pelee	West Indies	1902	36,000
Kelut	Indonesia	1919	5,000
Lamington	Papua New Guinea	1951	3,000
Merapi	Indonesia	1951	1,300
Agung	Indonesia	1963	3,800

Mt. St Helens	USA	1980	60
Nevado del Ruiz	Columbia	1985	22,000

2. What comes out of a Volcano?

The material erupting from a volcano can be divided into gases, aerosols, liquids and solids.

Gases

By volume, gases are the most abundant volcanic product but make up only a few percent of the total weight of erupted material. It is estimated, for example, that during the eruption of Paricutin in Mexico in 1945, thirteen thousand tons of steam was released every day.

Collecting samples of volcanic gases is obviously a very dangerous business.

Volcanologists have taken samples (some losing their lives in doing so) and found that the average components of volcanic gas are :

Water (steam)	77.0%
Carbon dioxide	11.7%
Nitrogen	3.0%
Carbon monoxide	0.5%
Hydrogen	0.5%
Sulfur dioxide	6.5%
Sulfur	0.3%
Chlorine	0.05%
Argon	0.05%

The amount of carbon dioxide, a major “greenhouse gas”, suggests that volcanic eruptions contribute greatly to the earth’s natural greenhouse effect and that during periods of extensive volcanism, the Earth’s climate may have been significantly altered.

The power of volcanic eruptions is caused, in part, by the expansion of volcanic gases dissolved in the rising magma. As the magma reaches the surface the dissolved gases expand up to 1000 times their volume due to the lower pressures. The release of this great pressure causes volcanic explosions, such as that of Krakatau (Indonesia) in 1883.

Often labelled as the loudest explosion ever heard by humans, the eruption of the volcanic island of Krakatau in 1883 shows the force of expanding gases during an eruption. The main blast of the eruption occurred on August 27, 1883, and the blast was heard over 2,000 km away from the island. The cause of the explosion is thought to have been the rapid expansion of seawater that seeped through a rift in the side of the island and boiled when coming in contact with the molten rock. 36,000 people died as a result of the eruption.

Aerosols

Of all the gases released by volcanic eruptions, sulfur dioxide is particularly important. During an eruption, vast amounts of sulfur dioxide are injected into the atmosphere where, over a period of hours to weeks, it reacts with water to form liquid aerosol particles of sulphuric acid.

Aerosol particles are a natural phenomenon and are normally only a few microns (thousandth of a millimeter) in diameter. Some of these particles have formed around minute ash flecks. The larger aerosol particles may settle out of the atmosphere in a few weeks, but the smaller aerosol particles can remain in the stratosphere for two or three years, long after the ash and pumice of the same eruption have settled onto the Earth’s surface.

Liquids

The liquid rock material escaping from a volcano is called lava. The chemical composition of the lava affects its viscosity, which limits the speed and distance it can flow away from the volcanic vent. This lava property also governs the shape of the volcano. The main chemical constituent affecting the physical properties of lava is the amount of SiO₂ (silica).

Igneous rocks (lava's and their intrusive counterparts) are classified by their silica content. The following table summarizes the classification scheme. In reality the classification scheme is more complex as other chemical constituents influence the mineral content of the rocks.

Silica Content	Extrusive <i>(erupted on surface)</i>	Intrusive <i>(solidified below surface)</i>
45-53%	Basalt	Gabbro
54-62%	Andesite	Diorite
62-70%	Dacite	Granodiorite
70-78%	Rhyolite	Granite

Lavas that are relatively low in silica (45-53%) are the least viscous. They flow quickly and for many kilometers away from the volcanic vent. These are the basaltic lavas – by volume the most abundant lava type found on earth. Lavas which are relatively high in silica content (70-78%) are the most viscous. These lavas flow very slowly and form expanding domes which plug up volcanic vents, bottling up the pressure and trapping the expanding gases. These lavas are classified as rhyolites.

Different volcanoes erupt different types of lava as the molten material comes from a different magma source. However, the same volcano may produce different lava during different eruptions due to *magmatic differentiation*.

Magmatic differentiation refers to the splitting of a “parent” magma into various components – some rich and other poor in silica. This occurs because as minerals precipitate from the magma they sink to the magma chamber floor, leaving the remaining magma with a different chemical composition than the original magma (Figure 1). Also, new parent magma may be injected into a chamber from adjacent molten pools. These changes in the magma chamber can produce different lava types over a period of time.

If no additional magma is added to a chamber, a volcano may initially erupt lava relatively low in silica (basalts) and erupt lavas progressively richer in silica over time until they are rhyolitic in composition.

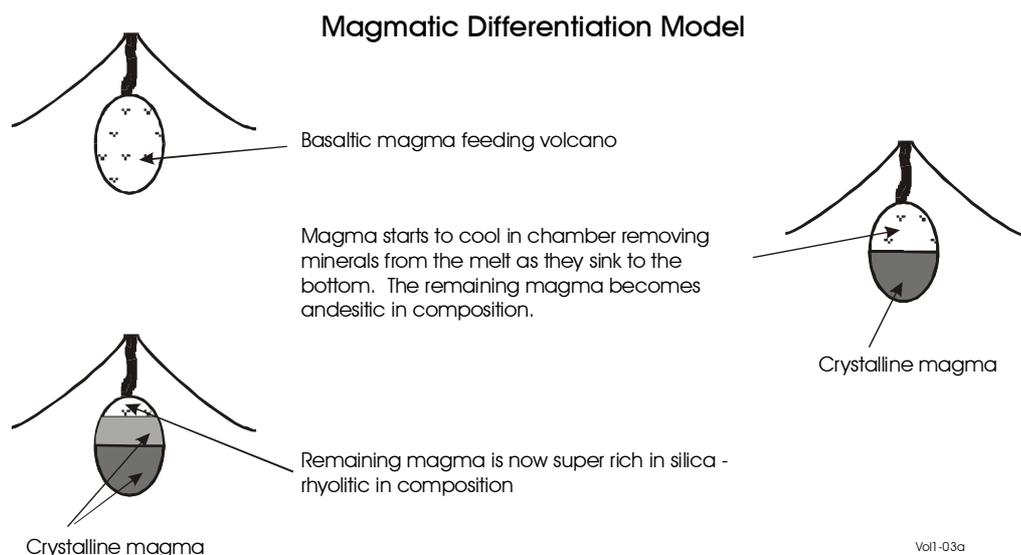


Figure 1. Magmatic Differentiation Model

The heat of lava as it flows from a volcano is hard to measure using standard equipment. Volcanologists use a color scale to work out an approximate heat when recording details about a lava flow. These colors are:

Heat Color	Temperature °C
Incipient red	540
Bright red	870
Yellowish red	1,100
Incipient white	1,260
White	1,480

The texture of cooled lava flows, especially in Hawaii, is often classified into two types – *pahoehoe* and *aa*. The *pahoehoe* type is often called *ropy lava* because of the resemblance to strands of rope. It forms from lava that cools to form a skin while the lava beneath continues to flow. *Aa* lava flows are a mass of angular, jagged blocks. Some lava flows leave the vent as *pahoehoe* and form *aa* further down slope, but never the other way around.

Once a crust forms on a *pahoehoe* lava flow, the still molten lava inside may continue to flow down slope and empty the crust to leave a hollow lava tube. Some of these lava tubes can be many kilometers long and up to 20 meters in diameter.

When lava flows occur under water, the cold water cools the outside of the lava which then squeezes along like toothpaste to form toothpaste pillow-like structures. These are known as *pillow lavas*, and these pillow structures can be found in ancient lava flows, indicating previous sub-marine environments.

Solids

The solid material ejected from a volcano ranges from huge blocks of solidified lava to fine dust which is so light it can drift around the earth in air currents. The accumulation of these materials around the vent helps, along with lava, to build up the volcanic cone.

All the fragmental material ejection by a volcano is given the term *pyroclastic* (“Pyro”-fire & “clastic”-broken) or *volcanoclastic*.

Volcanic solids are classified based on their particle size:

<i>Particle</i>	<i>Size</i>
Dust	<0.062mm
Ash	0.062mm-4.0mm
Lapilli	4.0mm – 3.2cm
Bombs	3.2cm – 25.6cm
Blocks	>25.6cm

3. Eruption Types

Volcanologists divide volcanic eruptions into several types. The major eruption types are:

Plinian eruptions

Plinian eruptions are named after Pliny the Elder, a widely respected Roman Admiral who died in the eruption of Vesuvius (Italy) in 79A.D. Pliny’s nephew, Pliny the Younger, while observing the same eruption from a boat, wrote an account of the eruption that buried the towns of Pompeii and Herculaneum.

Plinian eruptions are extremely explosive eruptions. They involve huge eruption columns, some reaching up to 45 km or more into the atmosphere. They involve vast amounts of ejected material – often tens of cubic kilometers. The eruption may last hours or days. The ash and pumice falling from the eruption column can cover millions of square kilometers. Plinian eruptions occur from volcanoes that are andesitic to rhyolitic in composition. However, some basaltic volcanoes, such as Tarawera in New Zealand in 1886, have had plinian eruptions. Fortunately, plinian eruptions are rare eruptive events with only two or three occurring each century. Volcanoes that have displayed this type of eruption are Vesuvius (Italy), 79A.D., and Mt. Pinatubo (Philippines), 1991.



Vulcanian eruptions

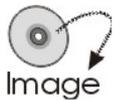
Vulcanian eruptions are named after a volcanic island, Vulcano, in the Aeolian Islands off the coast of Sicily.

These eruptions are small in magnitude, usually ejecting less than one cubic kilometer of material, but are characterized by high eruption columns that may reach 10-20 kilometers into the atmosphere. As this eruption column settles it spreads the volcanic dust and ash over a wide area. The eruption is quite explosive, often blasting away part of the volcanic cone. Vulcanian eruptions occur from volcanoes that are andesitic in composition. Other volcanoes that have displayed this type of eruption are Mt. Lamington (Papua New Guinea), Mt. Pelée (Martinique – Caribbean) and Sakurajima (Japan). Some of these volcanoes have also displayed plinian eruptions during their eruption history.

Strombolian eruptions

Strombolian eruptions are named after the small volcanic island Stromboli which is located between Sicily and Italy.

These eruptions consist of intermittent explosive bursts, which eject red-hot pyroclastic fragments up to a few 100 meters into the air. Each eruptive burst lasts only a few seconds and there may be long pauses of up to 30 minutes between each burst. Because of this pulsing activity no real eruption column of ash and gases forms above the volcanic vent. Strombolian eruptions occur from volcanoes that are mainly basaltic in composition. The volcano Stromboli has been erupting in this way for thousands of years and this type of eruption is not particularly dangerous. Other volcanoes that have displayed this type of eruption are Mt. Etna, (Sicily) and Mt. Erebus (Antarctica).



Icelandic eruptions

Icelandic eruptions, named after the style of the Iceland volcanoes, are the least explosive type of eruption. These eruptions take place along fissures, or long cracks, rather than vents. These fissures may be several kilometers in length. Lavas with low viscosity erupt from the fissures and flow away to form great lava sheets or “flood” lavas. No real volcanic cone is built up and, in ancient volcanic areas it may be impossible to find the location of the original fissure.

Icelandic eruptions occur from volcanoes that are basaltic in composition.

The volcanoes that make up the Mid Ocean Ridges display underwater Icelandic eruptions.

Hawaiian eruptions

Hawaiian eruptions are named after the style of volcanic activity found on the Hawaiian Islands. These eruptions take place from lines of vents that spray jets of liquid lava high into the air. These are referred to as *fire fountains* and can reach many hundreds of meters into the air. Some fire fountains may erupt for hours. The lava may cool in the air before falling to the ground or hit the ground in a still semi-molten state and form spatter fragments that weld together. Lava streams can also flow from the flanks of the volcano. Hawaiian eruptions are basaltic in composition.



4. Volcano Shapes



Image

The viscosity of the lava extruded from a volcano is the main force behind the eruption type, and eruption type is the main factor controlling the shape of the volcano.

Viscous lava (e.g. andesites) forms a steep sided plug over the vent called a lava dome.

Explosions, as part of eruptions, throw solid fragments from the crater, which form cones of pyroclastic material. These volcanoes, made up of layers of pyroclastics and lava, can have slopes close to 30° or more and are known as *composite* or *stratovolcanoes*. (Figure 2) E.g. Mt. St Helens, Mt. Fuji.

Composite Volcano

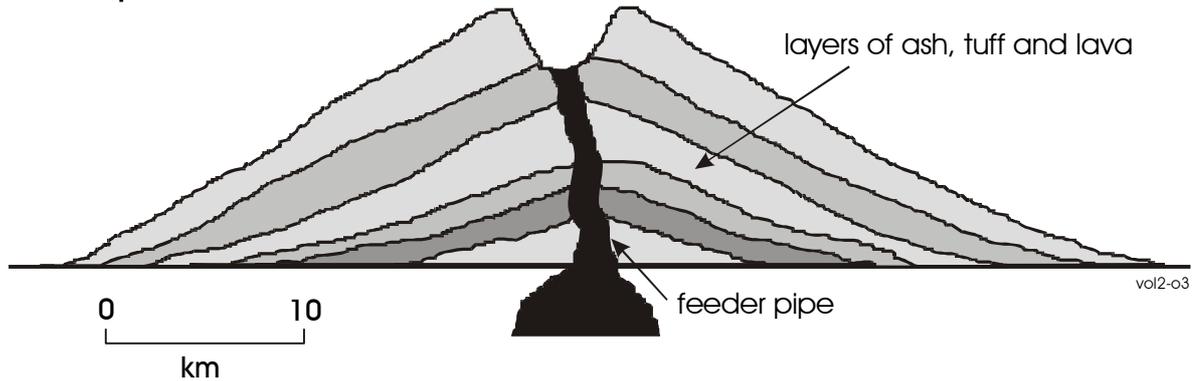


Figure 2. Composite Volcano



Image

Lavas poor in silica (basalts) can flow for long distances away from the vent and over time build up low sloping volcanic accumulations called *shield volcanoes* (Figure 3), e.g. Hawaiian island volcanoes.

Shield Volcano

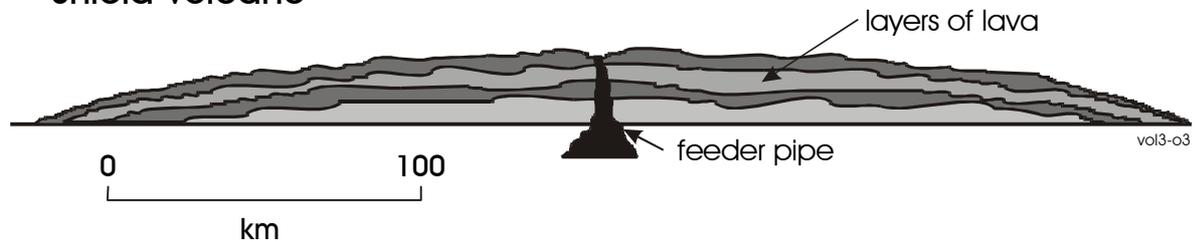
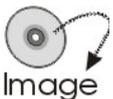


Figure 3. Shield Volcano

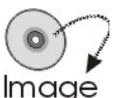
In some cases, when the lava becomes very viscous the lava plugs the volcano vents under which huge pressures build up due to escaping gas. These pressures can cause the volcano to explode, leaving only the outer shell of the original volcanic rim surviving.



Image

Some volcanoes empty their magma chambers after an eruption, and the mass of the volcano causes it to collapse in on itself. These large collapsed volcanoes are known as calderas.

5. Where are volcanoes found



Image

When the positions of active volcanoes are plotted on a world map, they fall onto distinctive zones. These zones correspond with the boundaries of crustal plates. In turn, the zones can be divided into two groups: The basaltic volcano zone and the andesitic volcano zone. Each of these groups corresponds to the type of plate boundary on which they occur.

Plate Tectonics

The theory of Plate Tectonics has the Earth's crust broken into about 12 rigid plates that slide over a semi-molten plastic layer of the mantle. There are three main types of plate boundaries (Figure 4):

1. Spreading or divergent boundaries – where plates are moving apart
2. Transform fault boundaries – where plates are moving past each other
3. Subduction or convergent boundaries – where one plate overrides another plate

Each plate is bounded by some combination of these three plate boundary types.

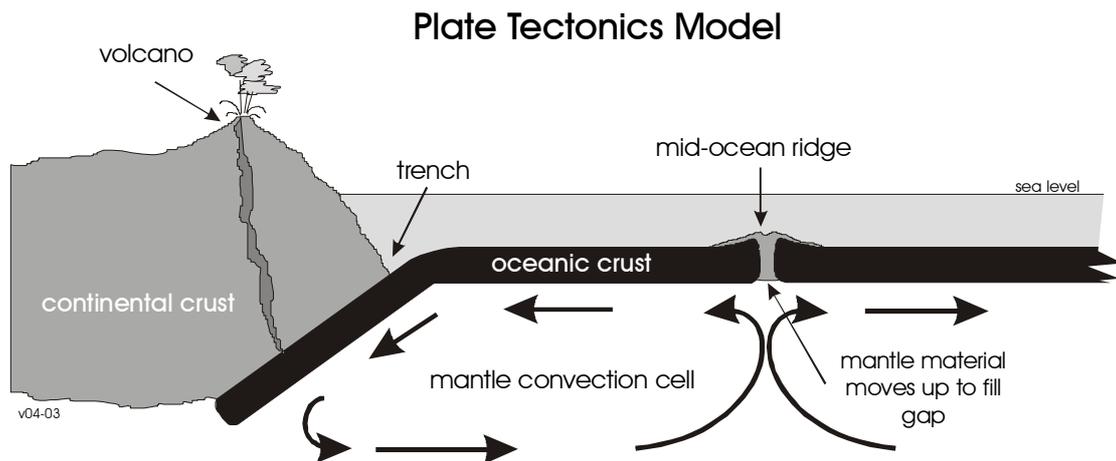


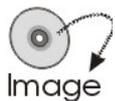
Figure 4. Plate tectonics model showing diverging and converging plate boundaries.

The composite volcanoes are located on the subduction plate boundaries where one plate slides under the other i.e. subducted. As the plate is subducted it takes with it some ocean sediments and water. These components cause zones of melting that rise up and break through to the surface. The resulting magma is dioritic in composition and feeds andesitic (composite) volcanoes.

Where plates are spreading, molten mantle material, poor in silica and therefore basaltic in composition, wells up in the space between the plates. The result is a great chain of volcanoes undergoing fissure eruptions (icelandic style eruptions).

Hot-spot volcanoes

In addition to the volcanoes that line the edges of plates, some volcanoes are found away from the plate boundaries. These volcanoes are thought to have formed from mantle *hot spots* from deep in the Earth that melt the plate above, forming a volcano. These volcanoes are normally basaltic in composition, but can include more silica rich material over time. It is in these hot-spot locations that the best shield volcanoes are developed.



The Hawaiian Islands are a chain of volcanoes formed where the Pacific Plate is moving across a hot spot. The movement of the plate can be seen as the volcanoes in the chain become older as you move northwards. (Figure 5)

Likewise, the Australian Plate is moving over a hot spot with ancient volcanoes found down the east coast from the oldest in north Queensland to the youngest in Victoria. The hot spot is now thought to be between Victoria and the west coast of Tasmania.



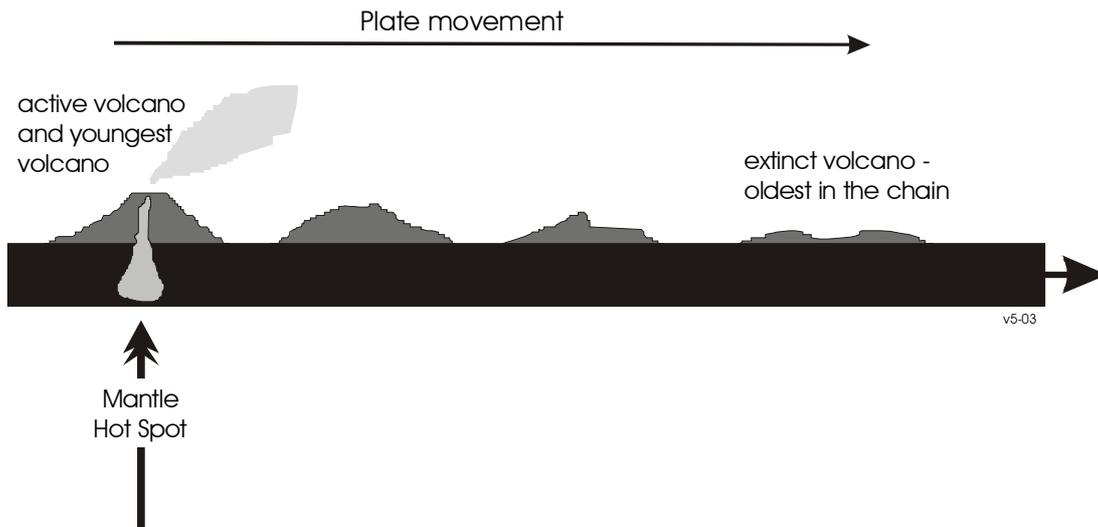


Figure 5. Diagram showing the formation of hot spot volcanoes. As the plate carries older volcanoes to the right, newer volcanoes are formed over the stationary hot spot.

6. Why are Volcanoes Dangerous?

It is often thought that the most dangerous part of a volcanic eruption is the lava flows rushing down the volcanic slopes. This is reinforced by countless movie and television programs that show people running away from the red hot lava.

In reality, the threat posed by flowing lava in the majority of eruptions is very small. Other volcanic debris and phenomenon are far more dangerous. Some of these are:

Ash Fall

The amount of material erupted from explosive plinian eruptions is immense. The majority of the material is ash, which is blasted up into the eruption column above the vent. As the ash settles it covers vast areas.



In some eruptions, the settling of this ash is extremely fast close to the volcanic vent, so fast in fact that people have been trapped while trying to escape. The excavation of Pompeii, buried in ash and pumice from the eruption of Vesuvius in 79 A.D., revealed a township caught by the fast deposition of an ash fall. Cavities found in the ash, when filled with plaster, revealed the death throes of some of Pompeii's inhabitants.

The deposition of ash on the roofs of houses causes an immediate threat to the occupants as the roof may collapse. The recent eruption in Rabaul (1994) had townships covered in ash with many buildings collapsing due to the weight of the ash.

Of wider implication is the damage to local agriculture through the burying of crops and pasture land. Many volcanic eruptions have left populations in famine as the once highly productive land is rendered useless by a few feet of volcanic ash.

Pyroclastic Flows

Of all the destructive volcanic phenomena, pyroclastic flows rate as potentially the most destructive. Pyroclastic flows are the flow of volcanic debris down the flank of a volcano as part of the eruption process. These may be flows of vesicular rock materials, such as pumice, or flows of hot hard rock fragments that move down the volcanic flank like a glowing cloud.

One of the major causes of massive pyroclastic flows is the collapse of the eruption column. After the initial eruption blast has shot ash and pumice up into the air, gravity starts to pull the material back towards the Earth's surface. In some cases, the initial eruption is so strong that the weight of the eruption column can no longer be supported after the blast has subsided and

the cloud, along with its ash and pumice, collapses back onto the volcano. The collapsed cloud rolls away from the volcano, carrying its ash and pumice in a wave that destroys everything in its path. These flows are called ignimbrites and ignimbrite deposits can be many tens of meters thick. Some ancient ignimbrite deposits are extremely thick – up to 250m near the volcanic vent. While no event of this magnitude has been observed, the threat of a similar event is always present in plinian eruptions.

Another form of pyroclastic flow is formed during an eruption when the flank of a volcanic dome collapses and hot rock materials roll down the volcanic slope. The volcanic gases suspend the material and large boulders can be lifted along in the flow. Eventually the gases can no longer support the weight of the flow and the material is dumped.

Volcanic Collapse



Sometimes a volcanic eruption takes place that causes the side of the volcano to collapse. The eruption of Mt. St Helens produced this phenomenon, with one side of the volcano being pushed out then collapsing into the valley below. The material mixed with the water of a lake, then flowed down the valley as a deep debris and mud flow.

Volcanic collapses close to sea level or underwater can cause huge waves or volcanic tsunamis. The collapse of a volcanic cone during the eruption of Krakatau in 1883 caused tsunamis, which killed 30,000 people several hundreds of kilometers away on the coastlines of Java and Sumatra. These waves may have been as high as 40 meters (~135 feet)!

Volcanic Gases

The escape of volcanic gases, even in a minor eruption, can cause a real threat to local inhabitants. Some volcanic gases are extremely poisonous. Carbon dioxide, for example, only needs to be at levels of 0.4% of air for it to kill. Being a colorless, odorless heavy gas, it can flood into low areas close to a volcano and kill the livestock and inhabitants. At even smaller concentrations it can reduce plant growth.

Threat to Aircraft



Sometimes flight patterns can post a risk to international travelers on aircraft. For example, while Australia has no active volcanoes on the mainland, the largest hazards volcanoes pose to Australians is that of damage to aircraft. All aircraft routes from Australian capital cities into Asia fly over areas of active volcanism. Aircraft can be severely affected when flying through ash and/or aerosol clouds.

On December 15, 1989, a KLM Boeing 747-400 flew into the ash cloud of a Redoubt volcano in Alaska at an altitude 25,000 feet. Within 60 seconds all four engines had decelerated below idle putting the aircraft into a steep descent. After dropping 13,000 feet the crew managed to restart the engines and return to the airport. A study of the engine showed that the ash had melted and resolidified on the engine fans reducing the airflow causing the engine to stall.

A similar incident occurred to a British Airways 747 flying from Kuala Lumpur to Perth on June 23, 1982, when it flew through the dust cloud of the Galunggung volcano in Indonesia. The plane dropped for 13 minutes before the crew managed to restart the engines.

Volcanic ash is not as visible to radar, the main aircraft navigational aids, as water droplets. Therefore ash clouds do not appear on radar screens like rain clouds. Australian scientists are developing an instrument, AVADS (airborne volcanic ash detection system), which will enable pilots to “see” ash clouds based on the heat radiated from the ash particles.

7. When Do Volcanoes Erupt?

One of the major goals of volcanologists is to predict when a volcano is going to erupt. Information that is required to increase accuracy of eruption forecasts includes past eruptive



history, earthquake activity around the volcano, surface deformation, temperature and gas emissions.

The eruptive history of a volcano can provide information on the regularity or irregularity of events. In many cases, the period of dormancy between eruptions has a bearing on the size and type of eruptive event. In other cases there appears to be no relationship. Unfortunately, only a small fraction of the world's volcanoes have had their eruptive histories studied.

Earthquake studies of volcanoes have shown to be good indicators of the movement of magma below a volcano. Earthquake swarms, hundreds of small quakes, have been recorded prior to eruptions, such as that of Mt. St Helens in 1980. However, some eruptions occur with no change in seismic activity. Volcanic tremor, a more-or-less continuous ground vibration, is normally always present during an eruption. It is thought that this tremor is caused by the release of gases as the magma rises towards the surface.

Accurate measurements of survey points on the summits and slopes of volcanoes are used to indicate changes to the surface due to the rise of magma beneath the volcano. Deformation monitoring is also one of the most important tools, especially with the recent increase in accuracy of the instrumentation. Prior to the eruption of Mt. St Helens, measurements indicated the start of a bulge on the volcano flank. This enabled volcanologists to start evacuations from those areas.

Temperature changes may seem obvious, but some volcanic regions display large fluctuations in temperature not related to any volcanic eruption. However, in some locations, temperature of groundwater or even surface lake waters may be an early detection tool.

Changes in the volume and chemical composition of volcanic gases are useful indicators of eruptions. Any change may indicate movement of new material at depth.

8. The Effects of Volcanic Aerosols

Volcanic aerosols produce a number of effects on the Earth. The most visible of these are the post-eruptional optical effects such as vividly colored sunsets, altered colors of celestial bodies (stars and planets), dulled starlight, rings around the sun (known as "bishop's rings" after Sereno Bishop who first reported them from Hawaii) and colored twilight afterglows. These effects were once attributed to the volcanic "dust" but are now known to be caused not by solid particles, but by the tiny acid aerosol droplets.

The existence of volcanic aerosols forming layers in the upper atmosphere was first pointed out by an American atmospheric scientist, Christian Junge, in 1961. The aerosol layer – sometimes called the Junge layer – is not a permanent feature but exists only after periods of volcanic activity. During volcanically "quiet" periods the stratosphere may become clear of the volcanic acid droplets.

Not all volcanic aerosols end up in the stratosphere. Those that form from non-explosive volcanism can also form dry volcanic fogs close to the Earth's surface.

Stratospheric aerosols affect the Earth's atmospheric heat budget. Incoming solar radiation is reflected and scattered by the aerosols. This layer therefore cuts out some of the solar radiation that would normally reach the Earth's surface. Also, infrared radiation reflected from the Earth's surface is absorbed by the aerosol layer, causing the stratosphere to become heated. Increases in the temperature of the stratosphere of up to 6°C have been recorded above Port Hedland in Western Australia.

Aerosol layers from the equatorial eruption at Tambora in Indonesia in April 1815 caused prolonged and brilliantly colored sunsets. The next year became known as the "year without summer" because of the low temperatures. A persistent dry fog was reported in the north-eastern United States – a stratospheric phenomenon. During that cold summer the author Mary Shelley spent the hours of her spoilt European holiday writing *Frankenstein*.

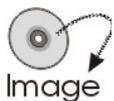
Aerosols can have immediate economic effects. For example, the acid aerosols caused by the 1982 El Chichon eruption caused crazing of the windows of aircraft that flew the trans-Arctic route, and one airline reported the cost of the damage to be \$1million.

Like all of the Earth's atmospheric circulation, aerosol layers and volcanic clouds migrate around the Earth, eventually returning to the vicinity of the volcano that first released them. For example, it took the eruption cloud of Pinatubo, which erupted in June 1991, 22 days to circumscribe the globe. The eruption clouds of volcanoes at higher latitudes take even less time to circumscribe the globe.

Eruption clouds also move towards the polar regions due to the effect of the spinning Earth and the transfer of heat from the tropics to the poles. The eruption cloud of volcanoes that erupt in high latitudes will only affect one hemisphere. Those close to the equator may spread around the entire globe. Therefore, large explosive eruptions close to the equator have a greater chance of affecting the climate of the entire globe.

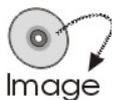
9. Volcanoes in the United States

Evidence of volcanism is present throughout most of North America, although most recent activity is concentrated in Hawaii, Alaska and the western United States. The USGS has established volcano observatories in Hawaii, Alaska, and the Cascades in the Pacific Northwest to research these active areas. U.S. citizens have witnessed a number of explosive, continental volcanoes in this century, and ongoing, quieter volcanism is a huge tourist draw in the Hawaiian Islands. The United States ranks third, behind Indonesia and Japan, in its number of historically active volcanoes.



Hawaiian Islands

The Big Island of Hawaii is the textbook example of an active, basaltic shield volcano, and is the most famous "hot spot" location. Although unrelated to any plate boundary, Mauna Loa is one of the world's largest active volcanoes, and measured from its base on the sea floor, it is taller than Mount Everest. The basaltic magma is very fluid, and therefore usually non-explosive. Thus the islands are the ideal location to study the nature of the magma, which originates from deep in the mantle, and the nature of volcanic activity over a hot spot. Kilauea, which sits on the southern flank on Mauna Loa, is building up another huge shield volcano. It has been in almost constant eruption for the last 20 years. The newest volcano in the Hawaiian chain is still underwater. Lo'ihi sits south of Kilauea and will take many thousands of years or more to break through the ocean surface to form a new island.



Alaska and the Aleutian Islands

According to the USGS, the Alaska Peninsula and the Aleutian Islands have about 80 major volcanic centers that consist of one or more volcanoes. Luckily, the area is mostly sparsely populated except in the Cook Inlet area, where the potential for a volcanic disaster does exist. The region is part of the "Ring of Fire", where the Pacific plate is colliding with the North American plate. Very large, catastrophic eruptions have occurred in this area over the last 10,000 years, the latest occurring in 1912 at Novarupta in the Katmai National Monument (which was also the largest eruption in the world last century). More recently, eruptions from Redoubt Volcano in 1989 and Crater Peak in 1992 caused disruptions in air traffic to Alaska, and the former threatened oil facilities in Cook Inlet. Volcanic eruptions in the area have also caused large landslides and associated tsunamis.



Cascade Range

In contrast to the Hawaiian volcanoes, the Cascade Range in north western United States exhibits a much more violent history. The area has produced nearly a dozen active volcanoes over the past 2,000 years, and has half as many potentially active locations. The Pacific Northwest volcanism is generated by the melting of the Juan de Fuca plate (made of dense, oceanic crust) as it is subducted beneath the North American plate (lighter, continental crust). Being located on a continent causes the resulting magma to be more silica-rich, gaseous, and highly viscous, forming steep-sided composite volcanoes. These characteristics also lead to

explosive eruptions, as witnessed at Lassen Peak, California, from 1914-1917, and during the Mount St. Helens eruption (Washington state) in May of 1980. This well-documented eruption revealed a massive landslide and the dynamics of a gaseous explosion, helping geologists to identify similar deposits in other parts of the world. The increased number of earthquakes, small steam explosions, and the bulging crater were recorded precursors to the explosion. A number of currently dormant volcanoes are considered quite dangerous, e.g. Mount Rainier and Mount Baker.

Along with these active locations, evidence for ancient volcanism exists in many parts of the U.S. Ancient lava flows and/or ancient calderas are present across the country, from New England to Virginia, Texas and Arizona, California and Colorado, to name a few. Calderas in Long Valley, California, and in Yellowstone Park, Wyoming, are showing increased "unrest" and growth in recent years, which may or may not indicate future eruptions but certainly warrant ongoing monitoring. In fact, the geothermal activity under Yellowstone is what causes its famous geysers and hot springs. Continued study of ancient and active areas in the U.S. will increase our ability to predict future sites that present a volcanic hazard.

10. Australian Volcanoes

Despite the popular misconception that there are no volcanoes in mainland Australia, young volcanic rocks are widespread in the eastern states. Aboriginal people probably were witnesses to this volcanism, especially in the Mount Gambier area around 4,600 years ago. Aboriginal stone tools have been found in Victoria buried beneath volcanic tuff deposits. A belt of recent volcanism occurs down the eastern states starting in far north Queensland (Torres Strait) and stretching down to the Victorian-South Australian coastline. This volcanism can be divided into two broad types – central volcanoes and lava fields.

Central Volcanoes

These are predominantly basaltic volcanoes but do have some silica-rich (rhyolitic) lava flows and intrusions. The volcanic rocks were produced from either a single central vent or a cluster of vents. The largest of these is the Tweed Volcano with Mt. Warning representing the harder central vent. Other central volcanoes include the Glasshouse Mountains, the Warrumbungles, Canobolas and Mt. Macedon.

Lava Fields

These are basaltic lava areas where large amounts of lava flowed from diffuse dikes and pipes over large areas. The lavas are normally very thin and now cap ridge and mountaintops. Lava fields can be found right along the eastern side of Queensland, New South Wales, Victoria and Tasmania. These were most probably Icelandic eruptions.

The remnants of one of the most extensive sequences of flood basalts in the world are found in the East Kimberly region of Western Australia. These are very old (530 million years) and outcrop over an area of 35,000 square kilometers with another 115,000 square kilometers found beneath younger sedimentary layers.

There is one active volcano on Australian Territory. It is called *Big Ben* and is located on Heard Island in the Southern Ocean. It is also the highest mountain on Australian Territory.

11. Why Study Volcanoes?

Other than the obvious desire to know what risk any volcano poses to life, limb and property, much of the Earth's richest agricultural land and many of the planet's mineral deposits are found in the vicinity of ancient volcanoes. Also, volcanoes have the potential to affect the planet's climate and can offer answers to the formation of the Earth's primitive atmosphere.

Agriculture

Volcanic material, when mixed with organic matter, makes up the richest soils on Earth. It is no mistake that the most productive farming land is found in volcanic areas, and it is the main reason for people to live so close to a potential geological hazard.

As the Earth's human population expands, more and more people will rely on the rich volcanic agricultural land.

Mineral Deposits

Volcanic activity is an important process in the concentration of a number of useful and/or valuable minerals such as copper, silver and gold. These deposits are either concentrated as part of the magmatic processes or by the secondary heating of groundwater in the volcanic pile to vast temperatures.

The process of magmatic differentiation can concentrate a number of elements into fluids which later cool to form rich mineral veins. In some locations entire magma chambers below volcanically active areas have become enriched in copper and when cool, form *porphyry copper* deposits.

Closer to the surface, the magma rising into a volcanic vent heats the surrounding country rocks and their contained water. If the water becomes hot enough, large convection cells of water develop which circulate through the country rock and the volcanic accumulations, leaching out metals from the minerals they pass. These fluids become superheated and extremely acidic. Occasionally these waters find a fracture in the rock that leads towards the surface into which they move, boil and precipitate metallic minerals. These are known as *epithermal deposits*.

In some settings the hot metallic rich waters break through to the surface. These have been found in deep ocean areas, for example, off southern California. Here the hot waters emerge onto the ocean floor where they mix with the cold seawater. The emanations form meter high pipes of precipitated minerals that are known as *smokers*. The metallic minerals precipitate from the waters released from the smokers and form a blanket on the sea floor. Over time these will form large accumulations.

Other Volcanic Products

As well as the associated mineral deposits, there has been an increase in the use of volcanic products such as pumice as an abrasive and filter. Vesicular volcanic rocks also retain heat and so are used in roasting barbecues!

Volcanic – Geothermal Power

In conventional coal or fired power stations, the fuel is burnt to heat water into steam which then drives turbines generating electricity. In volcanic areas, the amount of heat stored in rocks close the Earth's surface produces large reservoirs of superheated groundwater and steam that can be tapped directly into the generator. Exploring for suitable sites is similar to exploring for oil in that you need a geological formation that will trap the superheated water. Once these are found, the trapped water is drilled and tapped into a generator. Geothermal power plants are considered clean energy because they emit little carbon, no nitrogen oxides, and very low amounts of sulfur dioxide. Steam and flash plants emit mostly water vapor.

According to the U.S. Geothermal Energy Association (GEA), worldwide geothermal energy production has expanded 50% over the past decade and is now serving over 47 million people. Although growth has been small in the U.S. in the past decade, it leads the world in total geothermal energy production and will likely increase use as the price of producing it continues to drop and oil prices rise. In the United States, the hottest (and currently most valuable) resources are located in the western states, Alaska, and Hawaii. California geothermal energy is especially well developed, and The Geysers geothermal facility in Calistoga, California, is the world's largest producer of geothermal power (Pacific Gas and Electric Company).

Volcanoes and the Birth of Atmosphere

Volcanoes played an important part in the formation of the Earth's atmosphere.

The Earth formed around 4,700,000,000 years ago from a swirling body of cosmic dust left over from the universe's explosive beginnings. As the body contracted, elements separated based on their mass, with the heavier elements forming the core and mantle of the primitive

planet and the lighter elements an outer ring or primitive atmosphere, not unlike present day Saturn or Jupiter.

Volcanic activity on the cooling crust of the planet released large amounts of water vapor (steam), carbon dioxide, nitrogen and hydrogen sulfide gas. Some of the water vapor molecules that reached the upper atmosphere were broken down into oxygen and hydrogen. Oxygen in the atmosphere was converted to ozone, which started to screen the Earth's surface from ultraviolet rays. Over time this primitive atmosphere evolved to form one suitable for supporting the earliest life.

In a similar way today, every volcanic eruption adds gases to the atmosphere that have been trapped in the Earth's crust for millions of years.

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