Indian Institute of Technology, Kanpur

Department of Earth Sciences

ESO213A: Fundamentals of Earth Sciences

Lecture 34. Volcanoes

Santanu Misra
Department of Earth Sciences
Indian Institute of Technology, Kanpur
smisra@iitk.ac.in ● *http://home.iitk.ac.in/~smisra/*

Aims of this lecture

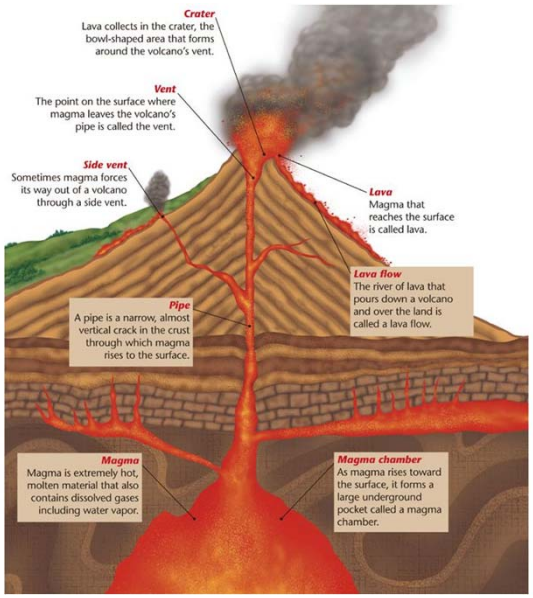
- Volcanoes – definition, eruptive processes
- Types of Volcanoes, Classifications, Lava
- Volcanic Hazards

Reading:
- Marshak's Book (Chapter 9; pages 272-309)
- Grotinger & Jordan's book (Chapter 12)

What is a Volcano?

- A volcano is a vent or 'chimney' that connects molten rock (magma) from within the Earth's crust to the Earth's surface.
- The volcano includes the surrounding cone of erupted material.

Anatomy of a Volcano



How and why do volcanoes erupt?

- Hot, molten rock (magma) is buoyant (has a lower density than the surrounding rocks) and will rise up through the crust to erupt on the surface.

  Same principle as hot air rising, e.g. how a hot air balloon works

- When magma reaches the surface it depends on how easily it flows (viscosity) and the amount of gas (H_2O, CO_2, S) it has in it as to how it erupts.
- Large amounts of gas and a high viscosity (sticky) magma will form an explosive eruption!

  Think about shaking a carbonated drink and then releasing the cap.

- Small amounts of gas and (or) low viscosity (runny) magma will form an effusive eruption

  Where the magma just trickles out of the volcano (lava flow).

Volcanoes and Earth System

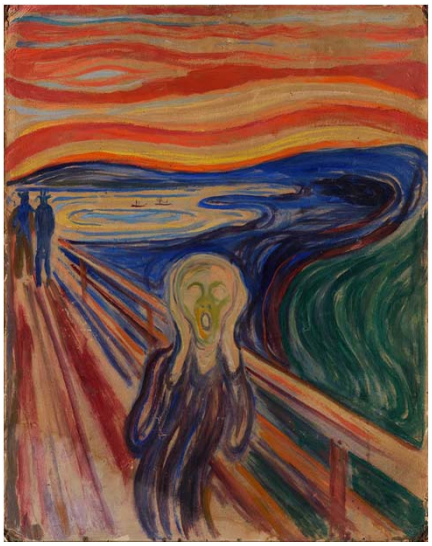
- **How do volcanoes affect Earth's spheres?**
  - Origin of atmosphere and oceans via outgassing
  - Mass extinctions

    K-T boundary – 65 million years ago – demise of the dinosaurs (Volcanism and/or asteroid?)
- **How do volcanoes affect climate?**
  - Gases and particles

    Tambora 1815 – followed by "year without a summer"

    Pinatubo, 1991: sulfuric acid formed aerosols; cooled temperatures in some areas by as much 0.5 degrees C
  - Volcanoes emit CO_2

The scream



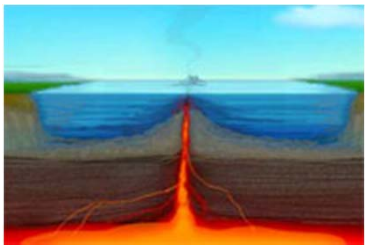
The Scream (1893) - Edvard Munch

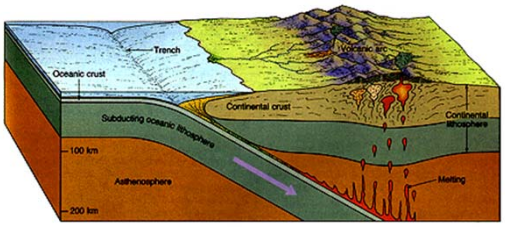
Painted in 1893 based on Munch's memory of the brilliant sunsets following the 1883 Krakatoa eruption.

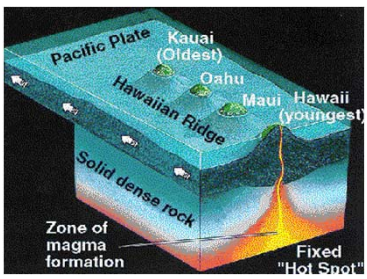
"I was walking along the road with two friends – the sun was setting – suddenly the sky turned blood red – I paused, feeling exhausted, and leaned on the fence – there was blood and tongues of fire above the blue-black fjord and the city – my friends walked on, and I stood there trembling with anxiety – and I sensed an infinite scream passing through nature.."

Where do the volcanoes occur?

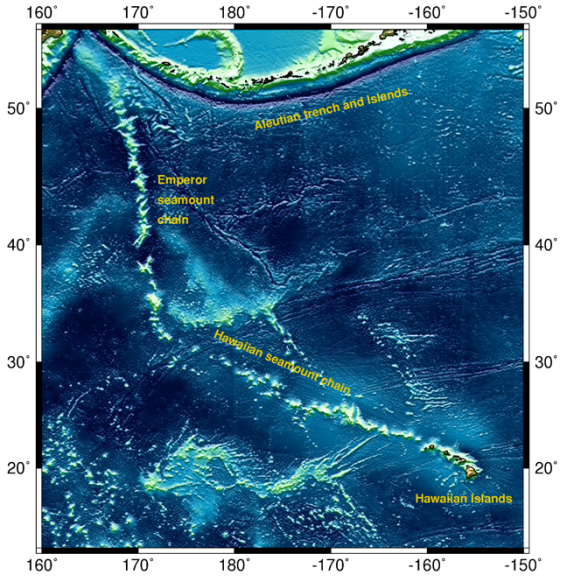
- Volcanoes occur at both divergent and convergent boundaries and also at hot spots.

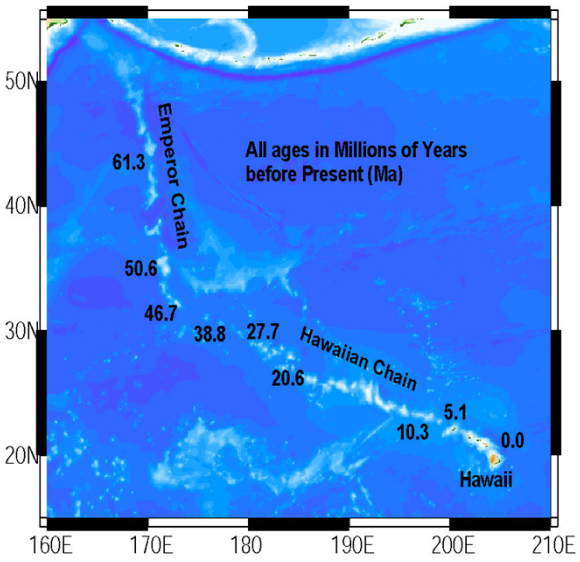




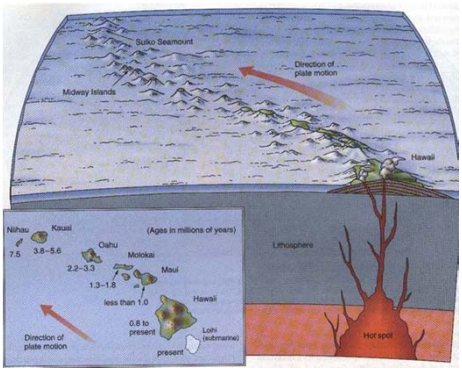


Volcanoes and plate tectonics





Volcanoes and Plate Tectonics



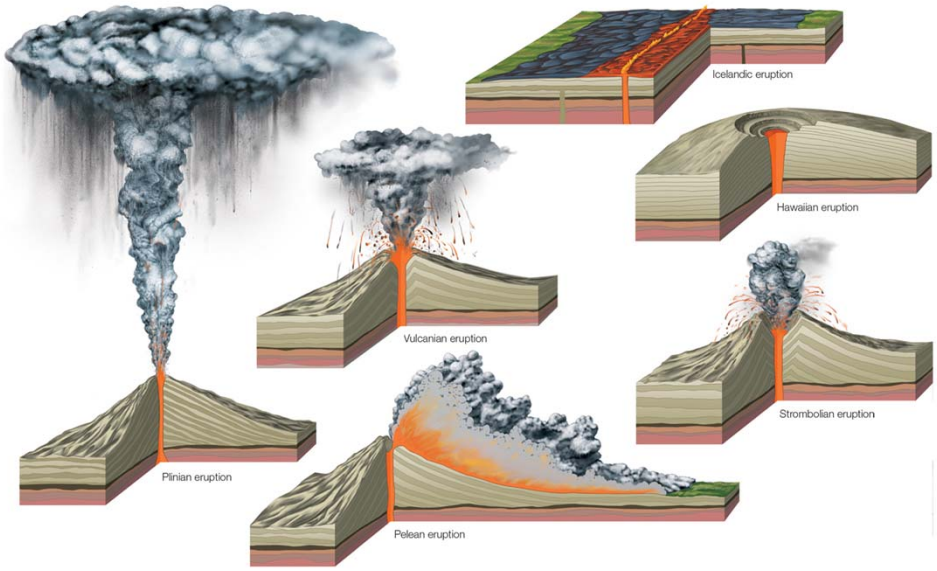
Volcanoes at divergent plate boundaries

- At a divergent boundary, the lithosphere becomes thinner as two plates pull away from each other.
- A set of deep cracks form in an area called a *rift zone*.
- Hot mantle rock rises to fill these cracks. As the rock rises, a decrease in pressure causes hot mantle rock to melt and form magma.
- The **magma** that reaches Earth's surface is called **lava**.
- Basaltic magma rises to Earth's surface through these fissures and erupts non-explosively

Types of Volcanoes

- Shield Volcanoes
- Flood Basalts
- Scoria Cones
- Lava Domes
- Calderas
- Stratovolcanoes

Types of Eruptions



Why do we have different types of volcanos?

- The process of magma formation is different at each type of plate boundary.
- Therefore, the composition of magma differs in each tectonic setting.
- Tectonic settings determine the types of volcanoes that form and the types of eruptions that take place.

Shield Volcanoes

Shield volcanoes form when repeated eruptions from the same magma conduit system build piles of overlapping lava flows. Profiles are upwardly convex.

- Low viscosity
- Low Volatiles
- Produce large volume from lava
- flows
- Basaltic
- Shallow slopes


Hekla, Iceland


Longonot, Kenya


Mauna Loa, Hawaii

Shield Volcanoes


Mauna Loa, Hawaii

Flood Basalts

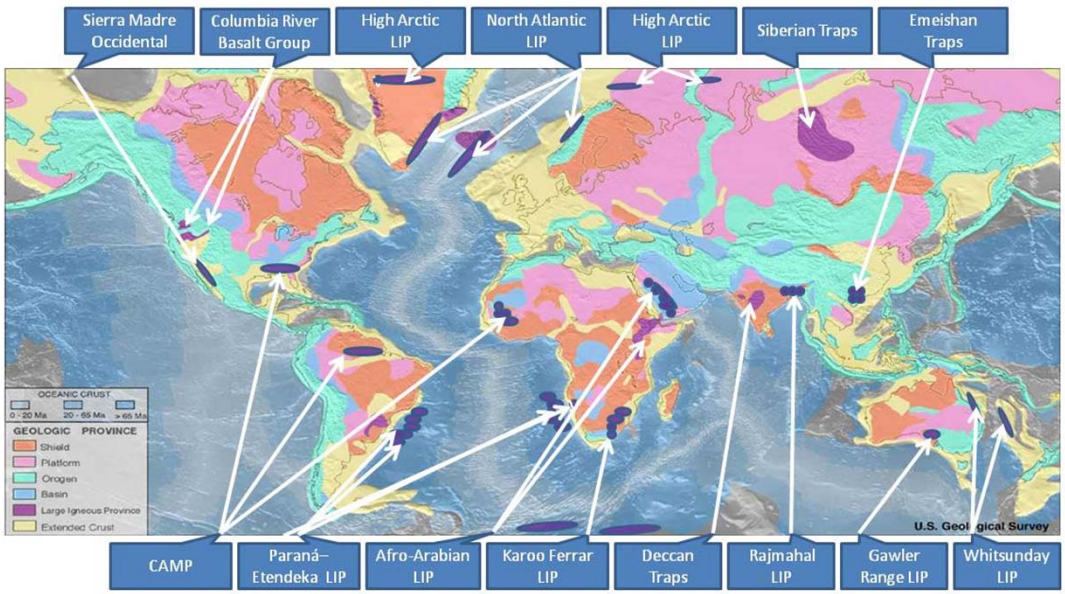
Some parts of the world are covered by thousands of square kilometers of thick basalt lava flows - individual flows may be more than 50 meters thick, and individual flows extend for hundreds of kilometers.

- Largest volcanic events on Earth.
- Erupt extremely large amounts of magma in a relatively short time of 1 million years.
- Occur on all continents and on all ocean floors, but none has occurred in historic time.
- Although lava flows are the main hazard, the large amount of CO2 and SO2 released is able to modify our climate.


Deccan Trap, India


Columbia River Flood Basalt, USA

Flood Basalts



Scoria / Cinder Cones

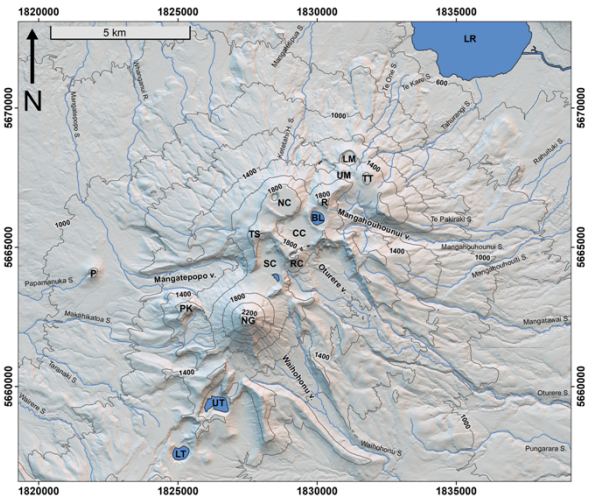
Produced during a single eruptive event (usually Strombolian eruptions), lasting a few hours to several years

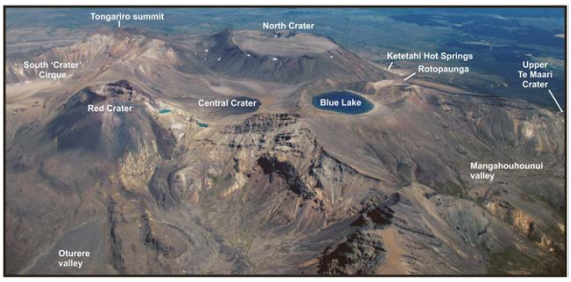
- Conical Hills, Low Height, large crater
- Basaltic-Andesitic
- Explosive
- Once activity ceases usually never active again

Stratovolvanoes

- Steep-sided, symmetrical peaks
- Built of alternating layers of pyroclastic deposits and capped by andesitic-rhyolitic lava flows
- Eruption styles vary from Vulcanian-Plinian
- Highly viscous lavas, Usually explosive eruptions
- Comprise 60% of the Earth's volcanoes
- Produce pyroclastic flows, lahars, ash plumes and lava flows

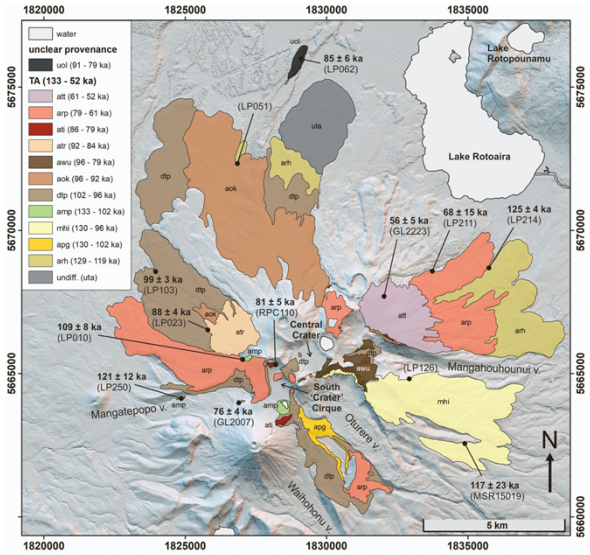
Stratovolvanoes

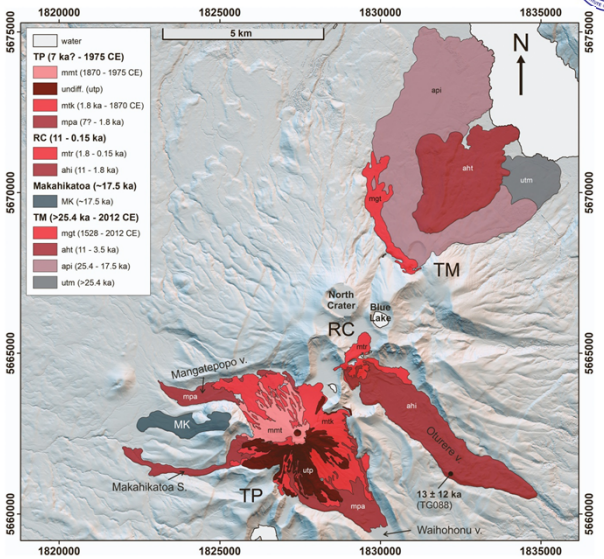




Pure et al., 2020

Stratovolvanoes

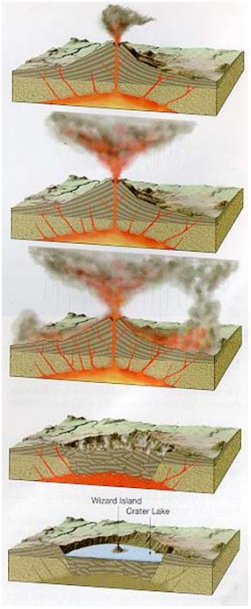




Pure et al., 2020

Calderas

- Caldera-forming eruptions are the largest of the violent, explosive volcanoes
- Large volcanic depressions formed by roof collapse into partially erupted magma chambers
- Calderas range from 2-75 km in diameter and are formed by inward collapse
- Collapse occurs following large Plinian eruptions producing pyroclasts. Void spaces are left causing the mountain to collapse into the magma chamber
- Three different Caldera settings:
    - Calderas in the summit of shield cones (Mauna Loa)
    - Summit of stratovolcanoes (Crater Lake Oregon)
    - Giant continental calderas (Yellowstone)



Calderas


Caldera Erta, Ethiopia


Kaguyak volcano, Alaska

Types of Lavas

Aa:	lava that is thick and sharp
Pahoehoe:	lava that forms thin crust and wrinkles
Pillow lava:	lava that erupts under water, has a round shape
Blocky lava:	cooler, lava that does not travel far from eruption, jagged when it dries.

Aa

Aa: lava that is thick and sharp

Pahoehoe


Pahoehoe: lava that forms thin crust and wrinkles

Pillow Lava

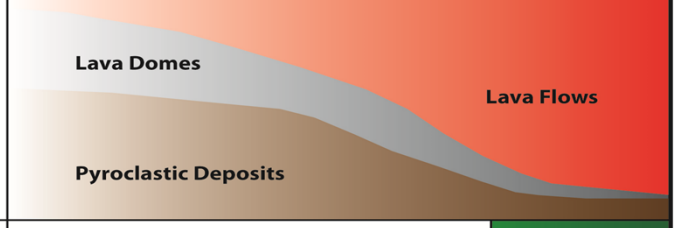
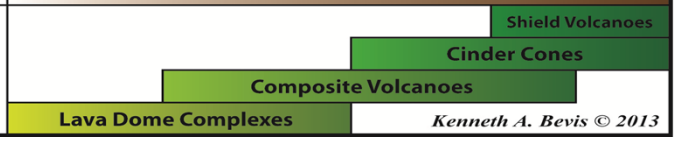


Pillow lava: lava that erupts under water, has a round shape

Blocky Lava

Blocky lava: cooler, lava that does not travel far from eruption, jagged when it dries.

Magma composition and flow properties

Magma Composition	Felsic	Intermediate	Mafic
Silica Content	70%	60%	50%
Water (Gas) Content	5.0%	2.0%	0.5%
Eruption Temperature	750-900 °C	900-1000 °C	1100-1200 °C
Viscosity	Higher	Intermediate	Lower
Explosiveness	More Explosive		More Effusive
Volcanism	Rhyolitic Dacitic	Andesitic	Basaltic
Volcanic Products			
Volcano Types			

Explosive eruptions

- Explosive volcanic eruptions can be catastrophic Erupt 10's-1000's km^3 of magma
- Send ash clouds >25 km into the stratosphere
- Have severe environmental and climatic effects
- Hazardous!!!
- Three products

  Ash Fall
  Pyroclastic Flow (more particles)
  Pyroclastic surge (more gas)

Large eruption column and ash cloud from an explosive eruption at Mt Redoubt, Alaska

Pyroclastic Flow and surge

A truck carrying volcanologists and a film crew attempting to out run a pyroclastic flow in Indonesia

Effusive Eruptions

- Effusive eruptions are characterized by outpourings of lava on to the ground.
- This happens either because there is not enough gas (volatiles) in the magma to break it apart upon escaping, or the magma is too viscous (sticky) to allow the volatiles to escape quickly.
- Lava flows generated by effusive eruptions vary in shape, thickness, length, and width depending on the type of lava erupted, discharge rate (how fast it comes out of the vent), slope of the ground over which the lava travels, and duration of eruption.
- Although not generally as hazardous as explosive eruptions, lava flows can burn and bury buildings and forests and do pose a danger to people living on or near an active volcano.

Volcanic Fatalities

- 92,000 Tambora, Indonesia 1815
- 36,000 Krakatau, Indonesia 1883
- 29,000 Mt Pelee, Martinique 1902
- 15,000 Mt Unzen, Japan 1792

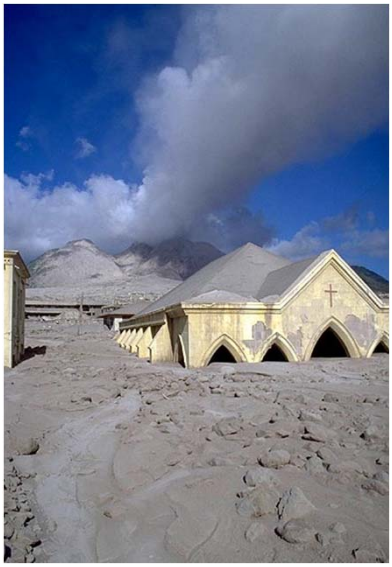
But, volcanoes cause fewer fatalities than earthquakes, hurricanes and famine.

Volcanic soil is very fertile and rich in minerals so people move on to the sides of volcanoes to plant crops. This puts them in great danger if there is an eruption.

Volcanic Fatalities

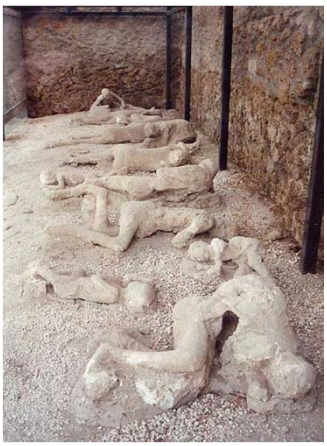
Volcanic Hazards

- Pyroclastic flow
- Lahars/Mud flows
- Pyroclastic fall
- Lava flow
- Noxious Gas
- Earthquakes



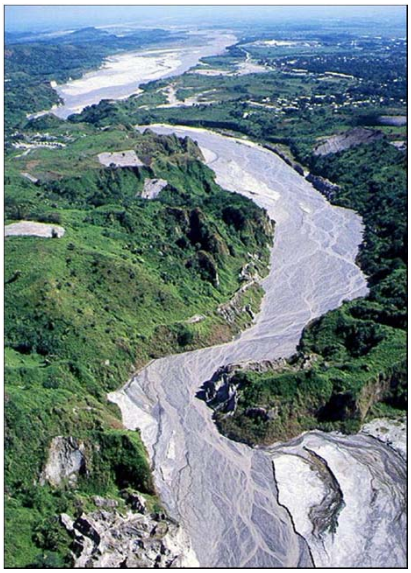
Pyroclastic Flow- POMPEII

On August 24, 79AD Mount Vesuvius literally blew its top, erupting tones of molten ash, pumice and sulfuric gas miles into the atmosphere. Pyroclastic flows flowed over the city of Pompeii and surrounding areas.


Lahar / Mud Flow

- Hot volcanic activity can melt snow and ice
- Melt water picks up rock and debris
- Forms fast flowing, high energy torrents
- Destroys all in its path

Pyroclastic Fall

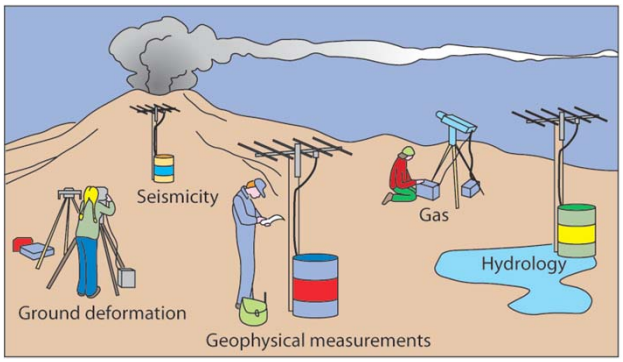
- Ash Load
- Collapses roofs
- Brings down power lines
- Kills plants
- Contaminates water supplies
- Respiratory hazard for humans and animals

Lava Flow

- Lava flows although generally slower moving and less catastrophic than pyroclastic flows still remain dangerous.
- Lava flows have temperatures in excess of 200 degrees Celsius. Therefore will burn any flamable material it contacts with.
- Thick lava flows will bury all in it's path including infrastructure (buildings, roads, waterways etc.) and agricultural land.

Volcano Monitoring

Volcano Observatories are set up on all active volcanoes that threaten the human population. These are designed to monitor and potentially to predict the eruptive behaviour of the volcano in question.



- Increased earthquakes in the area (increased seismicity)
- Swelling and cracking of the ground (deformation)
- Change in the amount of or chemistry of the gas coming out of the volcano
- Change in the groundwater levels or chemistry.