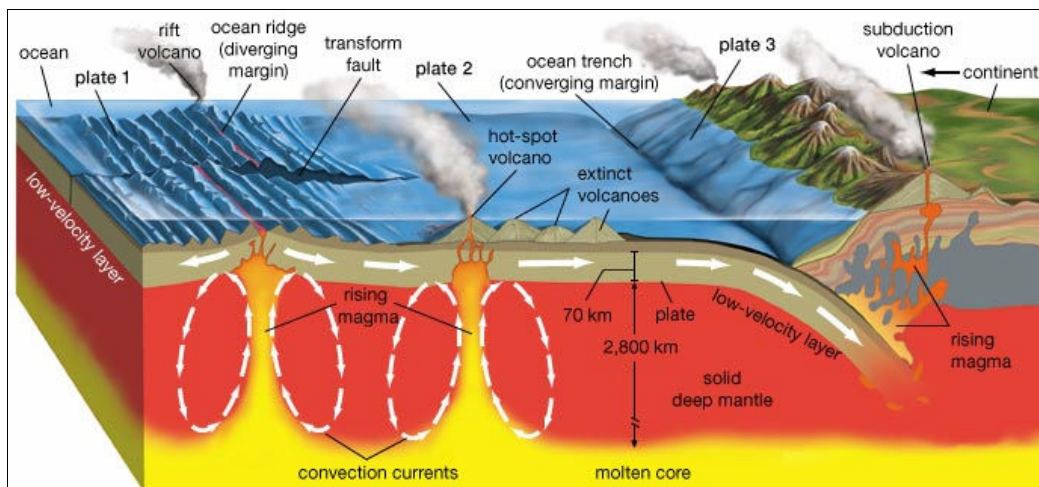


Introduction to Volcanoes

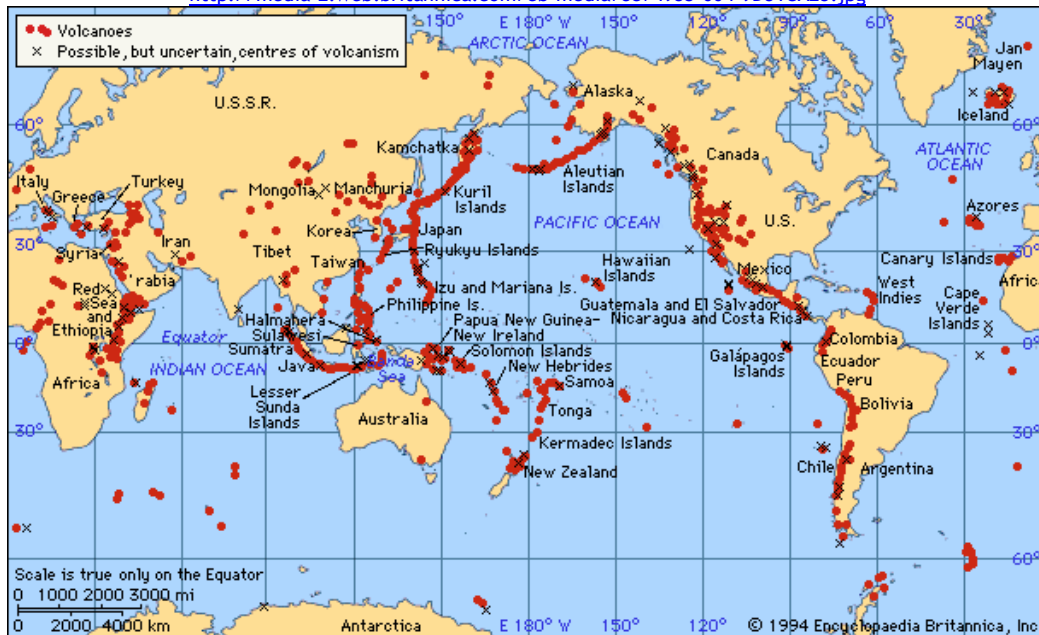
(Priority: Medium)

Volcano: opening / vent through which magma, molten rock or ash erupt on the Earth's surface. Magma reaches the surface through a vent & becomes lava when risen through a pipe and ejected through a crater

- ✓ Global distribution of volcanoes correlates with tectonic activity!
- ✓ 2/3 of world's volcanoes located in circum-Pacific region (Pacific Ring of Fire) where subduction produces volcanoes in fold mountains or volcanic island arcs
- ✓ Volcanic activity occurs in following tectonic settings:
 - Oceanic-oceanic divergence (seafloor spreading)
 - Oceanic-oceanic/continental convergence (subduction)
 - Intra-plate vulcanicity (hotspot)



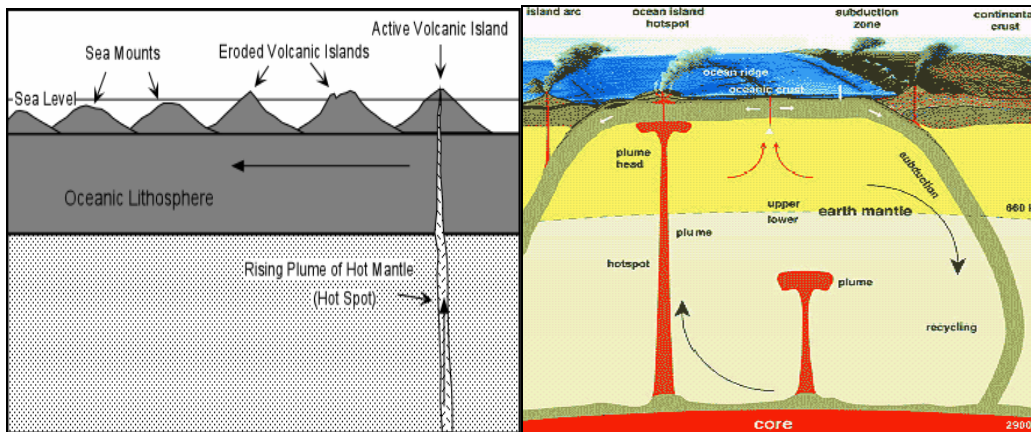
<http://media-2.web.britannica.com/eb-media/53/4953-004-9D51CA25.jpg>



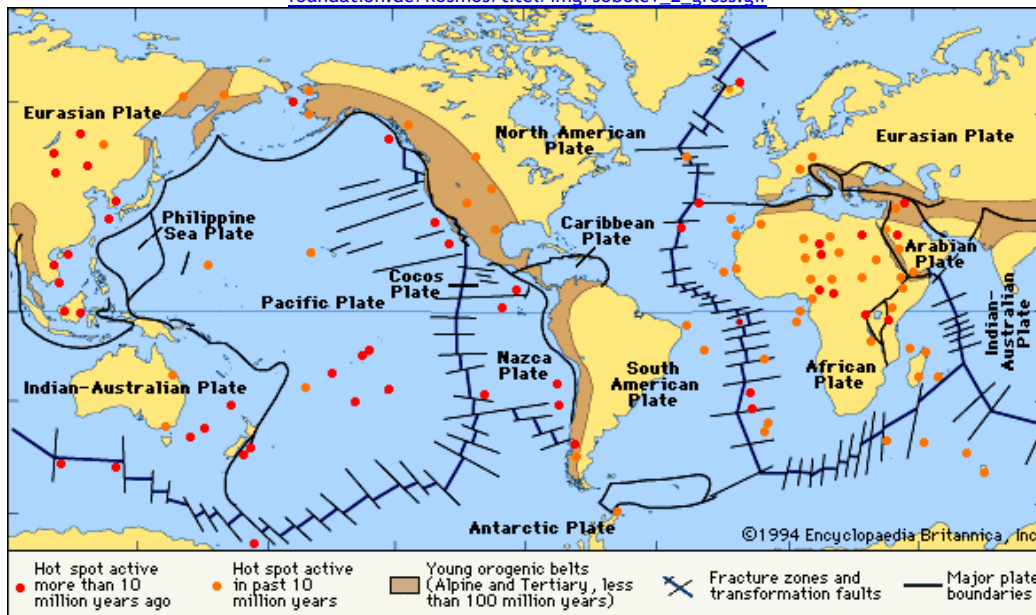
<http://cache.eb.com/eb/image?id=4949&rendTypeld=4>

- ✓ At spreading ridges, greatest volume of volcanic rock is produced

- Lithosphere pulls apart → less pressure on underlying rocks → partial melting of mantle → basaltic magma produced
- ✓ At subduction zones, volcanoes occur in conjunction with trenches
 - Sinking of denser oceanic crust → partial melting of subducted plate → magma produced
 - Associated with explosive volcanic eruptions
- ✓ At hot spots, stationary columns of magma originating deep within mantle (mantle plumes) slowly rise to the surface
 - As plates move over hot spots, trails of extinct progressively older volcanoes left behind
 - 100+ active hotspots beneath Earth's crust, mostly within plates but some near divergent plate boundaries



<http://www.tulane.edu/~sanelson/images/hotspot.gif> & http://www.humboldt-foundation.de/kosmos/titel/img/sobolev_2_gross.gif



<http://media-2.web.britannica.com/eb-media/37/3537-004-7B9EB83C.gif>

Magma

(Priority: Medium)

Magma: fused molten rock material found beneath Earth's crust from which igneous rocks are formed. Magma reaches Earth's surface through a volcano. Magma when effused onto Earth is known as lava!

- ✓ Composition of magma & lava determined by most abundant elements in Earth (Si, Al, Fe, Ca, Mg, Na, K, H & O)
- ✓ Silica (SiO₂) is predominant compound present, and high temperatures prevail (in excess of 1000 °C)
- ✓ Magma viscosity (resistance to flow) dependent on temperature & composition
 - Higher temperature & lower silica content, lower viscosity

Type	Basaltic	Andesitic	Rhyolitic
<i>SiO₂ content</i>	<50%	50-60%	>70%
<i>Eruption temperature (°C)</i>	1000 - 1200	800 - 1000	650 - 800
<i>Viscosity</i>	Thin & runny lava →→→→→ Thick & sticky lava		
<i>% of volcanoes</i>	80%	10%	10%
<i>Found at</i>	Spreading ridges & hotspots	Subduction zones	
<i>Formation process</i>	Melting of oceanic crust & mantle	Combination of basaltic magma & continental crust	Melting of continental crust
<i>Characteristics</i>	- Flows quickly & moves >20km away from vent - Volcanic gases escape easily → non-explosive eruptions - Forms shield volcanoes	- Erupts from stratovolcanoes as thick lava flow - Strong explosive eruptions forming pyroclastic flows, surges & huge eruption columns - Forms stratovolcanoes, island & volcanic arcs	- More dissolved gases → higher viscosity - Often solidifies before reaching Earth → solid rock dome blocking vertical eruption → sideways eruption / forms caldera - Sudden violent eruptions forming volcanic domes
<i>Examples</i>	Mauna Loa, Hawaii	Mt Fuji, Japan	Mt Lassen, USA

Volcanic Features

(Priority: Medium)

1. Shield volcano

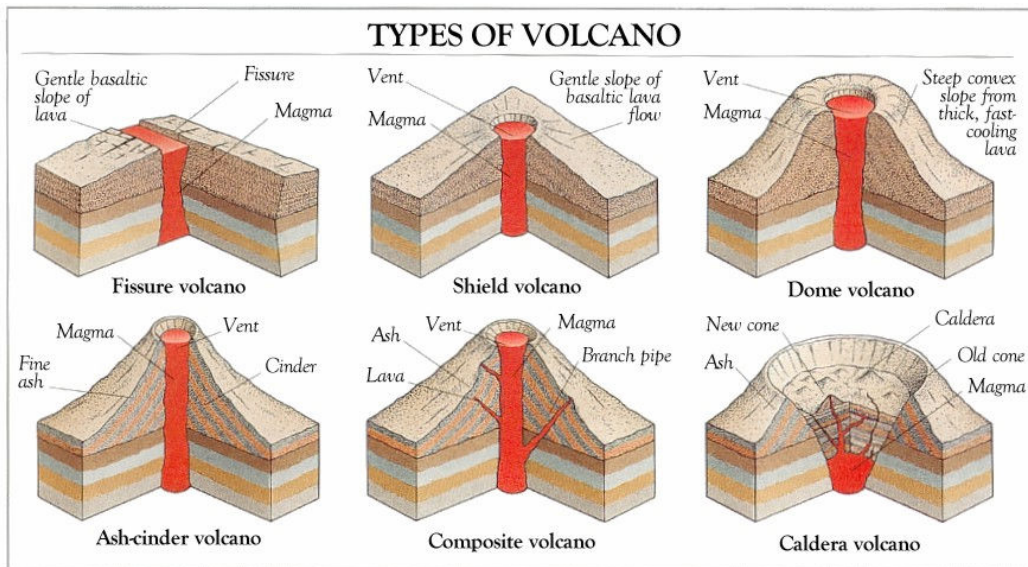
- ✓ Broad, slightly dome-shaped composed mainly of basaltic lava
- ✓ Formed by mild eruptions of large volumes of lava
- ✓ E.g. Mauna Loa, Hawaii

2. Stratovolcano / Composite volcano

- ✓ Classic, cone-shaped composed of inter-bedded layers of lava flows & pyroclastic debris
- ✓ Sills & dykes form as lava cools in the volcano
- ✓ Mostly located in Pacific Ring of Fire (E.g. Mt St Helens)

3. Caldera

- ✓ Enlarged crater formed by extremely violent eruption blasting off volcano peak or causing sinking into magma chamber
- ✓ Crater can fill with water to form crater lake (E.g. Lake Toba, Indonesia)



<http://mediatheek.thinkquest.nl/-/l125/images/volcano.jpg>

4. Geyser

- ✓ Groundwater heated by magma beneath volcanic areas → water & steam ejected from ground
- ✓ E.g. Old Faithful, Yellowstone National Park (ejects every 40 mins)

Nature & Style of Volcanic Eruptions (Priority: Low)

Volcanic eruption style dependent on lava viscosity & amount of dissolved gases: fluid basaltic lava with little dissolved gases produce quiet eruptions versus viscous lava with high dissolved gases

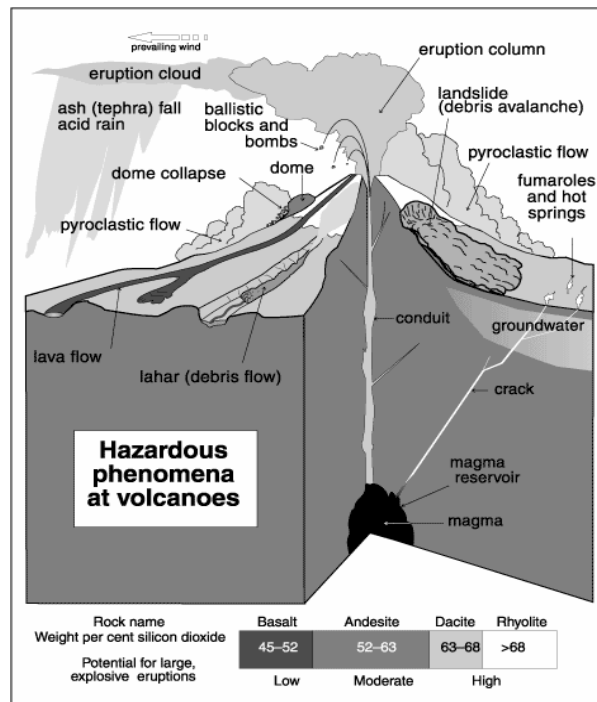
- ✓ Gas content affects magma mobility as gases expand within magma nearer Earth's surface due to decreasing pressure
 - Violence of eruption dependent on how easily gases escape
- ✓ Erupted materials include lava, gases & pyroclasts (rocks, ash, dust)

→→→ Increasing violence of eruption →→→			
<i>Fissure / Hawaiian</i>	<i>Strombolian</i>	<i>Vulcanian</i>	<i>Plinian</i>
VEI 0	VEI 1 - 3	VEI 3 - 5	VEI 4 - 7

(VEI - Volcanic Explosivity Index)

Volcanic Hazards (Priority: High)

Types of volcanic hazards: primary hazards (directly from eruption) include lava & pyroclastic flow, lateral blasts, ash fall & gas releases and secondary hazards (caused by primary effects) include lahar, landslides & fires



http://cgc.rncan.gc.ca/volcanoes/images/fig31_e.gif

Primary hazards

1. Lava flow

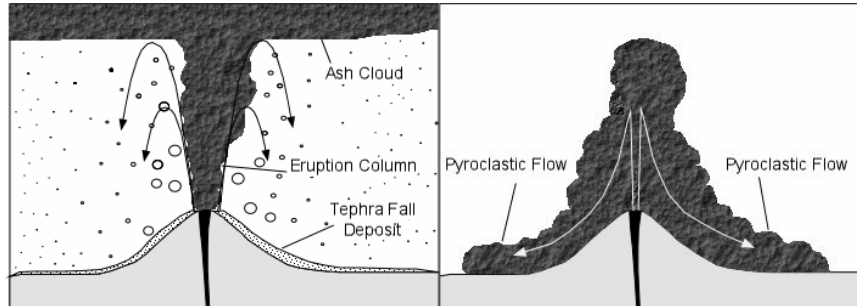
- ✓ Masses of molten rock pouring onto Earth's surface during effusive eruption (VEI 0 - 1)
- ✓ Lava flows refer to both moving lava & resulting solid deposit
- ✓ Lava temperatures above ignition point of many materials → combustion of all in its path
- ✓ Crust forms when dried but internal temperature of lava remains high for years
- ✓ Pahoehoe lava: flows in thin, broad sheets with smooth & wrinkled outer skin and molten flow beneath
- ✓ Aa lava: rough rubbly surface composed of broken lava blocks
- ✓ Pahoehoe & aa differ in way they flow despite same composition: fresh lava almost always liquid pahoehoe lava but as it cools and crystallizes it becomes aa lava
- ✓ Lava fountain: Jet of lava sprayed into air by rapid formation & expansion of gas bubbles in molten rock
- ✓ Damage potential: fire threat, transport debris from buoyancy effect, inundate farmland, dam / modify rivers & noxious haze



<http://geology.about.com/library/bl/images/blaa.htm> &
<http://geology.about.com/library/bl/images/blpahoehoe.htm>

2. Tephra

- ✓ Fragments of volcanic rock & lava blasted into air by explosion or carried upward by hot gases in eruption columns
- ✓ Includes ash, cinder, pumice & bombs
- ✓ Average size of individual rock particle decreases with increasing distance from volcano
- ✓ Damage potential: ignite fires, collapse roofs from heavy / dense ash, reduced visibility, source for lahars, water contamination & health problems, threat to aircraft engines
- ✓ Climatic impact: air pollution → haze & acid rain, albedo effect → climatic cooling



<http://www.tulane.edu/~sanelson/geol111/igneous.htm>

3. Pyroclastic flow

- ✓ Ground-hugging avalanche of hot ash, rock fragments & volcanic gas rushing down volcano sides as fast as 100 km/h (VEI 3 - 8)
- ✓ Temperatures can exceed 500°C
- ✓ Typically formed by dome collapse, explosion or eruption column collapse
- ✓ Small flows travel 5 - 10 km, larger flows can travel 50 - 100 km!
- ✓ Damage potential: destructive force of impact, inability to outrun, can travel across water and source for lahars

Secondary hazards

4. Lahar

- ✓ Volcanic mudflow of water & loose volcanic debris
- ✓ Can be formed via eruption onto snow / ice, breaching of crater lake, precipitation onto unconsolidated ash & pyroclastic deposits
- ✓ Travels 10 km at velocity 10 km/h
- ✓ Damage potential: bury land / property, clog & contaminate rivers (hazard can continue for years!)
- ✓ Mitigation: trip wires, barriers & dredging

5. Debris avalanche

- ✓ Moving masses of rock, soil & snow when volcano flank collapses and slides downwards

- ✓ Triggered by eruptions causing materials to break free; can travel several km before stopping or transform into water-rich lahars that travel even further downstream
- ✓ Can be extremely widespread (covering 100 - 1000 km²)
- ✓ Source for lahars & tsunami threat
- ✓ E.g. Mt St Helens, USA in 1980

6. Volcanogenic tsunami

- ✓ Generated by violent eruptions on volcanic island or coastal volcano
- ✓ Several waves generated, with deep water velocities exceeding 800 km/h and wave heights from 30 - 100m
- ✓ Very rapid dispersal and occurring with little warning, may also occur without eruption → widespread & huge impact
- ✓ Mitigation difficult without warning system
- ✓ E.g. Krakatoa, Indonesia in 1883 (killing ~36k)

Effects of Volcanic Hazards (Priority: Medium)

Category	Effects
P hysical / E nvironmental	<ul style="list-style-type: none"> ✓ Earthquakes ✓ Tsunamis ✓ Torrential rains → floods & landslides ✓ Poisonous gases → smog, acid rain, toxic soils
E conomic	<ul style="list-style-type: none"> ✓ Destroyed homes & infrastructure ✓ Destroyed / lost farmland
S ociocultural	<ul style="list-style-type: none"> ✓ Diseases & health problems ✓ Food crisis
C limatic	<ul style="list-style-type: none"> ✓ Haze / Acid rain ✓ Global temperatures lowered ✓ Ozone depletion

Volcanic Hazards Management (Priority: High)

Elusive objective in many countries despite advances in hazard prediction; DCs have better technology & resources available for such prediction measures. Hence attention turned towards mitigation & response!

PREDICTION	MITIGATION	RESPONSE
1. Recurrence interval prediction 2. Seismic activities 3. Ground deformation 4. Gas / steam emissions 5. Visual surveying	6. Lava diversion 7. Hazard-resistant structures 8. Evacuation planning 9. Hazard mapping	10. Provision of basic necessities 11. Provision of technical / financial / goods aid

Volcanic Hazard Prediction (Priority: High)

1. Recurrence interval prediction

- ✓ Predict possible eruptions with study of past eruptive history

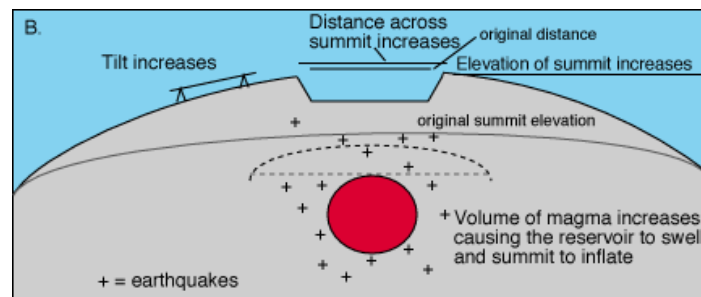
- ✓ Identify geologic deposits from past eruptions to determine characteristic behaviour of volcano
- ✓ (-) Prediction scope limited by availability of data

2. Seismic monitoring

- ✓ Important in prediction & monitoring; baseline monitoring
- ✓ Changes in seismic activity are earliest signs of impending eruption
 - Monitored by seismometers sending information continuously to central recording site
- ✓ Volcanic earthquakes / harmonic tremors (continuous vibration of ground) occur due to magma movements and hence precede eruptions
- ✓ (+) Successful in forecasting 25 earthquakes in 20 years, e.g. Mt Pinatubo, Philippines in 1991

3. Ground deformation monitoring

- ✓ Using tiltmeter to measure tilt of volcano flank
 - Magma forcing upwards causes volcano to "inflate" like a balloon, increasing distance across summit
 - After eruption, volcano "deflates" and distance across summit decreases
 - (-) Site specific as unable to measure across volcano
- ✓ Lateral displacement measurements using Global Positioning System (GPS)



<http://www.uhh.hawaii.edu/~kenhon/GEOL205/monitor/monitors.html>

4. Gas / steam emissions monitoring

- ✓ Gases dissolved in magma provide driving force for eruption
 - Gases include water vapour, CO₂ & SO₂
- ✓ Increased gas emissions can be detected as magma approaches surface → aim to identify changes in release of gases
- ✓ Amount of SO₂ released by volcano measured using a correlation spectrometer (COSPEC) by comparing light coming through volcanic plume to known spectra of SO₂

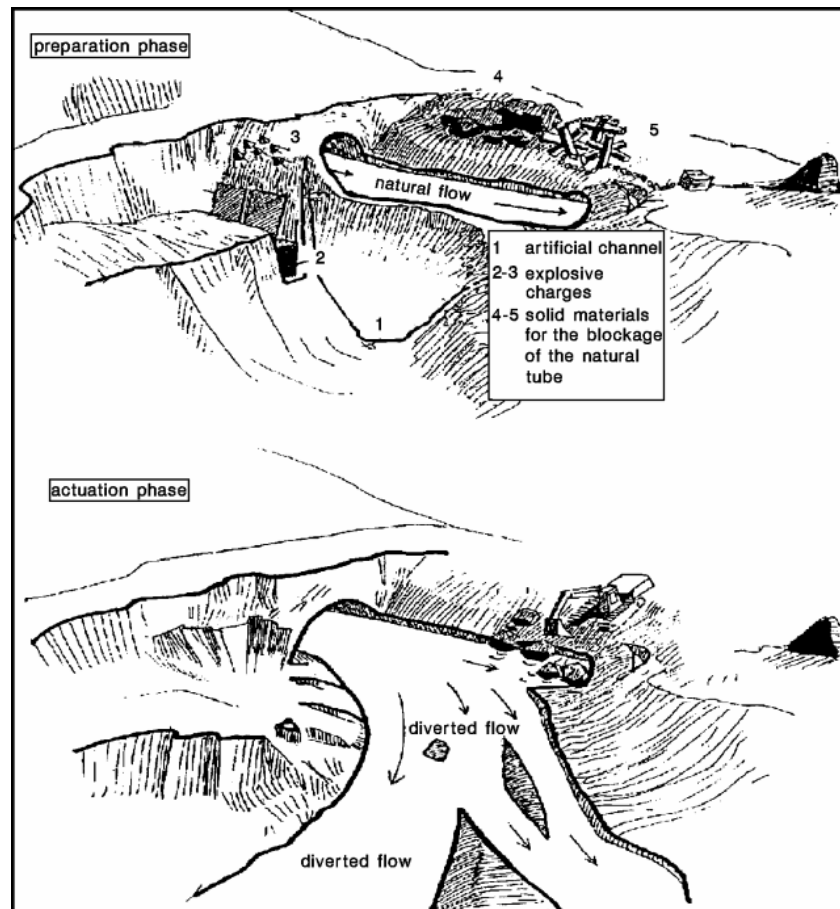
5. Direct visual surveying

- ✓ (+) Direct sampling for long-term study of volcanic systems allowing specific chemical analysis of data
- ✓ (-) Unsuitable for monitoring rapidly changing conditions in emergency because of time needed for laboratory analysis

Mitigation of volcanic hazards lessen the severity / intensity of the hazards

1. Lava diversion

- ✓ Only primary hazard humans have attempted to control
- ✓ Detonate explosives to disrupt lava flow, e.g. Mt Etna in 1983
- ✓ Spray water to cool lava flow, e.g. Heimaey, Iceland in 1973
- ✓ Construct artificial barriers, e.g. Hilo, Hawaii



<http://www.volcano.si.edu/volcanoes/region01/italy/etna/01etn54f.png>

2. Hazard resistant structures

- ✓ Strong roofs with steep-sloping sides designed to shed ash
- ✓ (-) Structures can do little to resist lava / pyroclastic flow and / or lahars

3. Evacuation management

- ✓ Extensive, expensive but effective strategy
- ✓ Identify risk → ensure community awareness, education & preparedness → monitor & recognize eruption precursors → forecast nature & area of activity, predict eruption duration
- ✓ Effective emergency response depends on pre-crisis education & training, established warning systems & a simple and understandable alert system

- ✓ E.g. Mt Iwate, Japan: emergency procedures produced by Iwate Volcano Bureau monitoring Mt Iwate
- ✓ Risk awareness & public education critical role in reducing impact of volcano eruptions
 - Progressive programme involving raising awareness, education about threat and training in preparedness & crisis response
 - Coherent public education programme important: multiple channels & agencies with consistent message!
 - Schools play vital role in public education
- ✓ E.g. Nevado del Ruiz, Colombia in 1985: lack of preparations for the eruption by scientists & locals alike contributed partly to high death tolls

4. Hazard mapping

- ✓ Identify hazard prone areas → planned land use zoning to reduce damage to property & lives
- ✓ E.g. hazard mapping of Hawaii influenced by location of volcanoes (Kilauea, Mauna Loa etc) and their main hazard (lava flows)

Volcanic Hazard Response

(Priority: Medium)

Response to volcanic hazards aims to minimize loss of lives. Ultimately, prevention is better than cure!

- ✓ Provision of basic necessities:
 - Shelter
 - Food
 - Basic hygiene amenities
 - Medical care
 - Technical aid
 - Financial / goods aid
- ✓ 600m people live close to dangerous volcanoes; 60 big cities are directly / indirectly threatened by volcanic eruptions
- ✓ Increasing vulnerability hence makes it necessary for measures to reduce disasters, adopt rational settlement planning & develop disaster preparedness programmes
 - Consolidate & disseminate knowledge about vulnerabilities & disaster management
 - Developing good land management, building codes & evacuation planning
 - Education & improving coordination between all parties involved