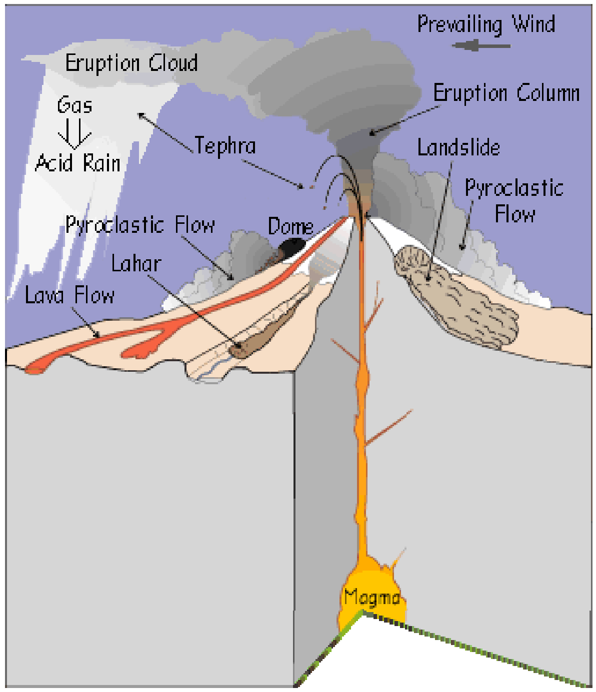
Volcanoes and Volcanic Hazards



Volcanic Hazards

- Effusive Eruptions
  - Lava Flows
- Explosive Eruptions
  - Pyroclastic flows
  - Lahars
  - Ash fall
  - Ash clouds
  - Phreatic eruptions
- All Eruptions/Volcanoes
  - Volcanic Gases
  - Landslides
  - Tsunami

Volcanic Behavior

Viscosity

- Viscosity: Ability to flow
  - The lower the viscosity the more fluid the behavior
    - Water (low viscosity) flows faster then honey (high viscosity)
  - Low viscosity magma flows like ice-cream on a hot day
  - High viscosity magma hardly flows at all
- Higher temperatures lowers viscosity
- High silica and oxygen contents increase viscosity
- Increased content of minerals (i.e. crystallized minerals) increases the viscosity
- *Viscous magmas are more prone to explosive eruptions*

Factors Affecting Magma Explosivity

Volatile Content

- **Volatile Content:** how much gas is contained in the magma
  - Volatiles include water/steam, carbon dioxide, sulfur dioxide, etc.
  - Gas content can range from < 1% (Kilauea) to > 5% (Mt. St. Helens) by weight
- The higher the volatile content, the more explosive the magma

Mageik Volcano, Alaska

http://volcanoes.usgs.gov/About/What/Monitor/Gas/sample.html

Volcanic Behavior

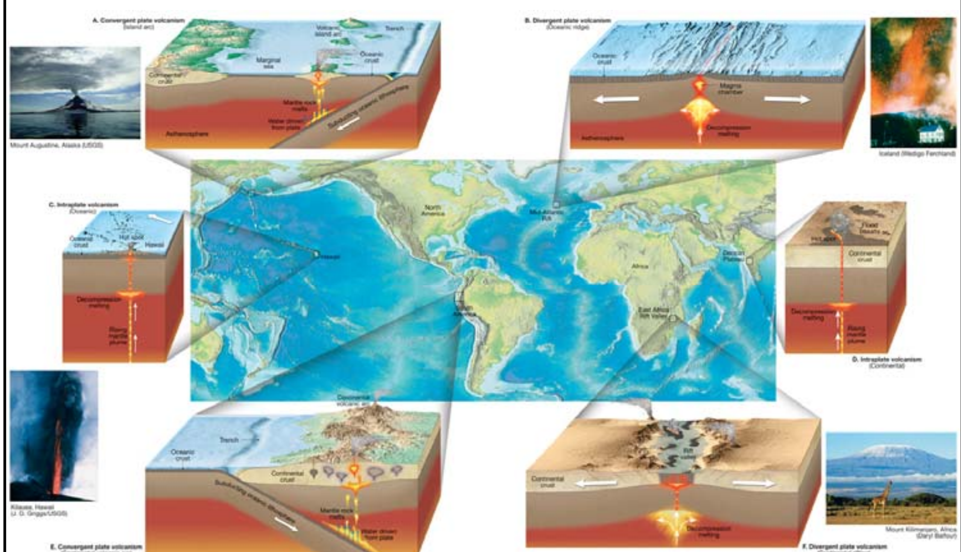
Volatile Content

- Volatile
  - Dissolved gas contained in the magma
  - Solubility in magma increases as pressure increases and temperature decreases
- Analogues to a soda under pressure by the bottle cap
  - When the cap is removed, reducing the pressure volatiles (CO_2) gas escapes
  - As the uncapped bottle warms, more volatiles are released (i.e. the soda goes flat)
- In low viscosity magmas gas easily escapes so pressure in the magma does not build up leading to non-explosive or effusive eruptions
- In high viscosity magmas gas becomes trapped in the magma causing pressures to increase.
  - When the pressure is reduced dissolved gasses expand in volume
  - Because gases cannot escape the high viscosity magma
    - Explosive eruptions can result

Where are the Major Volcanoes?

- 80% located at convergent boundaries, primarily subduction zones (explosive)
  - ~900 around the Pacific Ring of Fire (primarily in New Zealand, Japan, Alaska, Mexico, Central America, and South America)
  - ~250 in the Mediterranean
- Approximately 20% located along mid-oceanic ridges/spreading centers (effusive)
- Small percentage located at “hot spots” far from plate boundaries (e.g., Hawaii, Decan Traps) (effusive)
  - Explosive exceptions – Yellowstone (hot spot on continent), some Icelandic volcanoes (e.g., Eyjafjallajökull)


Hekla
Laki
Pavlof
Shishaldin
Bezymianny
Surtsey
Katmai
("Valley of
10,000 Smokes")
Mt. St. Helens
Vesuvius
Santorini
Fujiyama
Mt. Unzen
Kilauea
Popocatepetl
Canary Is.
Etna
Pinatubo
Mariana Is.
Mt. Mayon
Pelée
Paricutin
Mauna Loa
Galapagos Is.
Nevado del Ruiz
Krakatau
Cotopaxi
Misti
Kilimanjaro
Tambora
Tonga Is.
RING OF
FIRE
Easter Is.
New Zealand
South Sandwich Is.
Deception Is.

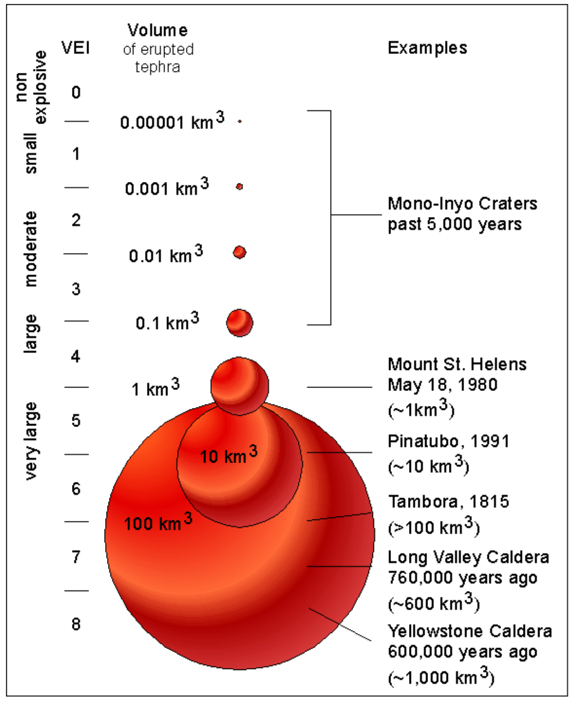


Volcanic Explosivity Index (VEI)

Historic Eruptions

VEI is primarily used to estimate the relative size of an explosive eruption

In the last 10,000 yrs
- 4 VEI 7 eruptions
- 39 VEI 6 eruptions
- 84 VEI 5 eruptions
- 278 VEI 4 eruptions
- 868 VEI 3 eruptions
- 3477 VEI 2 eruptions



Volcanic Hazards

Lava Flows

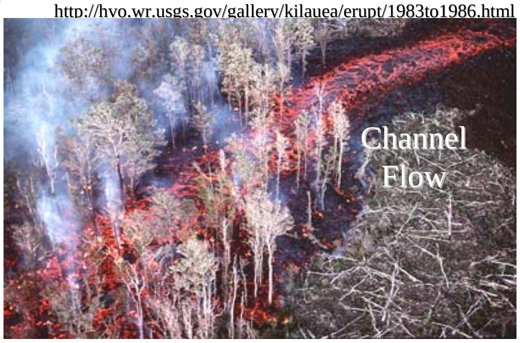
- Molten rock that pours, oozes, or fountains from erupting vent (effusive or mildly explosive)
- Flow speed depends on
  - Viscosity
  - Topography
  - Type of flow
    - Broad sheet
    - Confined channel
    - Lava Tube

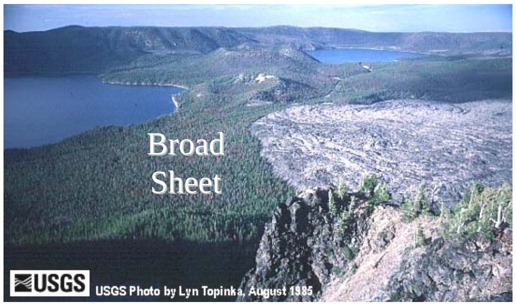
Volcanic Hazards

Lava Flows

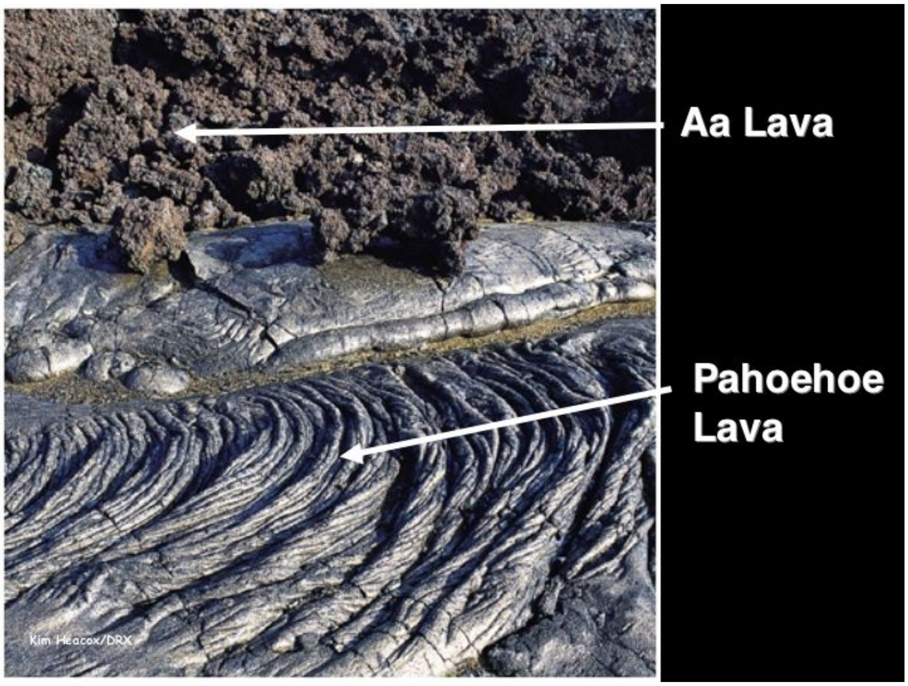
- Mafic Lavas (basalt)
  - Can extend 10's km
  - Typical speeds
    - Free flowing: <1 to 10 km/hr
    - Confined channels/tubes: > 30 km/hr
- Viscous Felsic Lavas
  - Andesite
    - Can extend < 8 km
    - Typical speeds ~1 km/hr
  - Dacite and Rhyolite
    - Forms steep sided mounds (a.k.a. lava domes) over erupting vent which can grow to > 30 m thick over periods of months to years
    - Speeds << 1 km/hr
      - Newberry Caldera, OR

http://hvo.wr.usgs.gov/gallery/kilauea/erupt/1983to1986.html

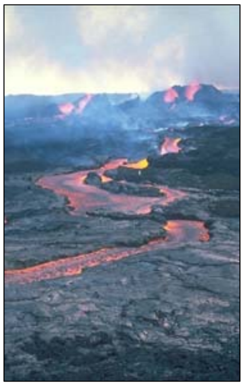




http://vulcan.wr.usgs.gov/Volcanoes/Newberry/images.html



Lava Flows



- Streams of molten rock
- Usually slow speed
  - Only a few mph
  - Can reach up to 60 mph
- Intermediate to mafic composition
- Most common hazard; leads to mostly destruction of property

Lava flow characteristics

Etna 1971

- VEI 0 - 1 eruptions
- Temperature of flowing lava above ignition point of many materials (750 to 1100ºC)
- Crust forms but internal temp can remain high for years
- Flow rate is viscosity dependent (a few 10's m/h to > 60 km/h)
- Thickness: a few to 10s m
- Tube & channel flow

Lava flow damage potential

- Fire threat
- Strength sufficient to destroy most structures
- Buoyancy effect may lift and transport objects
- Large areal extent: may inundate large areas of farmland
- May dam rivers & modify drainage
- Sustained lava eruptions may generate noxious haze (Laki, Iceland 1783)

Volcanic Hazards

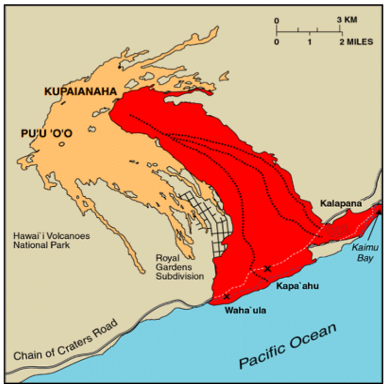
Lava Flows

- Generally not lethal
- Associated hazards
  - Knocks down, surrounds, buries, melts or burns everything in path; even far from the volcano
  - Melts snow and ice to form lahars
  - Water (in lakes or oceans) boils violently sending explosive showers of molten spatter over wide area
  - Methane gas, produced as lava buries vegetation, explodes when heated
  - Bury homes and agricultural land under meters of hardened black rock; land generally unusable thereafter

Visitors Center at Hawaii Volcanoes National Park (Kilauea Volcano)

http://wwwhvo.wr.usgs.gov/gallery/kilauea/erupt/1986to1991.html

Pu’u ‘O’o and Kupaianaha



Flow through 2002

- Started eruptions in 1983
- By 2002, 189 structures destroyed and 13 km of highway covered with up to 25m of lava

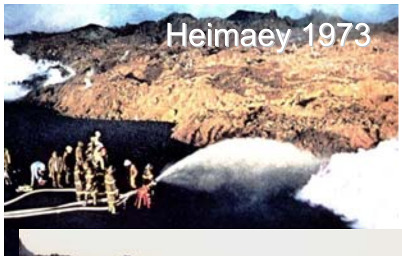
Kilauea, Hawaii

Lava Flows

- Royal Gardens Subdivision, Kalapana, Hawaii
  - Subdivision located on South Flank of Kilauea Volcano
  - What wasn’t destroyed was totally cut off by impassable lava flows
  - Tube-fed pahoehoe flow
- World-wide, as populations increase, a greater number of populations/structures are in the way of potential lava flows

Both from http://hvo.wr.usgs.gov/gallery/kilauea/erupt/1986to1991.html

Lava flow mitigation



- Bombing
  - (Kilauea 1940s)
- Water sprays
  - (Heimaey 1973)
- Barriers
- Feeder tube blocking
- Diversion
  - (all Etna 1983 & 1991 - 3)

Volcanic Ash

Ash characteristics

- Most voluminous product of explosive eruptions (VEI 2- 8)
- Eruption columns typically up to 10 km (may reach > 50 km)
- Strong wind influence
- Downwind transport velocities <10 - <100 km/h
- Exponential fall in thickness downwind
- Can extent >1000 km downwind

Bedded ashes
Laacher Zee (Germany)

Ash damage potential

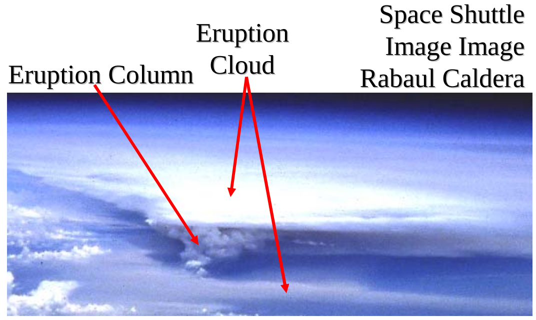
- Pumice may be hot enough to ignite fires at 30+km
- Density of compacted wet ash may be 1.6 tonnes/cubic m
  - 30 cm may collapse roofs
- Visibility may be a few 10s cm for hours
- Dry ash also causes visibility problems
- Highly abrasive
- Magnetic

Volcanic Hazards

Ash Clouds

- Column of tephra (fragmented materials produced by volcanic eruption) that forms above the volcanic vent
  - Vertical eruption column
  - Umbrella region in which cloud begins to spread horizontally
- Cloud moves downwind of the erupting volcano
  - If enters stratosphere, large clouds can encircle the Earth within days
- Only largest eruptions are able to puncture tropospheric-stratospheric boundary

Space Shuttle Image Image Rabaul Caldera



http://volcanoes.usgs.gov/Products/Pglossary/
http://www.avo.alaska.edu/avo4/atlas/volc/redou/photo.htm

Mount Saint Helens, Washington

May 18,1980 Eruption – Ash Cloud

Advancing ash cloud

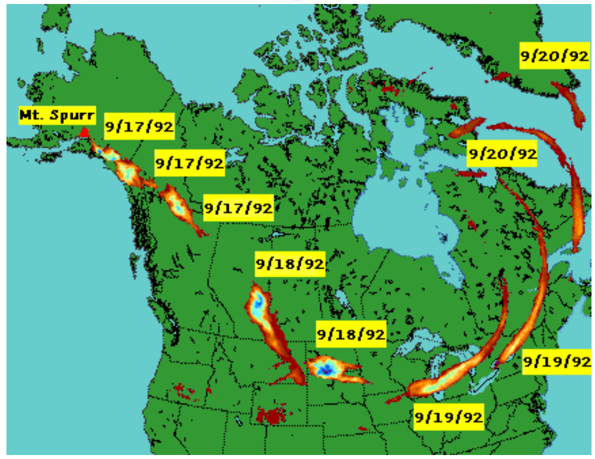
http://wrgis.wr.usgs.gov/fact-sheet/fs027-00/

Volcanic Hazards

Ash Clouds

- As ash cloud moves downwind of the erupting volcano
  - May drift 1000's km downwind
  - Spreads out over an increasing area with increasing distance from the volcano
  - As spreads out, ash particles become less concentrated
- Can potentially affect large numbers of people
- Can disrupt air traffic

1992 Mt. Spurr, Alaska



http://wrgis.wr.usgs.gov/fact-sheet/fs030-97/

Ash damage potential and mitigation

- Surface crusting of fine ash promotes runoff
- Provide source for lahars
- Disrupts transportation communication, power distribution, and electronics
- Crop and fishery damage and water contamination
- Human and livestock health problems
- Mitigation: roof design & ash clearance

Volcanic Hazards

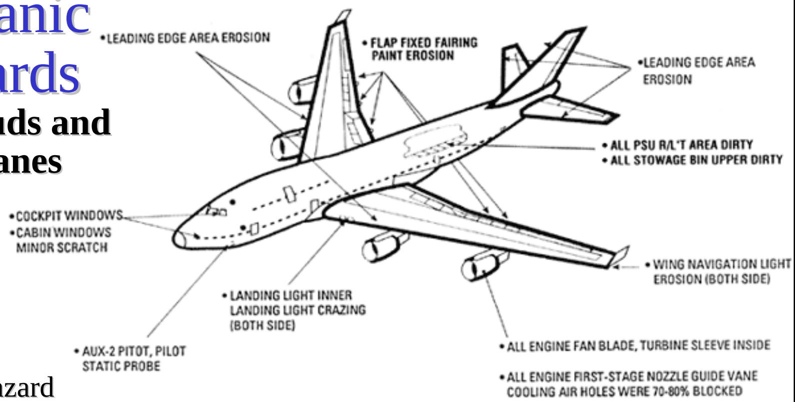
Ash Clouds: Long-Term Effects

- Ash Clouds
  - Solid tephra particles
  - Volcanic Gasses
    - Fine pulverized rock and gases, which are converted into droplets of sulfuric acid and hydrochloric acid
- Hazards
  - Ash fall
  - Aviation hazard
  - Natural source of pollution
    - Acid rain
    - Contaminates surface waters, vegetation
  - Emitted gases affects health of humans and animals.
- Climate affected if ash cloud reaches stratosphere
  - Ash and sulfur dioxide droplets cause global cooling
  - Especially pronounced for eruptions near the equator

http://pubs.usgs.gov/pinatubo/casa/

Volcanic Hazards

Ash Clouds and Airplanes



Aviation hazard
- >80 aircraft have unexpectedly encountered volcanic ash in flight and on ground
- Seven caused in-flight loss of jet engine power, which nearly resulted in crash of the airplane

Types of damage
- Reduces engine performance; May cause failure
  - Abrades components
  - Forms glassy coating which covers cooling passages
- Abrades external components, leading edges, windshields, etc.
- Contaminates interior

Galunggung Volcano, Indonesia

Event Summary: June 24, 1982 - I

British Airways Flight 9, a Boeing 747-200 with 247 passengers and 16 crew members, was flying at an altitude of 11,470 meters from Kuala Lumpur, Malaysia, to Perth, Australia. Dinner had been served and night had settled as the plane crossed southern Sumatra and western Java. Minutes earlier it passed over the Sunda Straits and Krakatau. The flight had been uneventful until Captain Eric Moody left his seat to check on the main cabin. He had barely reached the bottom of the stairs when he was called back to the flight deck. Running up the stairs he saw the flight engineer and co-pilot watching a spectacular display of St. Elmo's fire outside the plane. It was so intense that it looked as if magnesium flares were in the engines. Then, a series of apparently impossible events occurred. First, the number four engine failed. Then, one after another, the other three engines failed. With great reserve, the flight engineer said, "Number two's gone, number three's gone, and ... golly-gosh, we've lost the lot."

Four engines on modern jets do not fail; it simply does not happen. Mystified, the crew sent an immediate mayday call. "Djakarta, Djakarta, Mayday, Mayday. This is Speedbird 9. We have lost all four engines. Repeat, we have lost all four engines! ... There is a possibility that we may have to ditch." The radio transmission was difficult to understand because of the tremendous static from electrical discharges; the air traffic controllers in Djakarta thought they had heard right, but did not believe that four engines could have failed at the same time.

Galunggung Volcano, Indonesia

Event Summary: June 24, 1982 - II

From 11,470 meters, the 747 became an enormous glider as the crew repeatedly tried to restart the engines. During the first check the plane fell as much as 930 meters; the crew ran through the restart procedures at least twenty times after that. At 4,030 meters altitude, one engine was restarted and another started about 90 seconds later, and 20 seconds after that the remaining two engines came on with an enormous roar. But the number two engine was surging badly, causing the plane to lurch from side to side, so Captain Moody ordered it shut down.

As the plane turned into the approach to Djakarta airport for an emergency landing, the crew realized that the visibility was extremely bad because the windows had been sandblasted, and they could see only poorly through about a two-inch strip on either side of the windshield. The captain had to stand, peering through the side of the window, flying the plane on three engines. At an elevation of about 30 meters, Captain Moody remarked "Oh well, we aren't going to die now," and the plane made a smooth landing.

The British Airways crew had no idea that they had flown through an ash cloud. Since it was night when the jet passed through the ash cloud, the crew could not see it, but even during the day, a disseminated ash cloud does not look much different from an ordinary cloud. Nor are ash clouds dense enough to be visible on present onboard radar systems. In 1982 there were no warning systems nor any awareness that they were needed. Galunggung, located in south central Java, had been erupting for three months, with ash clouds sweeping east and south. Thousands of residents had been evacuated, but no thought was given to flights passing overhead.

Eyjafjallajökull, Iceland

Volcanic Ash

Volcanic Ash

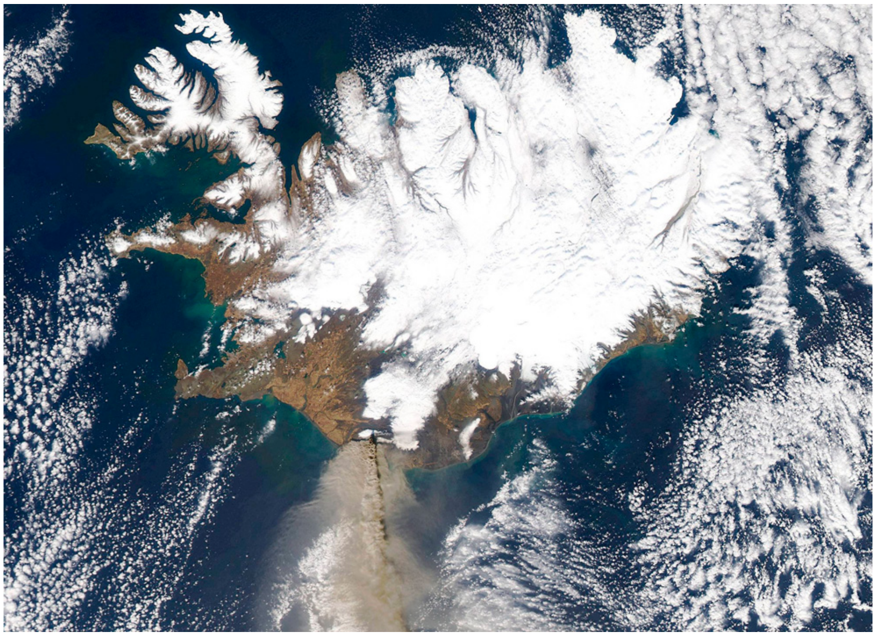
Volcanic Ash

Eyjafjallajökull, Iceland

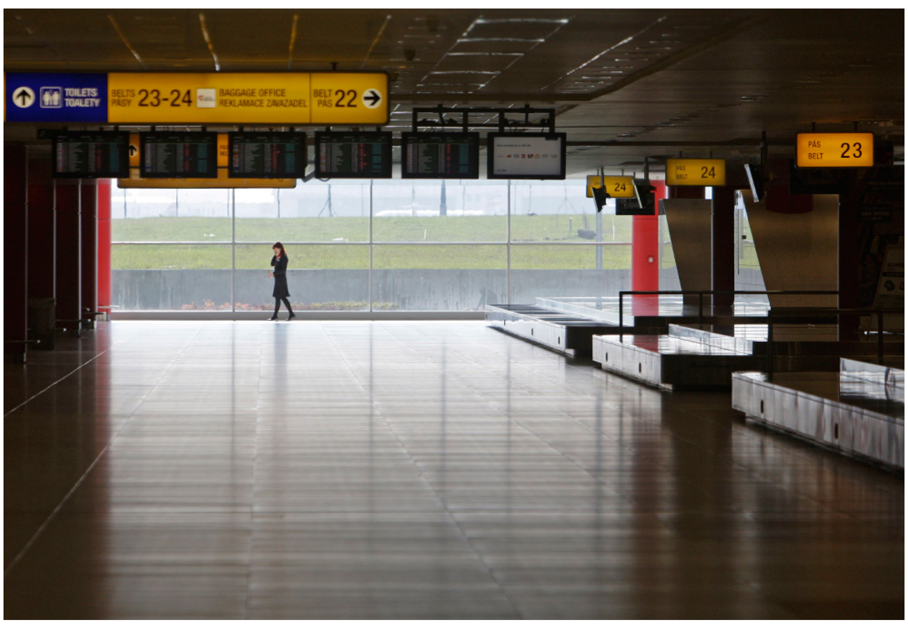
- Iceland – hot spot that straddles a mid-ocean spreading center
  - Expect basaltic lava
    - Flank and fissure vents erupt basaltic lava
    - Differentiation beneath the central volcano results in moderately silica-rich lava
      - Therefore relatively viscous
- Eyjafjallajökull
  - Silica-rich
  - Relatively high viscosity lava
  - High levels of gas supersaturation
    - Moderately high eruption rates
  - Plus the location of the fissure is under glacial ice
  - Very extensive interaction with glacial melt-water.
    - Increased the efficiency of the explosions
    - Generated much more fine ash than is typical of Icelandic eruptions
  - Fine ash stays in the atmosphere for extended periods
    - Very low settling velocities

Volcanic Ash

Volcanic Ash

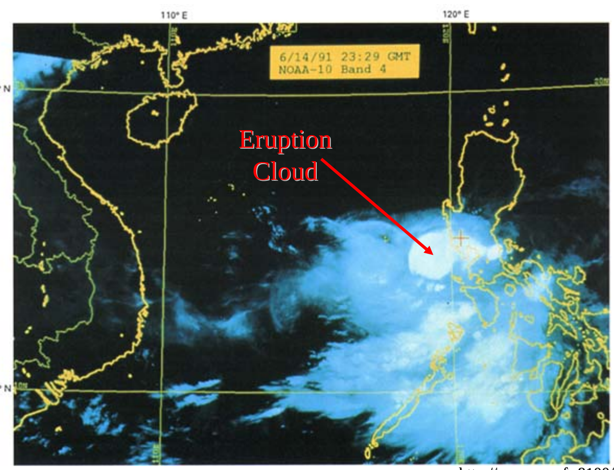


Volcanic Ash



Mt. Pinatubo, Philippines
1991

Both from http://pubs.usgs.gov/pinatubo/casa/



Damaged Jet Turbine Blades

Melted Ash Coating

http://ceos.cnes.fr:8100/cdrom-97/ceos1/casestud/volcano/plane1.htm

Volcanic Hazards
Ash Falls

1991 Mt. Pinatubo, Philippines

1997 Soufrière Hill, Montserrat, West Indies

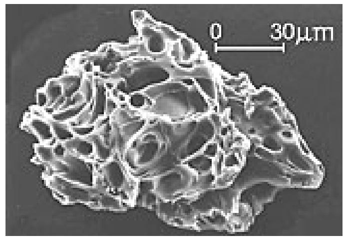
1994 Rabaul, Papau New Guinea

All from http://volcanoes.usgs.gov/Hazards/What/Tephra/tephra.html

Volcanic Hazards

Ash Falls

- **Ash**: smallest tephra fragments
  - <2 mm in diameter
  - Can be carried by wind
  - Can travel 1000's of km
- Affects far more people than other, more lethal volcanic hazards
- Covers everything, infiltrates most openings, and is highly abrasive
- Buries objects close to source
- Potential Effects
  - Daylight turns to darkness
  - Roofs collapse from weight
  - Machinery and vehicles abraded
  - Farmland covered
  - Streets become slippery/blocked
  - Power plants forced to shut down
  - Sewer systems clog
  - Gutters fill and collapse



Both from http://wrgis.wr.usgs.gov/fact-sheet/fs027-00/

Mount Saint Helens, Washington

May 18,1980 Eruption – Ash Fall

- Ash fall accumulations

http://geopubs.wr.usgs.gov/fact-sheet/fs027-00/

http://vulcan.wr.usgs.gov/Glossary/Tephra/images.html

http://wrgis.wr.usgs.gov/fact-sheet/fs027-00/

Mt. Pinatubo, Philippines

Clark Air Force Base, 1991

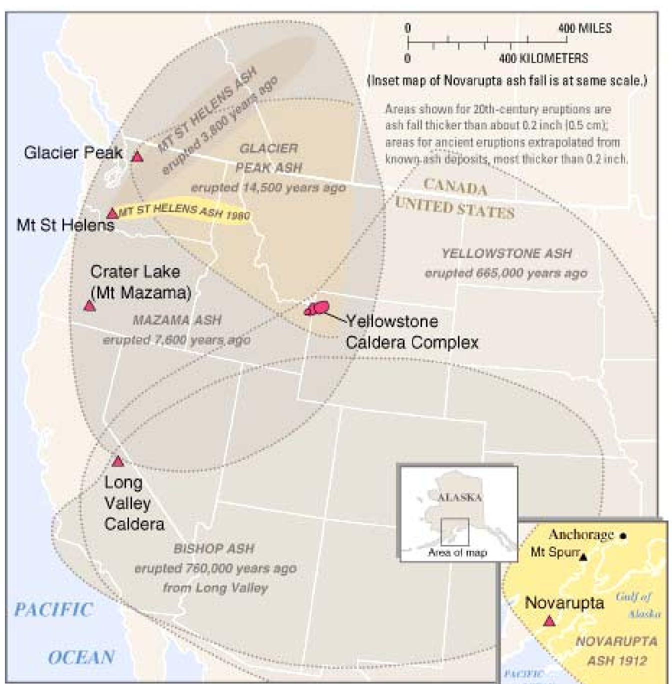
http://volcanoes.usgs.gov/Hazards/What/Tephra/tephra.html

http://volcanoes.usgs.gov/Imgs/Jpg/Pinatubo/

Volcanic Hazards

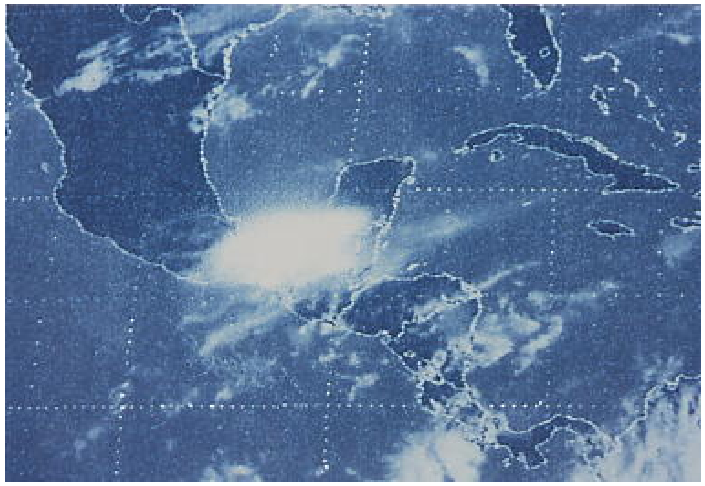
Ash Falls

- Certain prehistoric eruptions dwarf many modern, familiar eruptions
- Ash falls from largest prehistoric events affected areas of continental scale

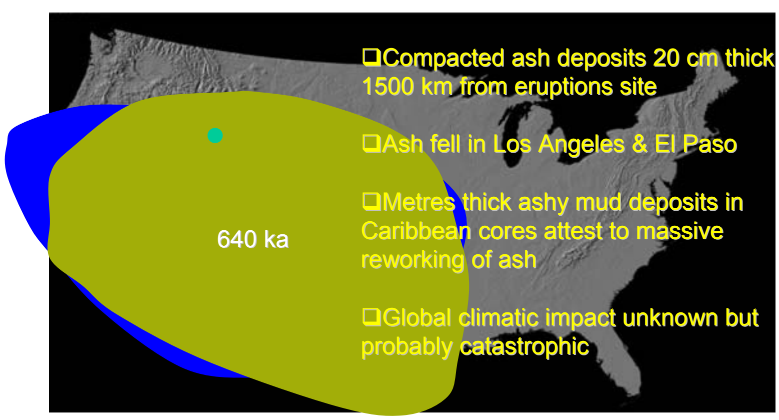


http://wrgis.wr.usgs.gov/fact-sheet/fs027-00/

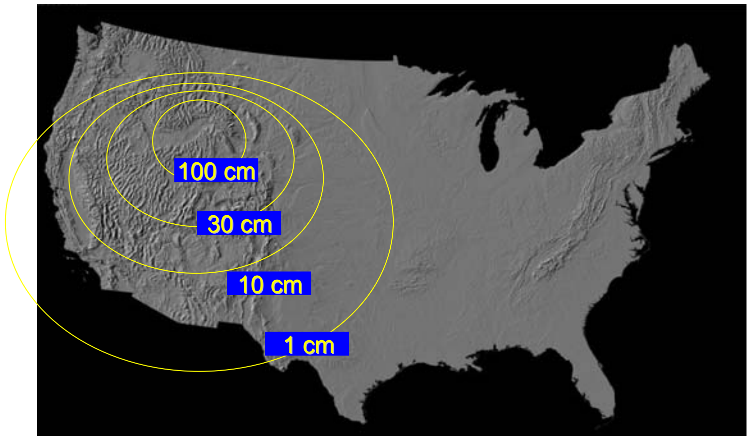
Ash cloud: El Chichon 1983



Yellowstone eruptions: 2.1 Ma and 640 ka BP



Depth of ash from a future Yellowstone super-eruption



Pyroclastic Flows

- Fluid avalanche of rock material, hot ash and gas
  - Can form when eruption columns collapse
  - Highly destructive
  - Typically faster than 80 km/hr and up to 700°C
  - Can incinerate, burn, and asphyxiate people

Escaping a Pyroclastic Flow at Mount Unzen, Japan, 1991


AP/Wide World Photos

Pyroclastic flow (*nueé ardente*)

- Mixture of hot gases, ash, and rocks forming a super heated and dense current capable of moving 150 km/hr.
- Buoyancy due to heated gas, density due to ash- turbulence keeps particles suspended in flow

Nuee Ardente

Volcanic Hazards

Pyroclastic Flows

- a.k.a. **nueé ardente**
- Ground-hugging, high-density mixtures of hot, dry rock fragments and hot gases
- Travel at >80 km/hr
- Temperature of 200-700°C
- Pyroclastic flows
  - Destroy by direct impact
  - Bury sites with hot rock debris
  - Melt snow and ice to form lahars
  - Burn forests, crops, buildings, & all other combustible material
- On margins of flow, serious injury may result from burns and inhalation of hot ash and gasses

Pyroclastic flow characteristics

- Common during moderate to large (VEI 3 - 8) explosive eruptions, e.g Vesuvius 79AD, Mont Pelee (Martinique) 1902, Montserrat 1997
- Concentrated (dense) gas - solid dispersion
- Flow durations rarely more than a few minutes
- Velocities may be up to 160 m/s
- Emplacement Temps: >100 and up to 900ºC
- May remain hot at depth for years

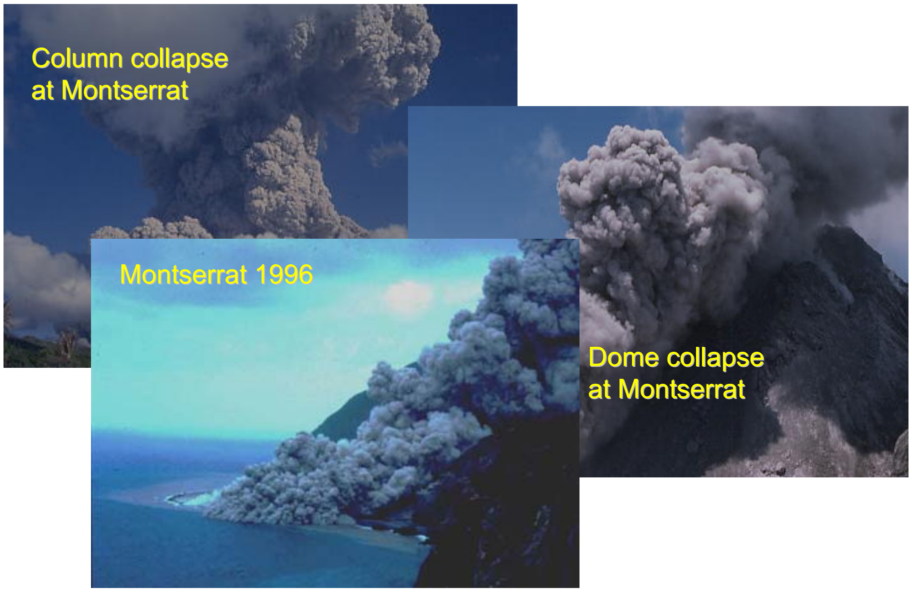
Pyroclastic flow characteristics

- Restricted to more Si-rich compositions
- Typically formed by dome collapse or explosion or eruption column collapse
  - block & ash flows
- Smaller flows are largely topographically controlled (travel distances 5 - 10km)
- Large flows may travel in all directions and can reach 50 - 100km
- Low concentration (dilute) pyroclastic surges may detach from flow

Pyroclastic flow damage potential and mitigation

- Above ignition T of many materials
- Force of impact extremely destructive
- High velocity ensures no possibility to out run
- Can overcome 1000 m high topography
- Surge can travel across water
- Generate co-pyroclastic flow ash fall
- Deposits may source lahars
- Buildings and clothing may offer some protection

Pyroclastic flow formation



Volcanic Hazards

Pyroclastic Flows

- During the May 18, 1980 eruption
  - ~17 separate pyroclastic flows descended the flanks of Mount St. Helens
  - Pyroclastic flowed at speeds of over 100 km/hr and reach temperatures of over 400ºC
- Result From
  - Collapse of the eruptive column during explosive eruptions of molten and/or solid rock fragments
  - Nonexplosive collapse of thick lava flows or domes down steep slopes

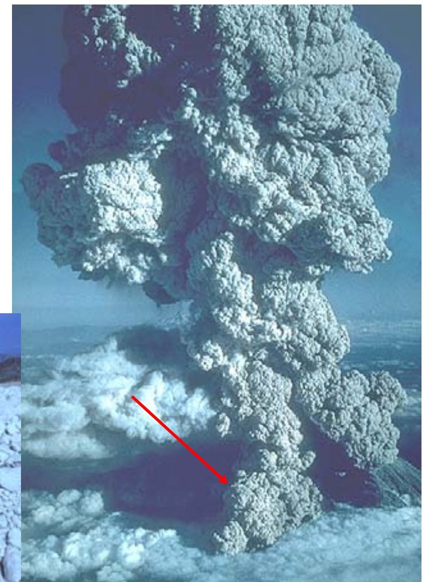
1980 Mt. St. Helens, Washington

http://vulcan.wr.usgs.gov/Glossary/PyroFlows/images.html

Mount Saint Helens, Washington

May 18,1980 Eruption – Pyroclastic Flows

- Leaves a "Pumice Plain" its wake



http://volcanoes.usgs.gov/Hazards/What/PF/PFMSH.html

Volcanic Hazards

Pyroclastic Flows

1988 Colima Volcano, Mexico
Collapsing lava dome

http://wrgis.wr.usgs.gov/fact-sheet/fs058-00/

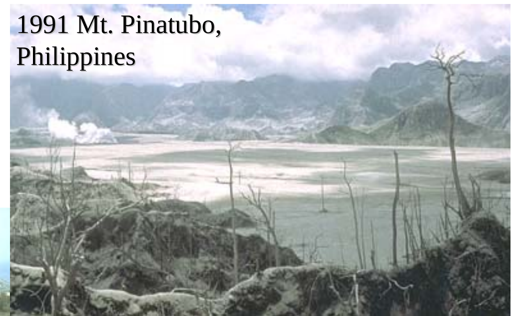
1984 Mayon Volcano, Philippines Eruption

http://volcanoes.usgs.gov/Products/Pglossary/PyroFlow.html

Volcanic Hazards

Pyroclastic Flows

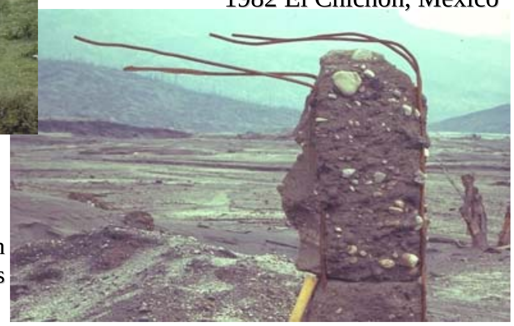
1991 Mt. Pinatubo, Philippines



Charred stream channel
5-6 km from lava dome

1997 Soufrière Hill, Montserrat, West Indies

1982 El Chichón, Mexico



Remnants of a building with bent steel reinforcing rods

All from http://volcanoes.usgs.gov/Hazards/What/PF/pcflows.html

Pyroclastic Flows

Unzen Volcano, Japan

- 1991-1995: Growth of lava dome with frequent pyroclastic flows
  - Traveled up to 5 km
- One such flow killed 43 people including 3 volcanologists
- Areas damaged by ash cloud surge extend beyond pyroclastic flow deposits

Ash Cloud Surge Effects

All from http://volcanoes.usgs.gov/Hazards/What/PF/PFUnzen.html

Pyroclastic Flows

Soufrière Hills Volcano, Montserrat

- 1995-Present: Episode of lava dome formation
- Collapse of the lava dome generated a series of pyroclastic flows and surges

All from http://volcanoes.usgs.gov/Hazards/Effects/SoufriereHills_PFeffects.html

Lahar

Lahars

- Like pyroclastic flows, but with more water
- 20-60% sediment: very turbulent
- >80% sediment: smooth flow
  - much faster than turbulent
  - can float very large objects

Form from:

1) Snow/ice water mixed with debris
2) Pyroclastic flows mixed with river water
3) Rainfall on loose material (ash)

Lahar characteristics

- May be formed by
  - eruption onto snow or ice field
  - breaching of a crater lake
  - precipitation onto unconsolidated ash & PF deposits
- Velocities 10s km/h
- Travel for 10s km
- Deposits may be metres to 10s m thick
- May be hot or cold
- Largely topographically controlled

Lahar damage potential and mitigation

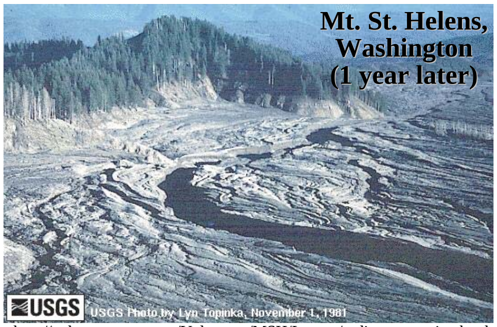
- May be erosive or bury land and property
- Can contain house-size blocks
- May clog rivers, overspill banks and block channels
- Can contaminate water supplies
- Hazard may continue for years
- Mitigation: trip wires; refuges; barriers and dredging

Volcanic Hazards

http://volcanoes.usgs.gov/Hazards/What/Landslides/landslides.html

Lahars

- Rapidly flowing mixture of rock debris and water
- Can travel 10's of km's, typically down river valleys
- Hot or cold
- Especially common at stratovolcanoes
- Generated
  - Without eruptions
    - Landslides mixed with water
  - During eruptions
    - Melting of snow and ice by pyroclastic flows, lava flows
  - After eruptions
    - Heavy rainfall erodes deposited ash, etc.
    - Sudden release of water from crater lakes



http://vulcan.wr.usgs.gov/Volcanoes/MSH/Images/sediment_erosion.html

Volcanic Hazards
Lahars

- By eroding rock debris and incorporating additional water, lahars can grow to >10 times their initial size
  - As slows, looses sediment load and becomes smaller again
- Effects
  - Destroy by direct impact; Often contain larger boulders and tree trunks
  - Bury buildings, communities, and valuable land in cement-like layers of rock debris
  - May trap people
  - Increase sedimentation rates in local streams and rivers; Leads to flooding and secondary lahars
  - Block tributary streams creating lakes that may suddenly flood

Nevado del Ruiz Volcano, Columbia

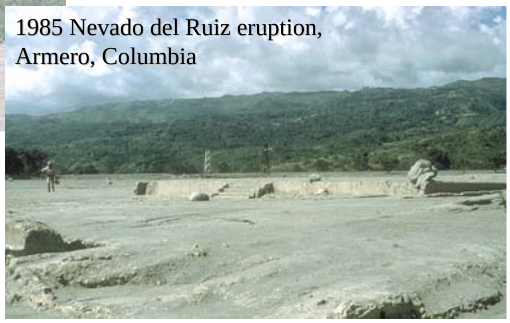
A lahar destroyed the town of Armero, November 13, 1985

http://volcanoes.usgs.gov/Hazards/What/Lahars/RuizLahars.html

Volcanic Hazards
Lahars

1992-93 Unzen volcano, Japan

Lake formed behind lahar deposits from the 1991 Mt. Pinatubo, Philippines eruption



1985 Nevado del Ruiz eruption, Armero, Columbia

All from http://volcanoes.usgs.gov/Hazards/What/Lahars/lahars.html

Mount Saint Helens, Washington

May 18,1980 Eruption – Lahars (a.k.a. mudflows)

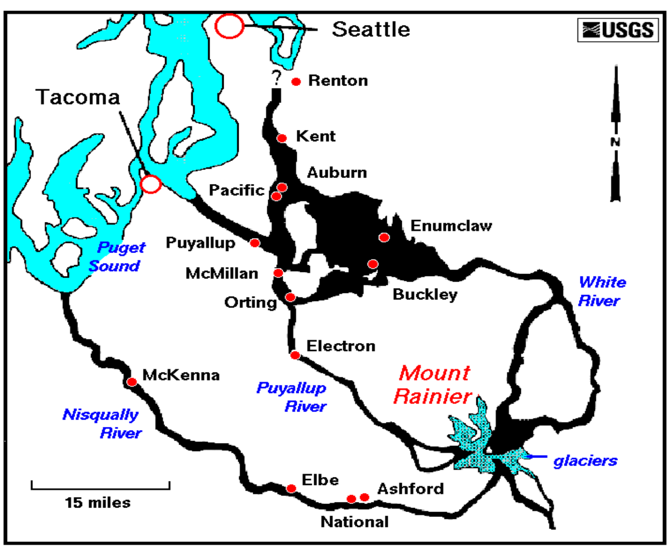
http://volcanoes.usgs.gov/Hazards/What/Lahars/lahars.html

http://vulcan.wr.usgs.gov/Photo/SlideSet/ljt_slideset.html

http://volcanoes.usgs.gov/Hazards/Effects/MuddyLahar.html

http://vulcan.wr.usgs.gov/Volcanoes/MSH/Images/may18_devastation.html

Mudflow hazard map: Mount Rainier



Nevado del Ruiz, Columbia

November 13, 1985 Eruption

- Clear signs of unrest beginning in November, 1984
- On November 13, 1995, in heavy rain, an explosive eruption sent pyroclastic flows and surges across the volcanoes broad ice-covered summit
  - 10% of ice cover melted
  - Mixtures of water, ice, pumice, & rock debris poured from volcano into neighboring rivers
  - Eventually funneled into 6 major river valleys
- Eruption relatively small

http://volcanoes.usgs.gov/Hazards/What/Lahars/RuizLahars.html

Nevado del Ruiz, Columbia

November 13, 1985 – Generation of Lahars

- Lahars
  - Average velocities 60 mph
  - Increased in size with distance from volcano (up to 4 times initial volume)
  - As thick as 50 m in narrow canyons
- Two lahar pulses traveled down river valleys/canyons and were noted in towns high enough above the rivers to escape damage
- Lahars strike towns at the mouth of canyons; hardest hit was Armero

Photograph by N. Banks
December 18, 1985

http://volcanoes.usgs.gov/Hazards/What/Lahars/RuizLahars.html

Nevado del Ruiz, Columbia

November 13, 1985 Eruption – Destruction of Armero

- Amero
  - Lahar hits 4 hours after beginning of eruption
  - Lahar traveled more than 100 km
  - Three quarters of 28,000 inhabitants perished
  - Flow depths from 2-5 meters
  - 8-9 pulses of water
- Total Destruction
  - 23,000 fatalities
  - 5,000 injured
  - > 5,000 homes destroyed

Totally avoidable

http://volcanoes.usgs.gov/Hazards/What/Lahars/RuizLahars.html

Landslides

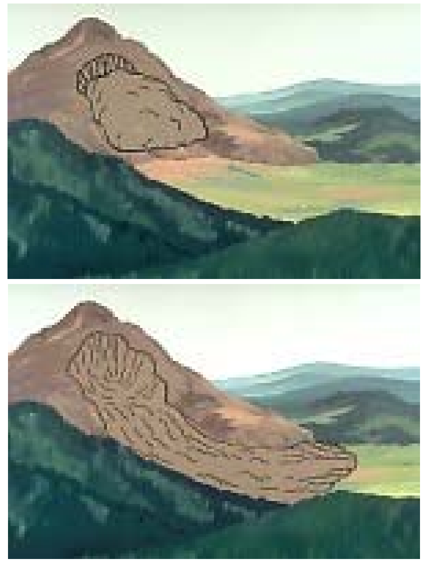
- Large masses of earth that fall, slide or flow rapidly
- Can trigger volcanic explosions, lahars, and tsunamis

- Formed by weakening of slopes from volcanic activity
  - Magma intrusion, earthquakes, eruptions, intense rainfall
- Large scale landsliding on south flank of Kilauea causing south side of Hawaii to fall into the sea

Landslides

General

- Large rock & soil masses that rapidly fall, slide, or flow under the force of gravity
  – May travel several km's, typically down river valleys
- Occur on slopes that have become oversteepened
  – Failure frequently occurs on planes of weakness within the hill slope
- Can be triggered by
  1. Displacing or shaking the ground surface
  2. Weakening the rock and soil on the hill slope
     - Water (e.g., large rainfall events) reduces the resistance of geological materials to sliding



http://volcanoes.usgs.gov/Hazards/What/Landslides/landslides.html

Volcanic landslide characteristics

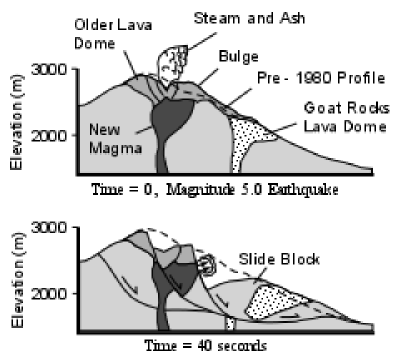
- Lateral sector collapse involving at least 10 - 20 million cubic m
- Terrestrial collapses: volumes up to 40 cubic km and runouts of >120 km
- Oceanic volcano collapse: volumes > 1000 cubic km
- Where magma is involved in collapse may generate entire spectrum of volcanic hazards
- Emplacement velocities up to 100 m/s
- Can overcome obstacles up to 1000 m high

Caldera Taburiente
La Palma

Volcanic Hazards

Volcanic Landslides (a.k.a. Debris Avalanche)

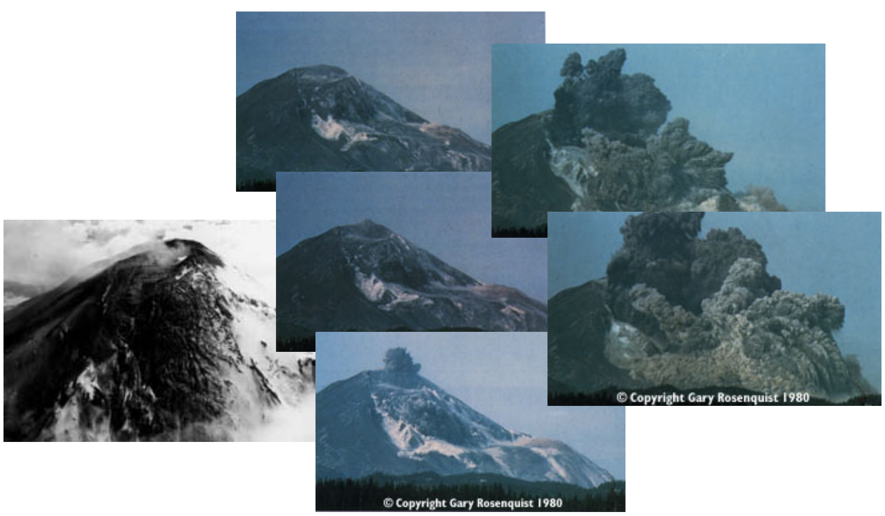
- Landslides commonly occur at volcanoes
  - Steep topography
  - Amalgamation of alternating lava and ash layers
  - Magma intrusions lead to oversteepening
  - Volcanic gasses create acid that weakens rock
  - Mass of volcano creates internal faults
- Cold
- Dry or Wet (may become a lahar)



http://volcanoes.usgs.gov/Hazards/What/Landslides/MSHSlide.html

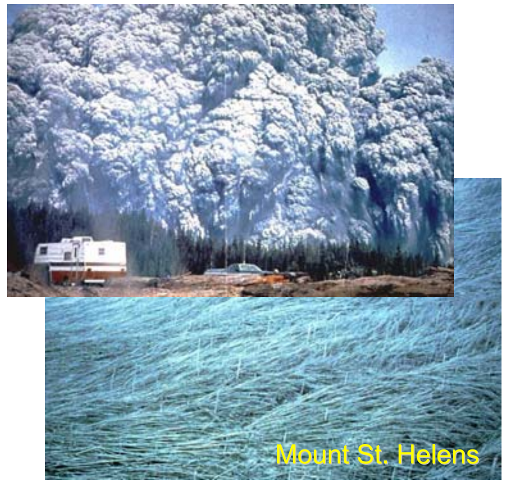
Mt. St. Helens May 18, 1980

Mount St. Helens. May 18 1980



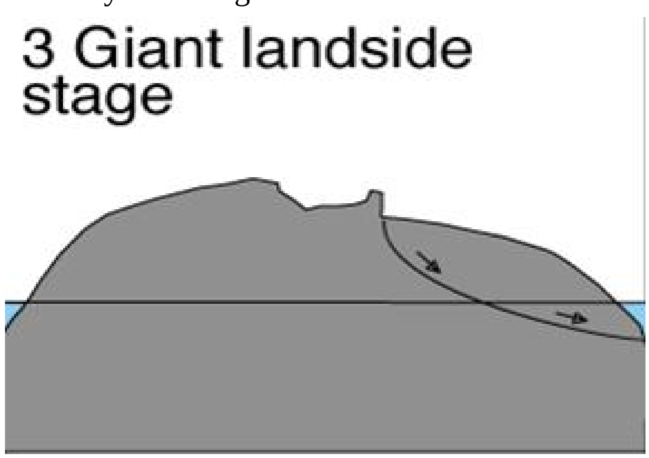
Volcanic landslide damage potential

- May be extremely widespread:
  - slide deposit may cover 100s - 1000s square km
  - lahar source
  - tsunami threat if emplaced in water
- If eruption triggered
  - atmospheric shock wave
  - PF flows and surges
  - extensive ash fall



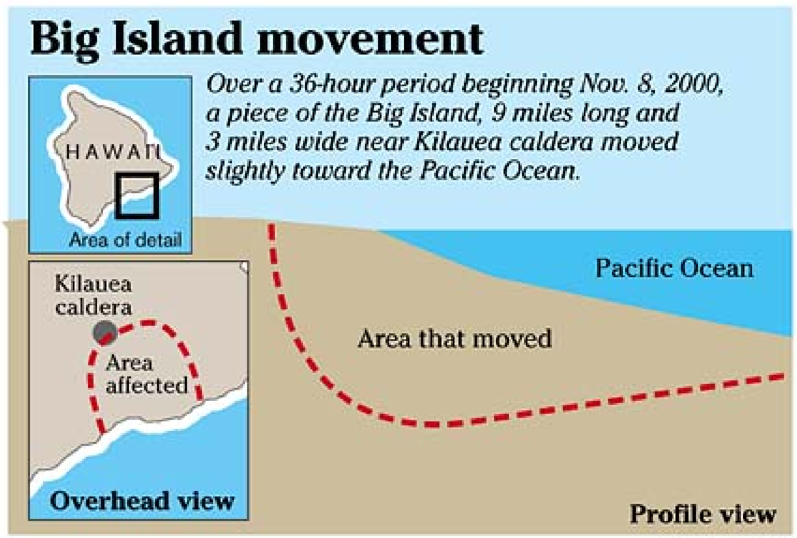
Hawaii Volcano Growth Stage 3

- During the shield-building stage
  - Flanks of most volcanoes suffer giant landslides
  - Currently occurring on the south flank of Kilauea



Starbulletin.com

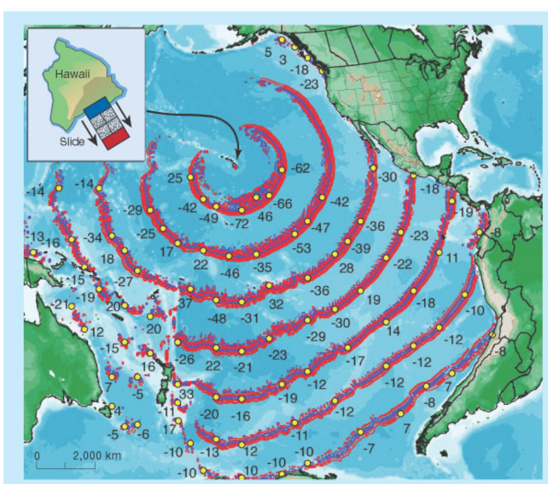
Slow land shift observed on Kilauea



Tuesday, March 5, 2002

Tsunami – Consequence of Landslides?

- At least one scientist predicted massive tsunamis from such a landslide

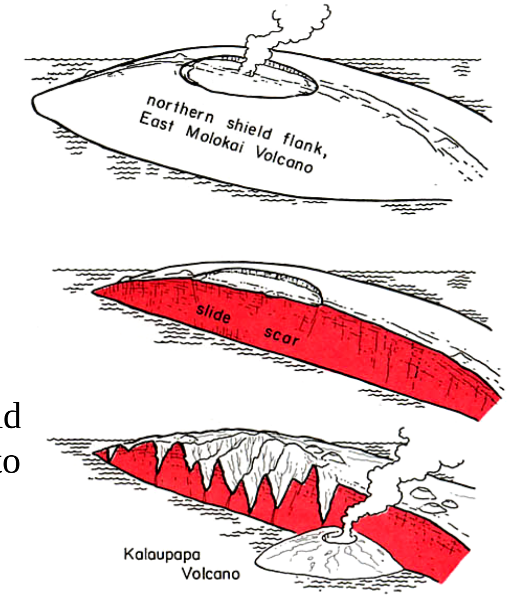


Computer simulation of the tsunami waves that might be set off in a collapse of Kilauea's southeast flank

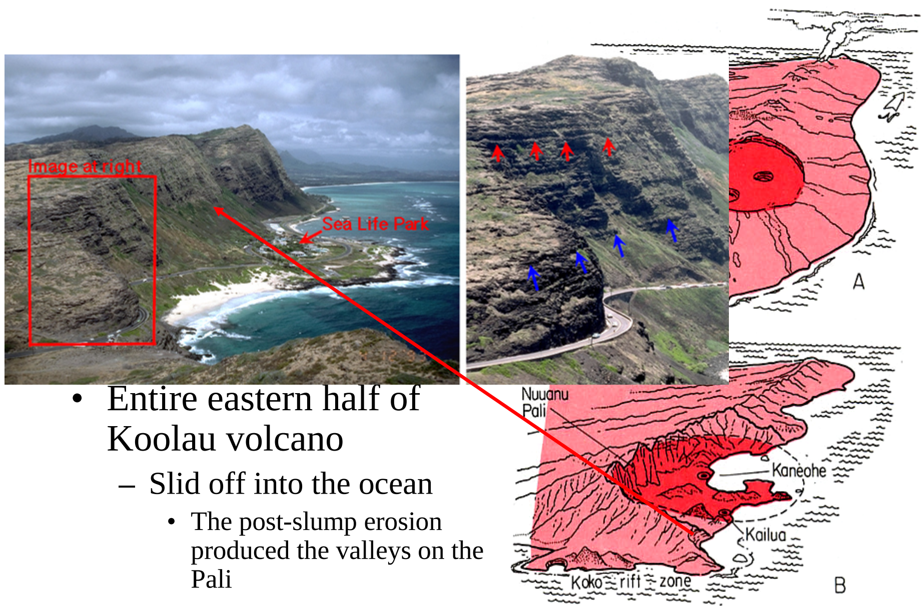
The model predicts potentially devastating 30-m waves beaching on the west coast of North America

Evidence of Landslides - Molokai

- The east Molokai shield volcano
  - Built by eruptions along east rift zone
- After the shield was built
  - The northern flank slid off onto the seafloor to the north



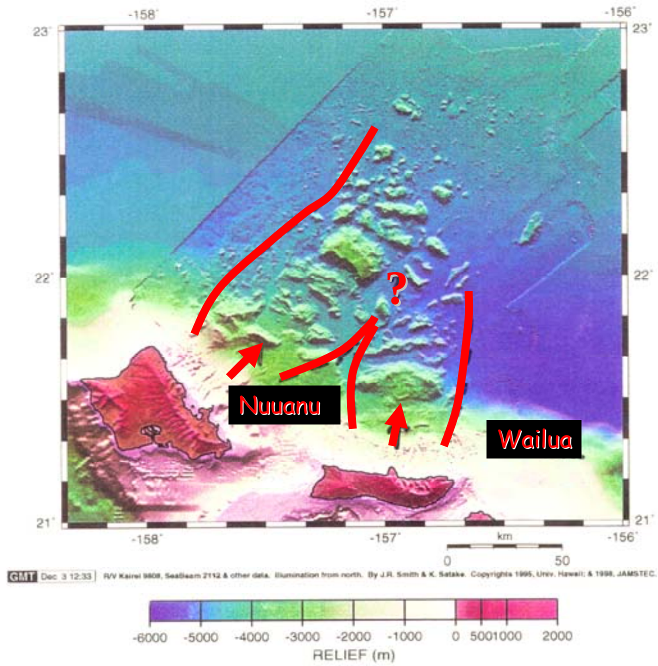
Evidence of Landslides - Oahu



- Entire eastern half of Koolau volcano
  - Slid off into the ocean
    - The post-slump erosion produced the valleys on the Pali

O … les

- I … N … d



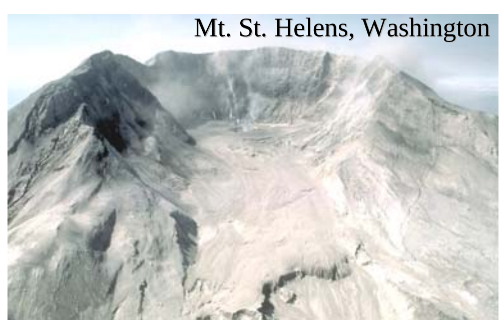
Volcanic Hazards

Volcanic Landslides

- Possible triggers
  - Intrusion of magma
  - Explosive eruptions
  - Earthquakes at or near volcano
  - Intense rainfall
- Volcanic landslides can …
  - Trigger volcanic eruptions
  - Generate lahars when mixed with water
  - Generate tsunamis when enter lake or ocean
  - Bury river valleys with rock debris; dam tributary streams to form lakes

http://volcanoes.usgs.gov/Hazards/What/Lahars/HuilaLahar.html


Nevado del Huila, Columbia

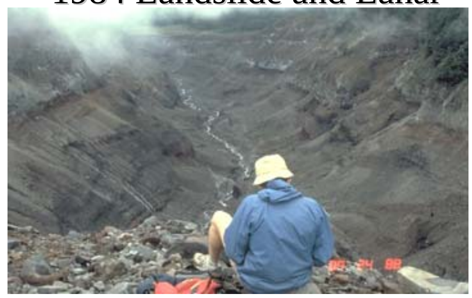

Mt. St. Helens, Washington

http://volcanoes.usgs.gov/Imgs/Jpg/MSH/30212265-050_caption.html

Mt. Ontake, Japan

1984 Landslide and Lahar

- Triggered by M=6.8 earthquake 1.1 km beneath volcano (dormant) after several days of heavy rain
- Volume: 32-36 million m^3
- Traveled 8 km as unsaturated debris flow (avg. 80 m thick); then transformed into a lahar and traveled at least another 4 km (39-60 m thick)
- 75 km/hour
- 15 fatalities



All from http://volcanoes.usgs.gov/Hazards/What/Lahars/OntakeLahar.html

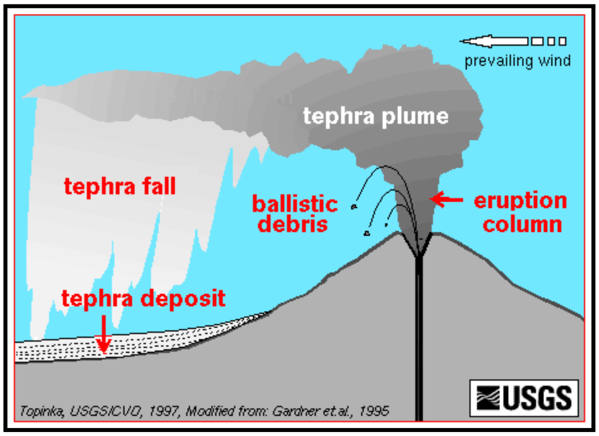
Tephra

- Airborne volcanic rock
- Consists of wide range of rock types
- Larger rocks fall closer to volcano; ash can travel thousands of kilometers
- Bombs (>64mm), lapilli (2-64mm) and ash (>2mm)

Reticulite

Pele's hair

Tephra hazard



Ballistic characteristics

Large bomb (Etna)

- Distribution usually circular; within 3 – 5 km of vent
- Wind direction & velocity has little effect
- Directed blast may give symmetric distribution
- Projectiles > ~ 10cm may have terminal velocities & high impact energies
- Densities can be up to 3 tonnes/cubic m
- Some projectiles may be above ignition T of many materials

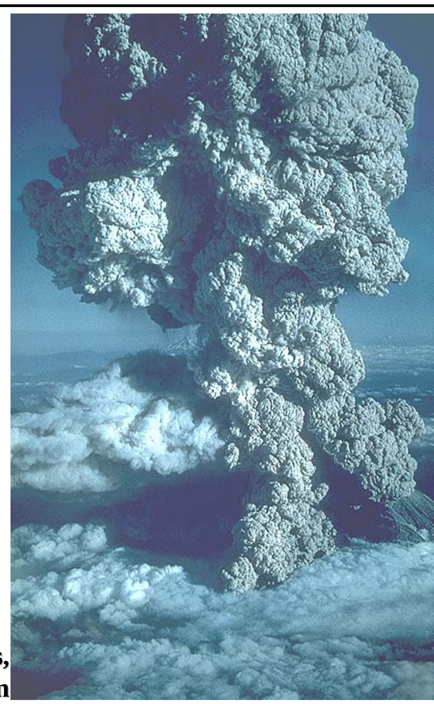
Ballistic damage potential: Etna & Montserrat

Volcanic Eruptions

Plinian Eruptions

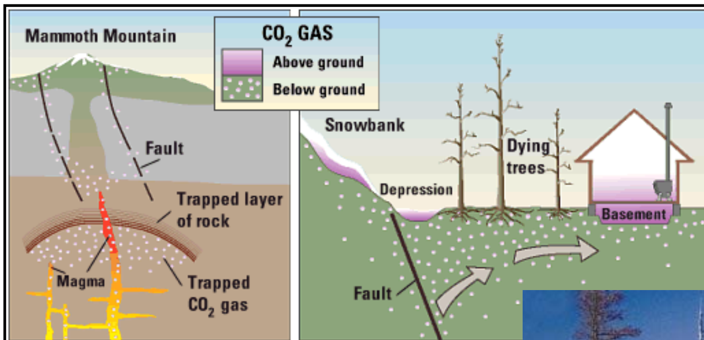
- Large, explosive eruptions
- Form enormous dark columns of tephra and gas that extend high into the stratosphere (>11 km)
- Driven upward by buoyancy of hot gasses
- Associated hazards
  - Pyroclastic flows and surges as eruptive column collapses
  - Extensive ash falls
  - Ash Clouds

- High viscosity
- High volatiles
- Large volume



Mt. St. Helens, Washington

http://volcanoes.usgs.gov/Hazards/What/PF/PFMSH.html

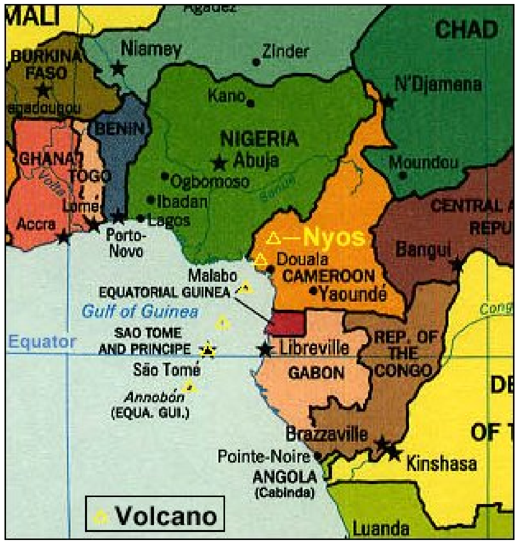


Volcanic Gases

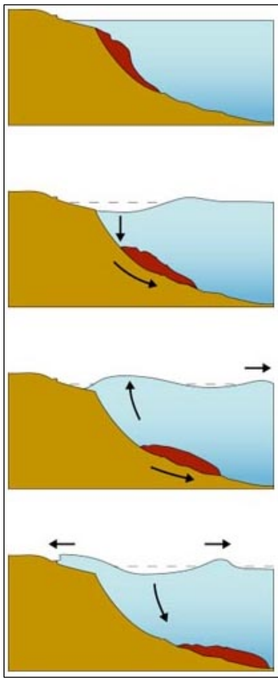
Volcanic Gases

- Gases released: H_20 vapor, CO_2, SO_2, HCl, HF, H_2S, CO, H_2, NH_3, CH_4 and SiF_4
- Formation of acid rain (from SO_2) can cause water contamination and plant damage
- Prevailing winds can blow gases thousands of kilometers away

Lake Nyos - Cameroon

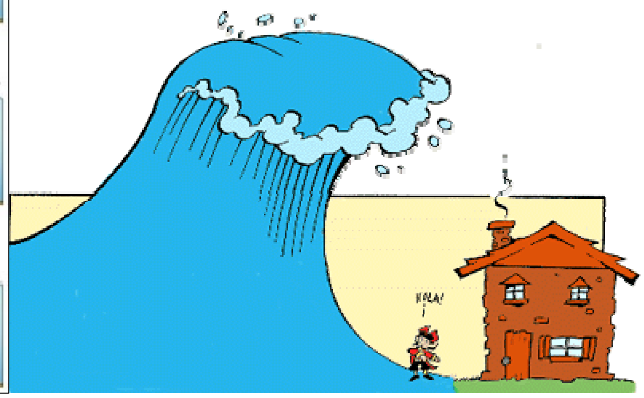


Lake Nyos - Cameroon



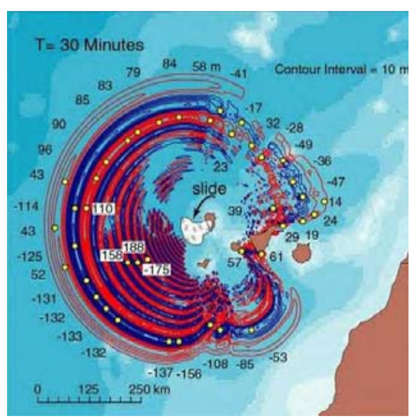
Tsunamis

- Giant ocean waves
- Cause: earthquakes or giant landslides



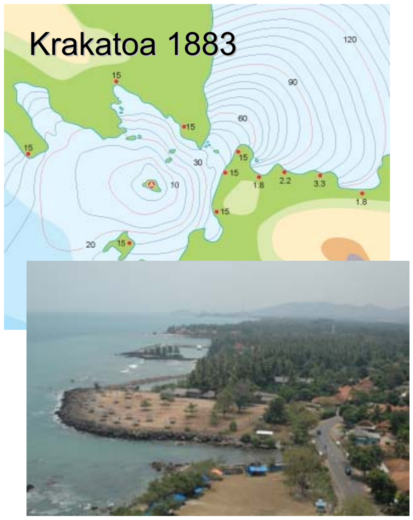
Volcanogenic tsunami

- Generated by:
  - landslides
  - large, violent eruptions at island or coastal volcanoes
- Typically, several waves are generated
- Deep water velocities can exceed 800 km/h
- Inundation velocities in range 1 - 8 m/s
- Wave heights may be 30+m high; exceptionally 100’s m high



Predicted La Palma tsunami

Tsunami damage potential



- Very rapid dispersal due to high velocities
- Little warning, especially close to source
- May occur without eruption
- Widespread areal impact (ocean basin wide in largest events)
- High impact energies
- Wavelengths of hundreds of km
- Mitigation difficult without warning system

Historical volcanic tsunami

Volcano	Year	Cause	Death toll	Notes
Komaga-Take (Japan)	1640	landslide	700	
Santorini (Greece)	1650	eruption	50	
Long Island (Papua New Guines)	1660	eruption	~2000	Tsunami and pyroclastic flows
Gamkonora (Indonesia)	1673	eruption	many	
Oshima-Oshima (Japan)	1741	landslide	1475	
Unzen (Japan)	1792	landslide	14,528	
Tambora (Indonesia)	1815	eruption	many	10,000 killed by direct effects of eruption
Ruang (Indonesia)	1871	landslide	400	Collapse of lava dome
Krakatoa (Indonesia)	1883	eruption	36,417	Most killed by tsunami
Ritter Island (Papua New Guinea)	1888	landslide	~3000	Waves 12-15m high
Taal (Philippines)	1965	eruption	>200	Most drowned due to boats capsizing
Iliwerung (Indonesia)	1979	landslide	539	Waves 9m high

Critical issues in volcanic hazard mitigation

- Identifying the risk
- Awareness and education
- Baseline monitoring
- Recognition of eruption precursors
- Forecasting nature of activity & hazard zonation
- Eruption duration and climax

Mount St. Helens 1980

Reducing volcanic risk

- Return period analysis and risk estimation
- Hazard mapping
- Volcano monitoring
- Eruption forecasting
- Intervention
- Building construction

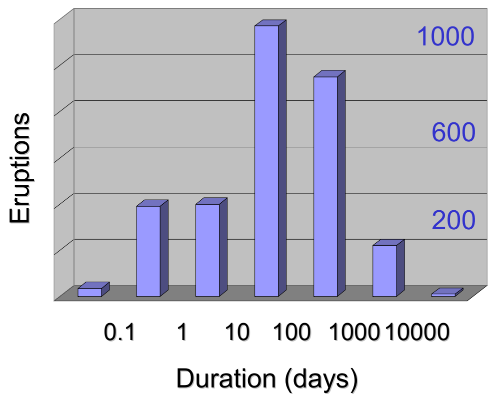
The ‘Volcanic Gap’ concept

- By using average return periods in estimates of volcanic risk we are defining something akin to a volcanic equivalent of a ‘seismic gap’
- Generally speaking, the longer the period of repose, the larger the next eruption
- Clearly the potentially most worrying ‘volcanic gaps’ are located at those Holocene volcanoes for which there are no dated or documented eruptions.
- Length of a ‘gap’ will not be comparable between volcanoes, but will depend on average return period of eruption for each volcano

Identifying the risk: when is a volcano ‘dead’?

- Active: potential to erupt again or actually erupting (also ‘in eruption’)
- Dormant: not erupted for a long (undefined) period. May be ended by an unusually violent eruption
- Extinct: No means of distinguishing long dormant from recently extinct volcanoes (Critical: difference between zero risk and the risk of a huge eruption)
- Life-span: some volcanoes may be active for millions or even > 10 million years. Often with very long periods of dormancy (10s of thousands y)

How long do eruptions last?

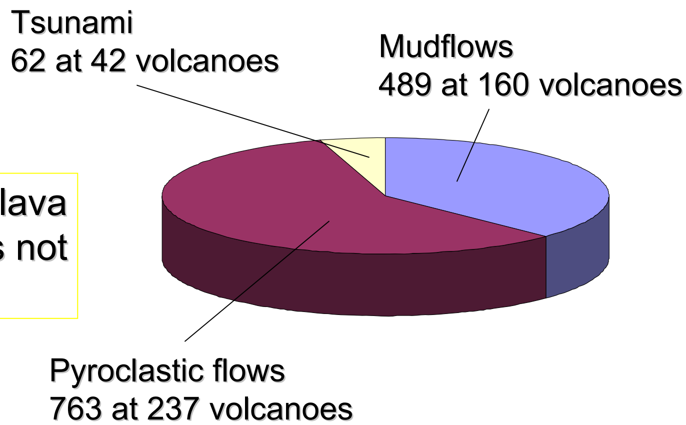


- Major implications for emergency planning
- Eruption length highly variable
- Learn from past activity
- Most eruptions last 10 - 1000 days
- Less than 20% over within 72 hours
- Median is 7 weeks

Eruption climax parameters

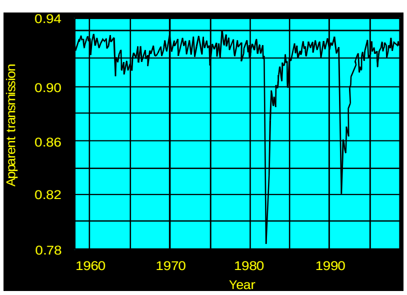
- Most eruptions have a CLIMACTIC phase: during which most damage occurs
- Timing, scale, and duration very difficult to predict:
  - Krakatoa (1883) and Mount St. Helens (1980): after several months
  - Soufriere Hills, Montserrat (1995-present) after two years
  - Rabaul, PNG (1994) within hours
  - Beware of false climaxes (Tambora, Indonesia 1815). Big bang - 5 day gap - bigger bang!

The most destructive volcanic hazards



Ash and lava eruptions not included

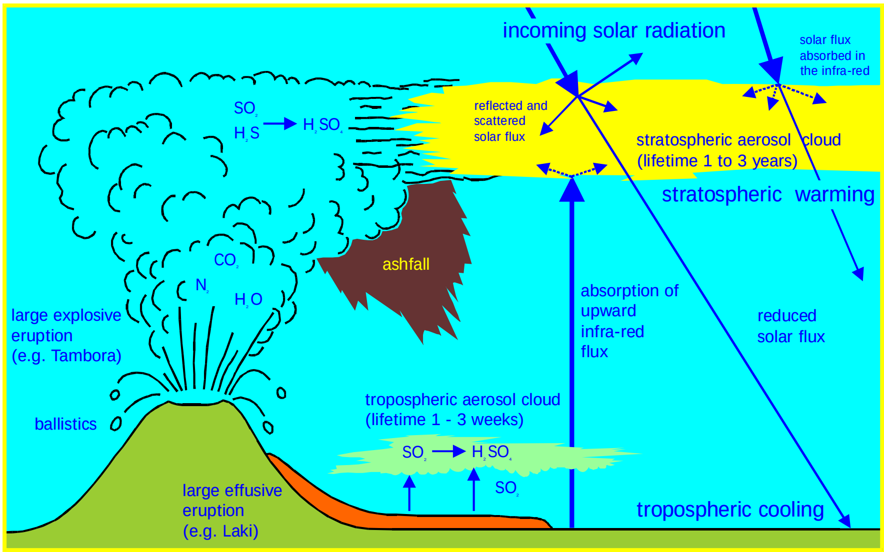
Climatic and other secondary effects



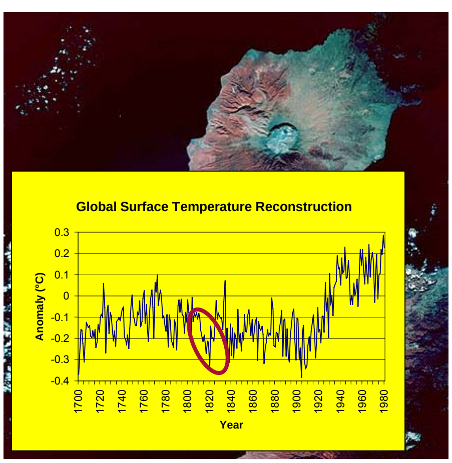
Atmospheric transmission at Mauna Loa Observatory (Hawaii)

- Climate modification
  - sulfuric acid aerosols
  - Tambora 1815
  - Laki 1783
  - El Chichon/Pinatubo
- Noxious gases
  - Lake Nyos (Cameroon)1986, 1700 dead
  - Poas (Costa Rica) crops affected by acid gas emissions
- Famine & disease
  - fluorosis
  - respiratory problems

Impact of volcanic eruptions on the atmosphere

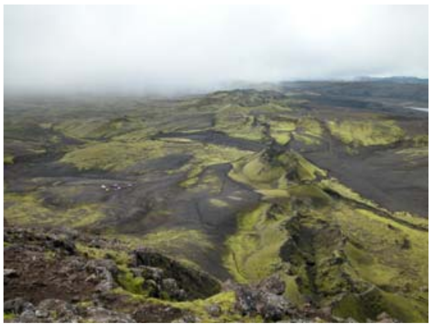


Tambora & 'the year without a summer'



- Largest known historic eruption → 200 Mt sulphate aerosol in stratosphere
- 1816 one of coldest northern hemisphere summers of last 600y
- Extreme weather
  - June snow in eastern North Am.
  - Summer killing frosts led to near total failure of crops in New England
  - Europe Summer T 3ºC cooler than 1951-70 average
- Cooling effect continued for 3 years
- 1816-19 'last great subsistence crisis in western world' bread riots; famine; typhus & cholera

Lakagigar (Iceland) 1783



- Iceland’s greatest natural disaster
- Second largest basalt flood eruption in historic times
  - 14.7 km^3 lava
- 8 months of lava effusion together with 10 moderate explosive events
- Released 122 Mt of sulphur dioxide
- Massive livestock loss in Iceland; death of 25% of population
- Sulphur aerosol haze caused 1783 summer warming followed by severe cooling over North America & Europe
- UK 1783 Summer mortality rates up by 10,000
- Today would stop air traffic in region for several months