In the name of God

Volcanoes and hazards associated with them

آتشفشان ها و خطرات مرتبط با آنها

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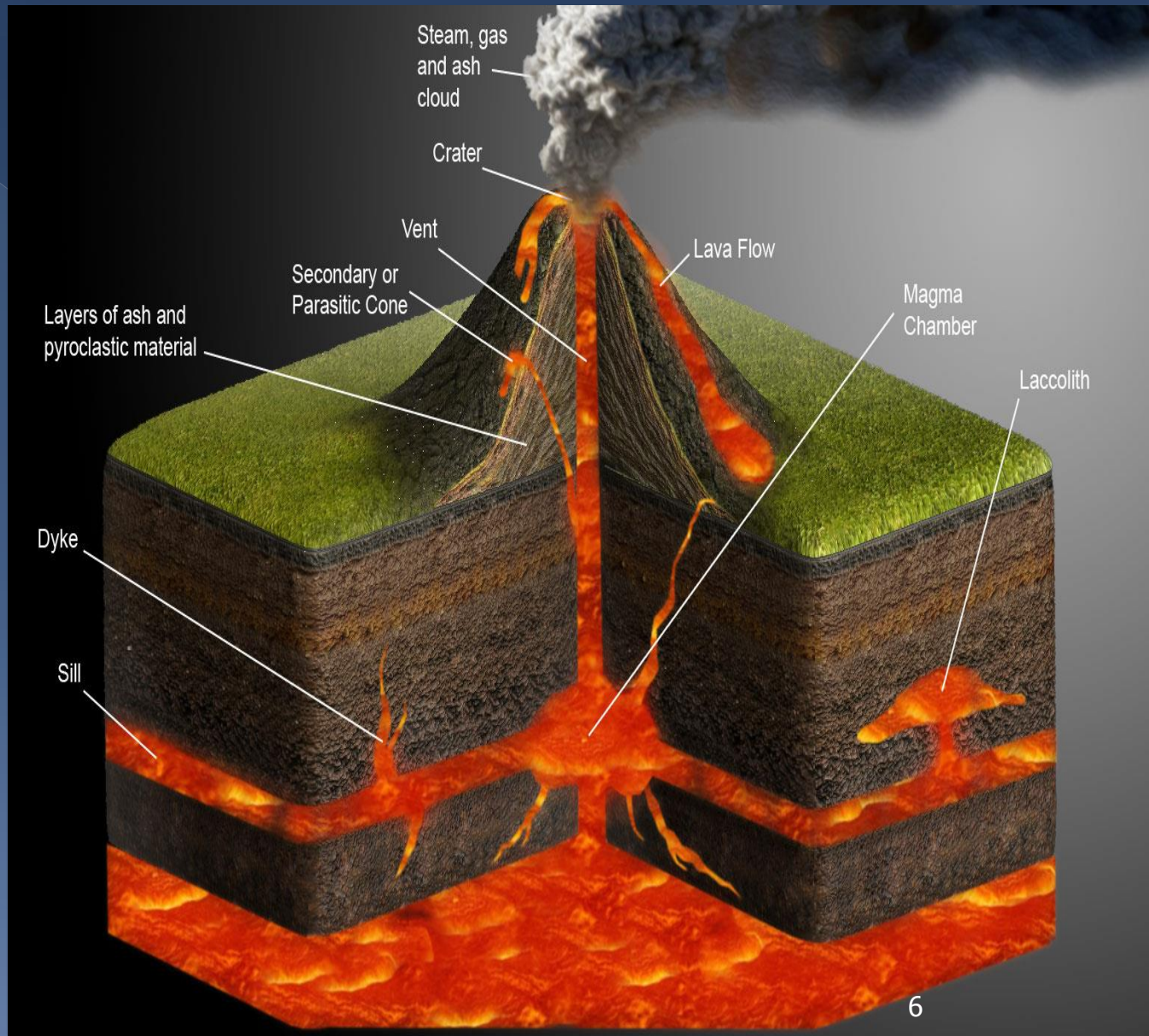
What is a Volcano?

- A volcano is a vent or chimney which transfers molten rock known as magma from depth to the Earth's surface
- Volcanoes are beneficial to humans living on or near them.
- They produce fertile soil, and provide valuable minerals, water reservoirs, geothermal resources, and scenic beauty. But volcanoes can be very dangerous.

What Are The Different Parts Of A Volcano?

- Magma Chamber
- Lava
- Main Vent
- Throat
- Crater
- Pyroclastic Flow
- Ash Cloud
- Volcanic Bombs
- Secondary Vent
- Secondary Cone



Types of *Volcanic* Eruptions

Volcanic eruptions can be placed into two general categories:

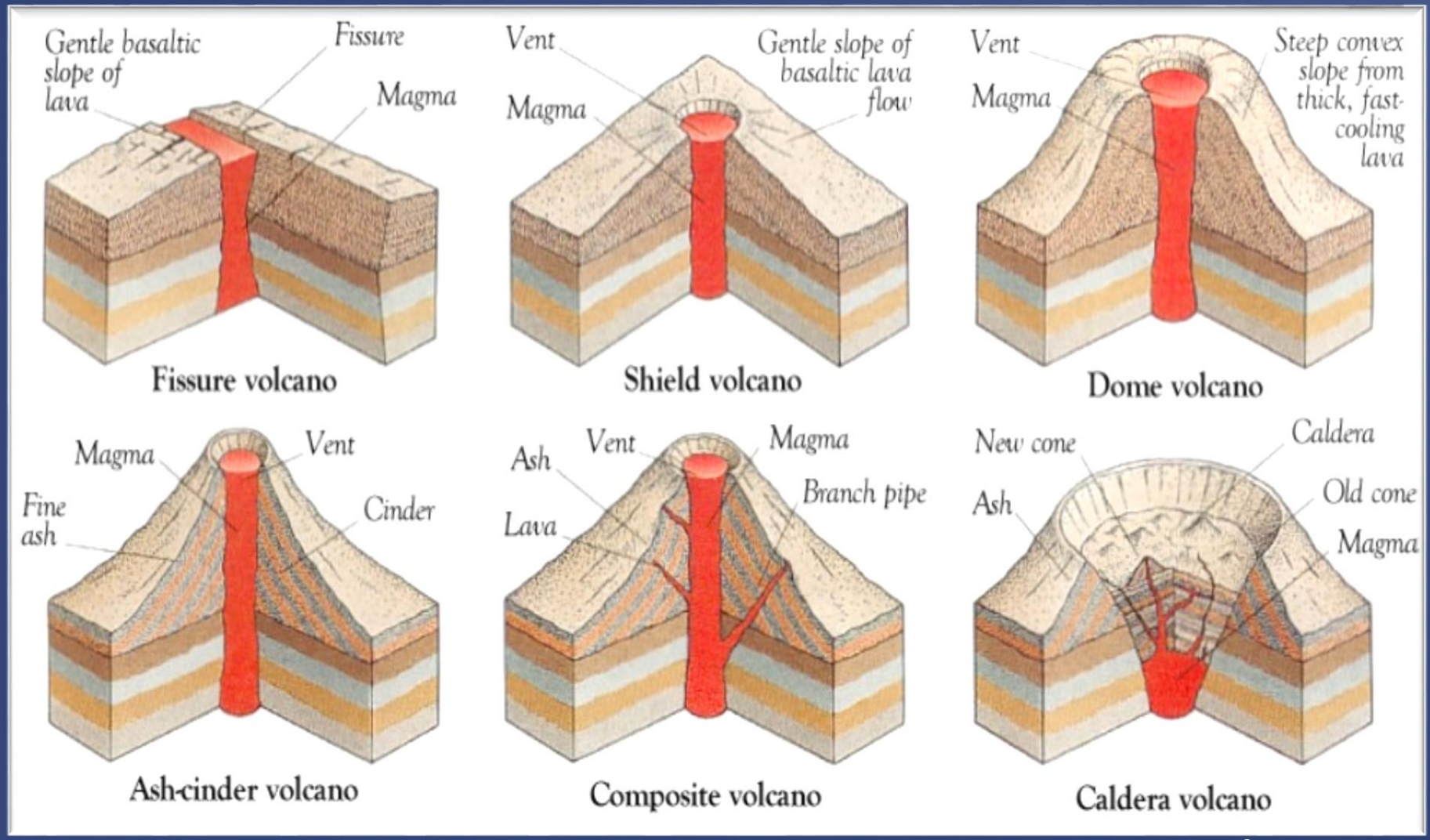
Explosive

- Explosive activity causes widespread ash fall, pyroclastic flows, debris avalanches, landslides, pyroclastic surges, and lahars
- such as at Mount St. Helens
- Explosivity is usually the result of gases expanding within a viscous lava.
- Another mechanism for explosions at volcanoes occurs when surface water or ground water enters a magma chamber. These eruptions are likely when a volcano occurs in a wet area or in the sea.

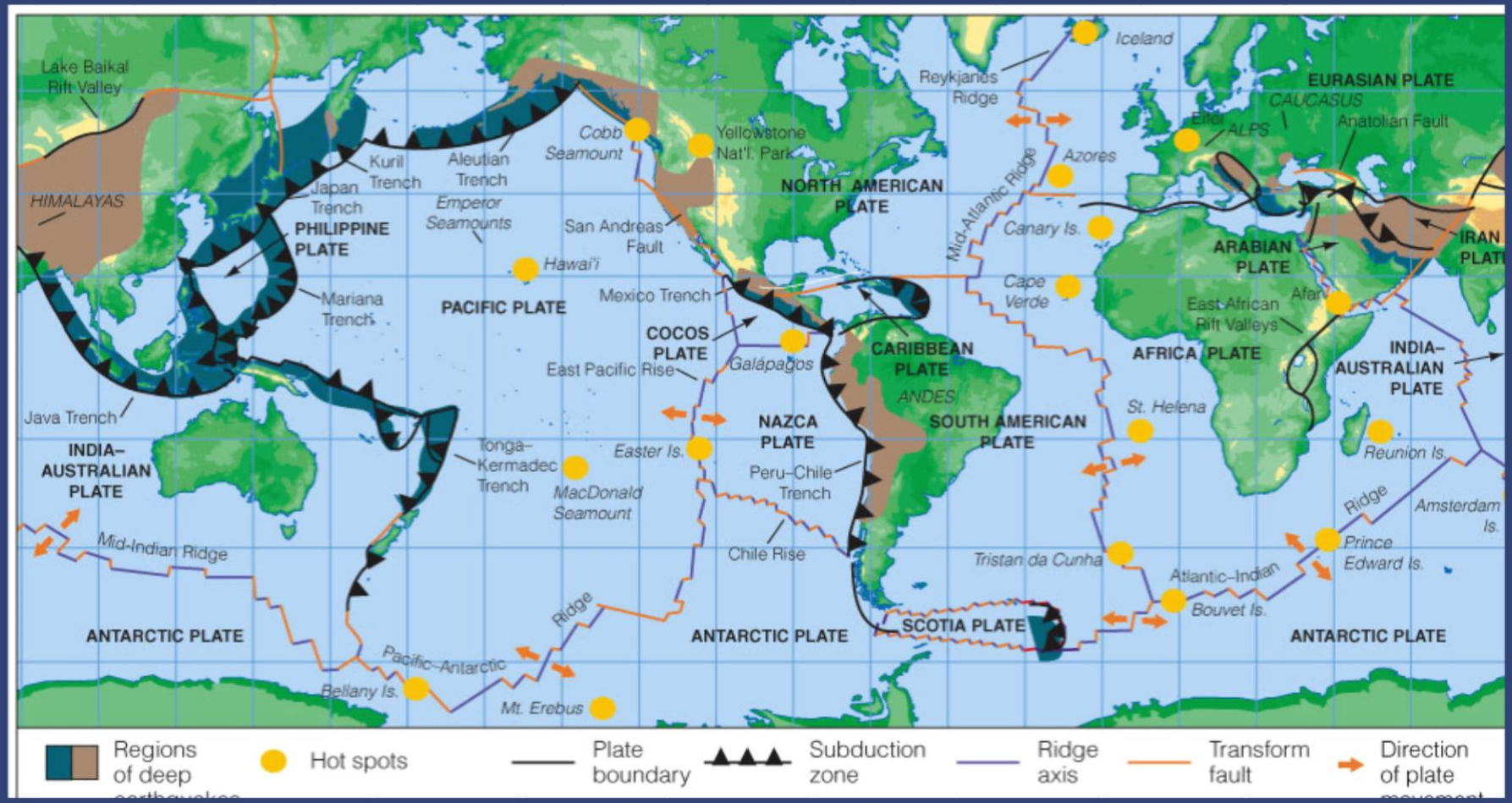
nonexplosive volcanism

- flood basalts
- Lava flows from this type of eruption are extruded from fissures and cover vast areas
- the least dangerous type of volcanic eruption
- people rarely get killed by them
- devastating and may have global consequences

What Types of Volcanoes are there?



Tectonic Plates and Active Volcanoes of the World



What is a Volcanic Hazard?

A volcanic hazard refers to any potentially dangerous volcanic process (e.g. lava flows, pyroclastic flows , ash).

A volcanic risk is any potential loss or damage as a result of the volcanic hazard that might be incurred by persons, property, etc. or which negatively impacts the productive capacity/sustainability of a population.

Risk not only includes the potential monetary and human losses, but also includes a population's vulnerability.

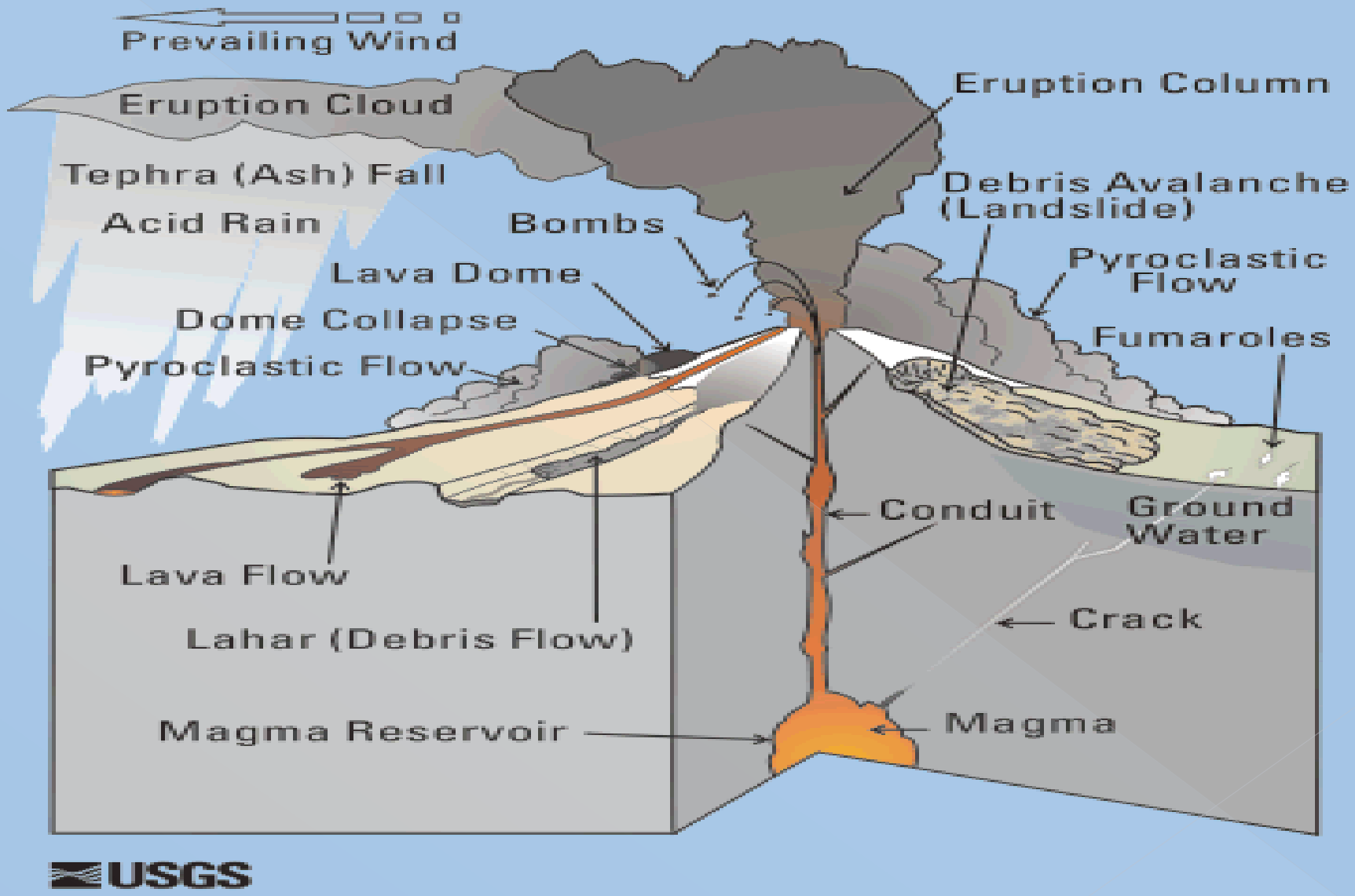
- In the past 500 years, over 200,000 people have lost their lives due to volcanic eruptions.
- An average of 845 people died each year between 1900 and 1986 from volcanic hazards.

- The number of deaths for these years is far greater than the number of deaths for previous centuries .
- The reason behind this increase is not due to increased volcanism, but due, instead, to an increase in the amount of people populating the flanks of active volcanoes and valley areas near those volcanoes

Types of Volcanic Hazards

- Volcanic Earthquakes
- Directed Blast
- Tephra
- Volcanic Gases
- Lava Flows
- Debris Avalanches, Landslides, and Tsunamis
- Pyroclastic Surges
- Pyroclastic Flows
- Lahars

Volcano Hazards



Hazards Prevention

When scientists study volcanoes

- They map past volcanic deposits
- Use satellites to look at volcanic features
- Ash clouds
- Gas emissions
- Monitor seismic activity
- Ground deformation
- Geomagnetic
- Gravimetric
- Geoelectrical and thermal changes at a volcano
- Study and monitor volcanic gases and monitor the temperature, flow rate, sediment transport, and water level of streams and lakes near the volcano

Volcanic Earthquakes

- Earthquakes related to volcanic activity may produce hazards which include ground cracks, ground deformation, and damage to manmade structures
- There are two general categories of earthquakes that can occur at a volcano:

1- volcano-tectonic earthquakes

- Earthquakes produced by stress changes in solid rock due to the injection or withdrawal of *magma* (molton rock)
- cause land to subside and can produce large ground cracks
- occur as rock is moving to fill in spaces where magma is no longer present
- don't indicate that the volcano will be erupting but can occur at anytime
- cause damage to manmade structures and landsliding

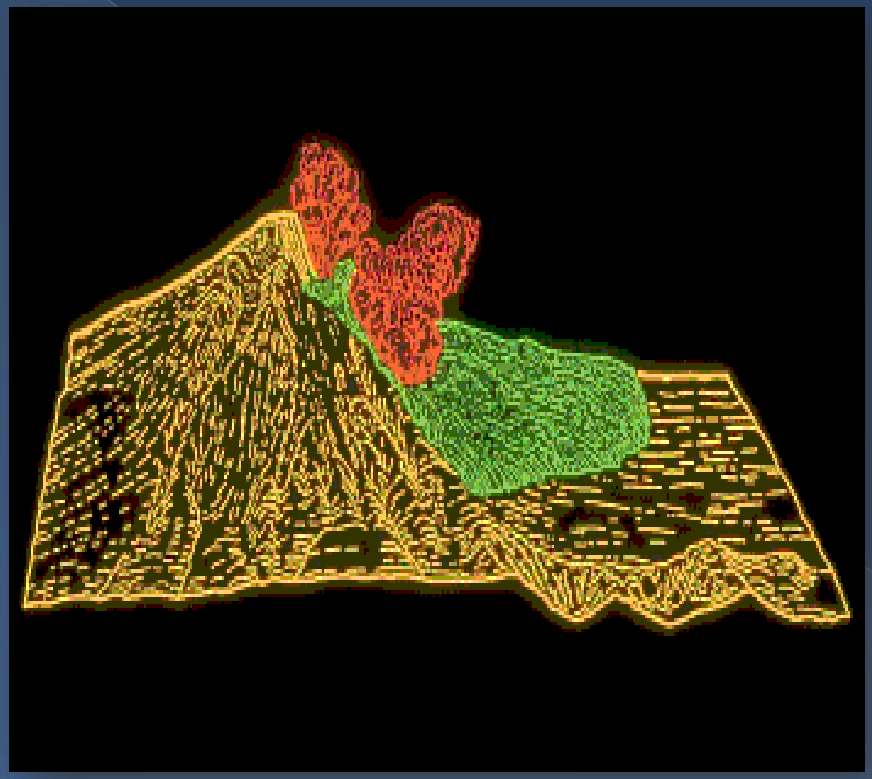
2- long period earthquakes

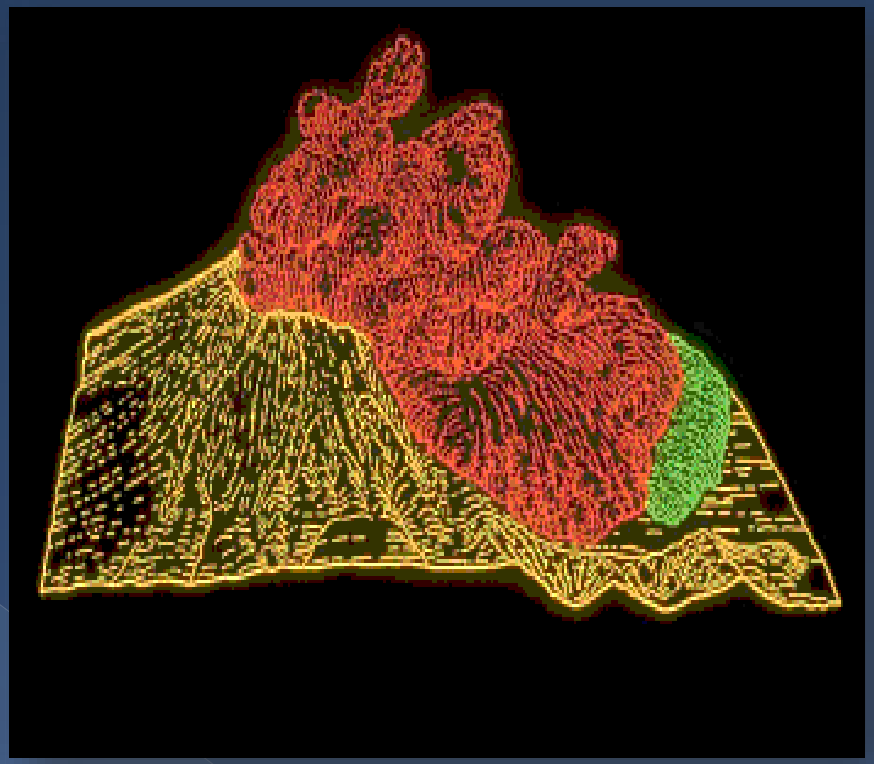
- produced by the injection of magma into surrounding rock
- result of pressure changes during the unsteady transport of the magma
- This type of activity indicates that a volcano is about to erupt

- **To prevent damage**
- structures should be built according to earthquake standards
- building foundations should be constructed on firm ground and not unconsolidated material which may amplify earthquake intensity
- buildings should be constructed on stable slopes in areas of low hazard potential

Directed Blast

In a typical volcanic eruption, an eruption column consisting of pyroclastic material is ejected into the atmosphere. The base of this column is known as the *gas thrust zone* where material is shot ballistically from the volcanic vent. Above this zone is the *convective thrust zone*. This zone is where heat buoys pyroclastic material upward toward the top of the troposphere. Once the eruption column reaches the stratosphere, shearing occurs and the material is spread out in an *umbrella* shape





These illustrations show the landslide (green) and directed blast (red) that occurred during the first few minutes of the eruption of Mount St. Helens in 1980

a

c

b

d

Greater than 19 miles from the volcano, trees were seared black due to hot gases
Material from the initial blast cloud itself was very hot ranging between 100 and 300 degrees C

Residual lateral blast effects in the *channelized blast zone*, some thirty years after the eruption. Damage ranged from scorched earth, through tree trunks snapped at various heights, to more superficial effects.

Lakes nearest to Mount St. Helens have been partly covered with felled trees for more than thirty years

Lava Flows

Lava Flows

- The least hazardous of all processes in volcanic eruptions
- Don't move very fast so people rarely get killed by them
- How far a lava flow travels depends on the flows temperature, silica content, extrusion rate, and slope of the land
- Very hot between 550 degrees C and 1400 degrees
- The biggest hazard of lava flows is that they destroy property
- They can melt snow and ice which can produce flooding
- Can also dam rivers which may in the future produce flooding if the dam were to break
- The main concern with lava flows is how far they will ultimately extend

How do you stop a lava flow if you know it's heading toward your property?

- Breaching the sides of a lava tube or channel
- Diverting the flow
- Constructing barriers,
- Bombing the lava flow
- Increase the lava flow's viscosity by spraying it with water
- Increasing the rate at which gas escapes from the flow
- Seeding the flow with foreign nuclei
- Stirring the flow

Debris Avalanches, Landslides, and Tsunamis

debris avalanche **is formed when an unstable slope collapses and debris is transported away from the slope**

There are two general types of debris avalanches:

1) cold

results from a slope becoming unstable

2) hot

result of volcanic activity such as volcanic earthquakes or the injection of magma which causes slope instability

Landslide

- **a general term for mass movement**
- **a gradual movement rather than the more sudden movement of an avalanche**

Mount St. Helens erupted in 1980

magma was injected into the north flank of the volcano creating a bulge that was extremely unstable. An earthquake triggered the movement of land in this area and the result was a fast moving debris avalanche

hazards that avalanches and landslides

- Both processes can travel large distances
- wipe out everything in their paths
- dam rivers and lakes and produce flooding
- lead to a decrease in pressure and cause a volcanic explosion
- The mixture of debris from a landslide or avalanche with water may produce lahars which can affect people living in valley areas far away from the volcano's summit
- Another important hazard that can be produced from avalanches and landslides are ***tsunamis***

Tsunamis

- large sea waves that have long wave periods
- aren't always produced by collapsing land masses
- produced by volcanic earthquakes and explosions, atmospheric shock waves due to rapidly moving volcanic material
- lahars or pyroclastic flows that have entered the sea

- Not much can be done to stop avalanches or landslides from occuring
- The best way to prevent disaster from happening is to be aware of what has happened in the past and what is happening in the present

Lahars

Lahars

- One of the greatest volcanic hazards is lahars.
- *Lahars* are similar to pyroclastic flows but contain more water
- Lahars that contain 20 to 60 percent sediment are usually very turbulent
- Lahars that contain greater than 80 percent sediment usually flow more smoothly (laminar flow)
- These smooth flowing lahars usually travel much faster than their turbulent counterparts and can float boulders, cars, buildings, and bridges
- They have a wide range of velocities varying from 1 m/s to 40 m/s
- The velocity of a lahar depends on the channel width, channel slope, volume of the flow, and grain size composition
- Lahars can travel long distances

Lahars are extremely dangerous especially to those living in valley areas near a volcano

Lahars can bury and destroy manmade structures including roads and bridges

❖Many methods have been used to stop or at least detour a lahar

These methods include building retention basins, alternate channels, tunnels, and concrete structures

The best preventative measure is to establish a warning system

Warning systems that have been used include **seismometers** that pick up the signal of a lahar as it moves down valley and **rain gauges** that collect water and warn when lahar formation is possible.

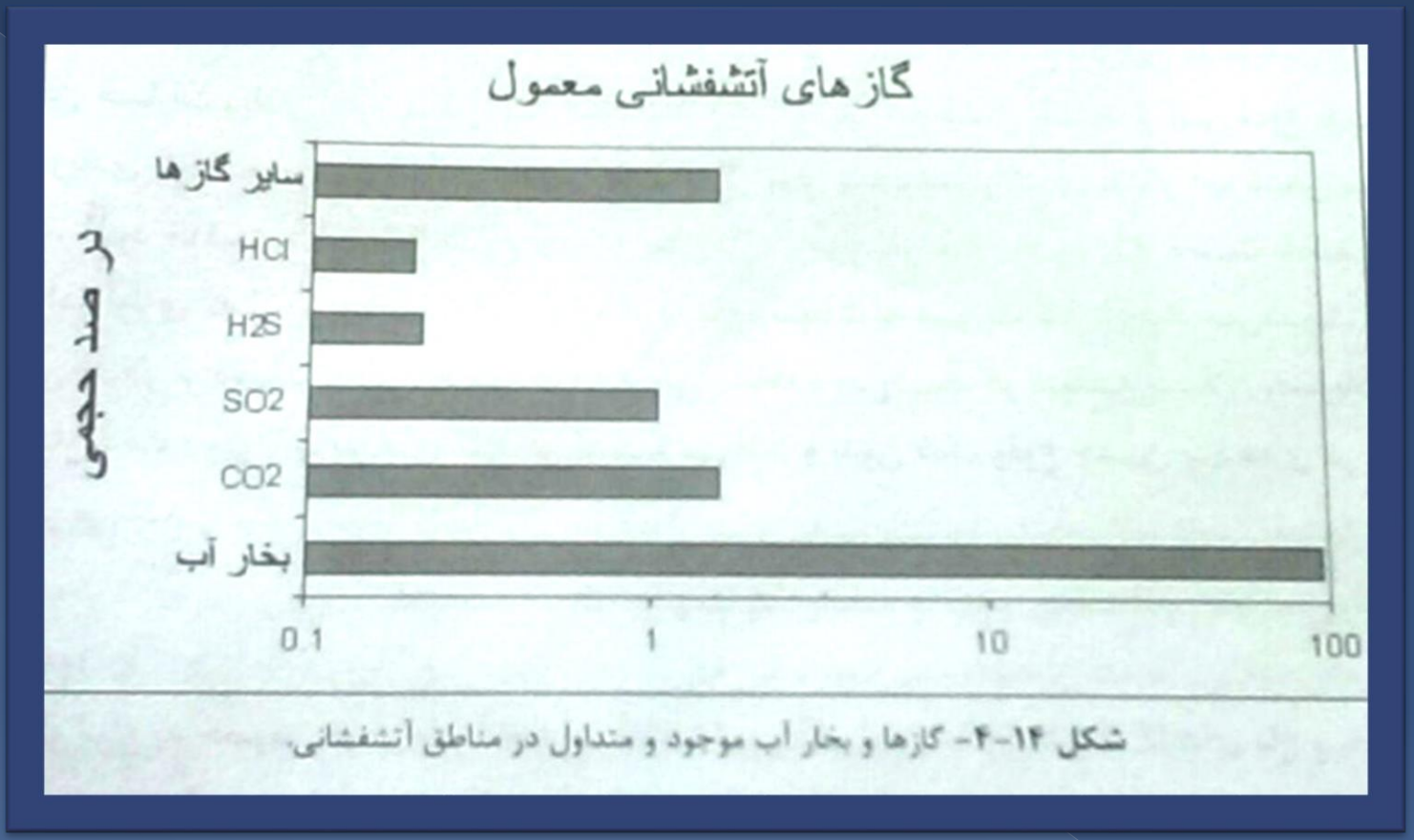
Volcanic Gases

❖An erupting volcano will release gases, tephra, and heat into the atmosphere

- The largest portion of gases released into the atmosphere is water vapor

- Other gases include carbon dioxide (CO_2), sulfur dioxide (SO_2), hydrochloric acid (HCl), hydrogen fluoride (HF), hydrogen sulfide (H_2S), carbon monoxide (CO), hydrogen gas (H_2), NH_3, methane (CH_4), and SiF_4

- Volcanic gases are also produced when water is heated by magma. Gases also escape from pyroclastic flows, lahars, and lava flows, and may also be produced from burning vegetation
- Acid rain can be produced when high concentrations of these gases are leached out of the atmosphere



The largest portion of gases released into the atmosphere is water vapor

Fluoride and chloride

- contaminate water
- Livestock have died from drinking such contaminated water
- irritating to the skin and eyes of animals
- can damage clothes and machinery

Carbon monoxide and carbon dioxide

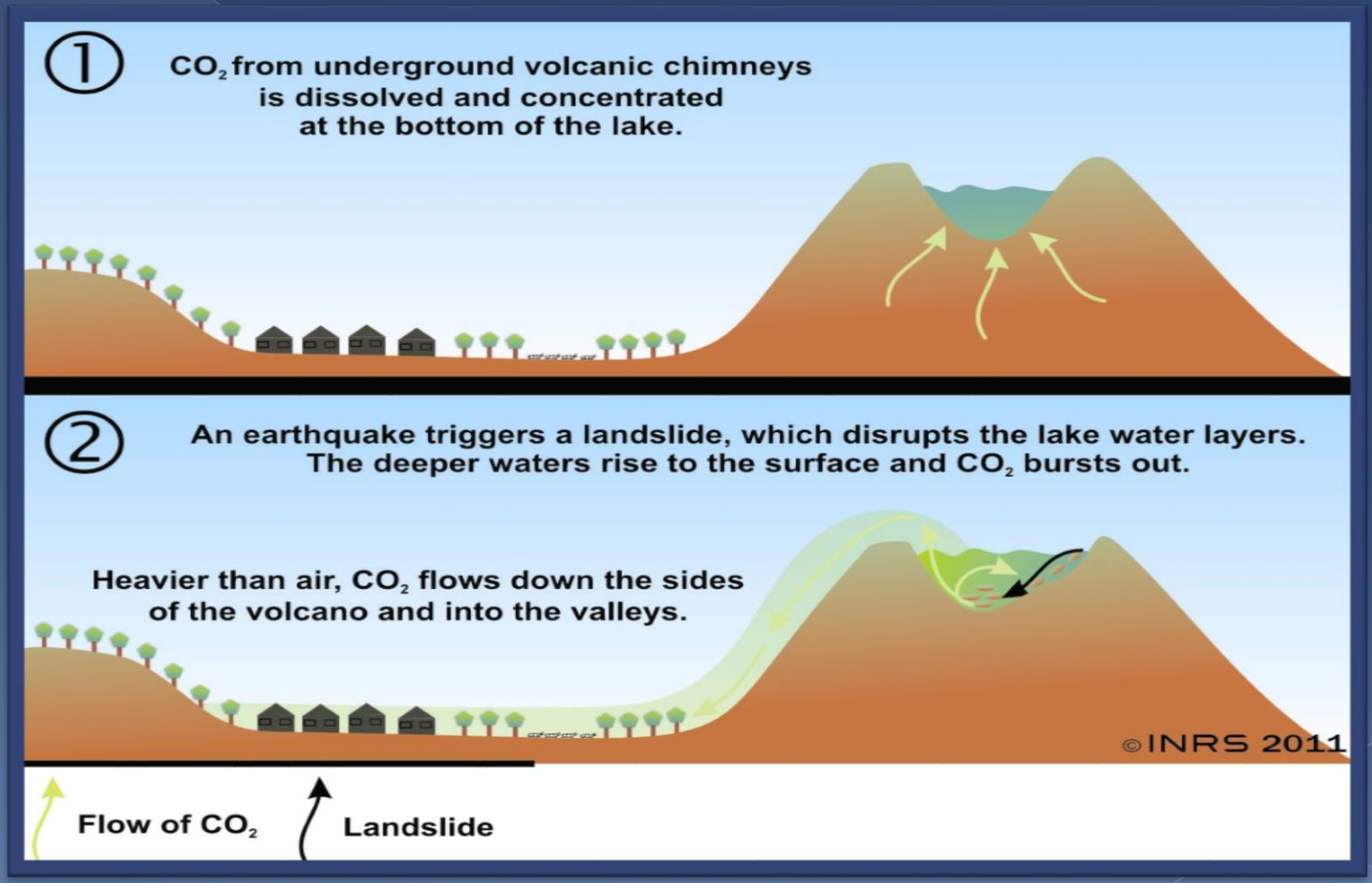
- usually produced in small amounts
- large amounts of these gases will sometimes build up in low lying areas and can asphyxiate livestock and harm vegetation

CaF2

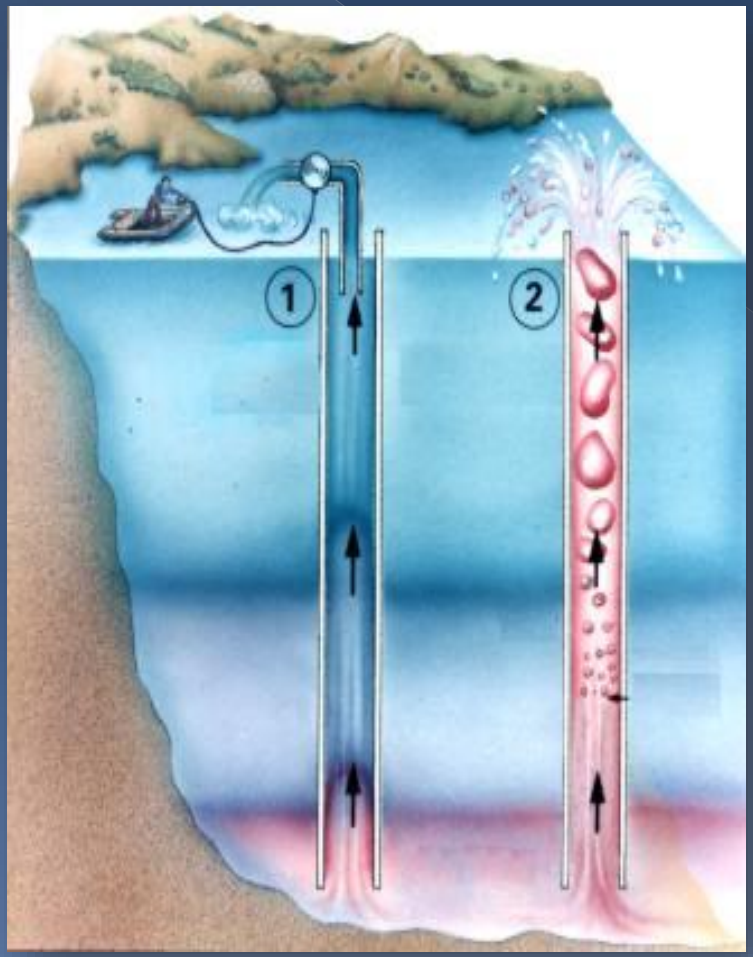
- burn vegetation and other material on contact

How did Lake Nyos suddenly kill 1,700 people?

What happened at Lake Nyos?



Degassing Lake Nyos - Hazard Prevention



Pyroclastic Flows

- the greatest volcanic hazards
- can incinerate, burn, and asphyxiate people
- fluidized masses of rock fragments and gases that move rapidly in response to gravity
- can form in several different ways

  when an eruption column collapses

  as the result of gravitational collapse

  explosion on a lava dome or lava flow
- more dense than pyroclastic surges
- contain as much as 80 % unconsolidated material
- fluidized because it contains water and gas from the eruption, water vapor from melted snow and ice, and air from the flow overriding air as it moves downslope

The image shows the formation of pyroclastic flows during a 1980 eruption of Mount St. Helens

Ignimbrites and nuees ardentes are two types of pyroclastic flows

Ignimbite

contains mostly vesiculated material

Nuee ardente

contains denser material

means glowing cloud and was named for the pyroclastic flows seen at Mount Pelee

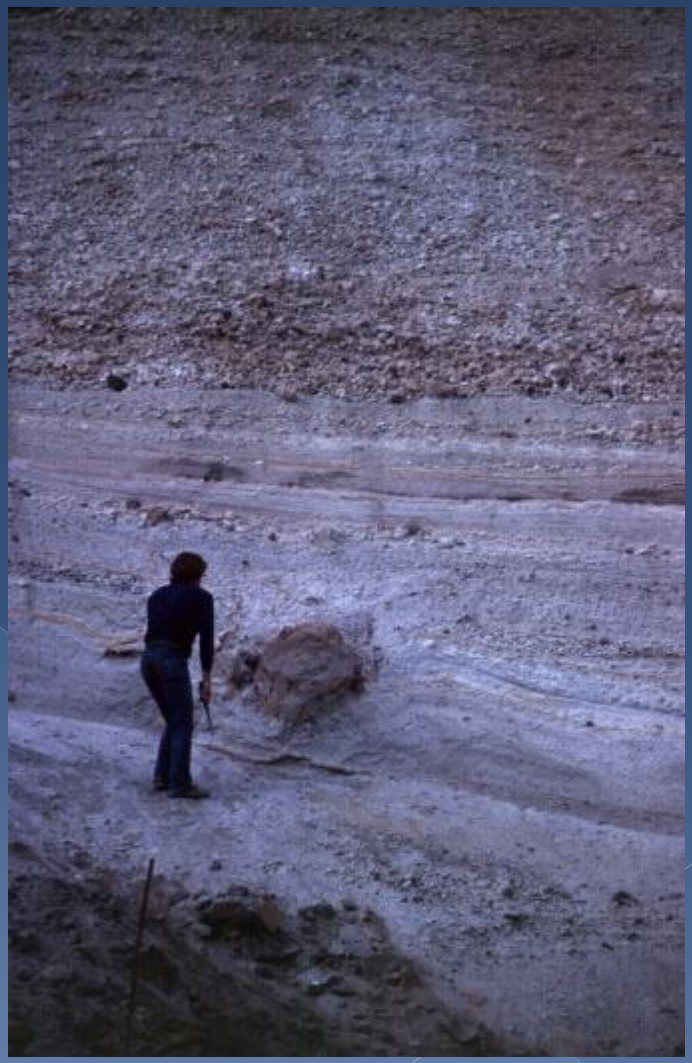
have been known to extend 50 kilometers from their source

Pyroclastic flows can be very hot

- Mount Pelee had temperatures as high as 1075 degrees C
- Pinatubo had temperatures of 750 degrees C
- Mount St. Helens had temperatures of 350 degrees C

Pyroclastic Surges

- Pyroclastic surges are low density flows of pyroclastic material
- low density
- lack a high concentration of particles and contain a lot of gases
- These flows are very turbulent and fast
- They overtop high topographic features and are not confined to valleys
- does not travel as far as a pyroclastic flow
- Pyroclastic surges can travel up to at least 10 kilometers from the source



- Pyroclastic surges are very hazardous
- bury, burn, and destroy things upon impact
- contain lots of gases that can asphyxiate people
- the greatest number of people killed by pyroclastic surges was in 1902 near Mount Pelee in the town of St. Pierre when 30,000 people lost their lives
- pyroclastic surges are fast and not constrained by topography it is hard to find a safe place to be when they come
- The best way to be safe from this hazard is to put a lot of distance between you and the volcano.

There are three types of pyroclastic surges

1) base surge

- formed when the volcano initially starts to erupt from the base of the eruption column as it collapses
- does not travel greater than 10 kilometers from its source

2) ash cloud surge

- forms at the base of a pyroclastic flow

3) ground surge

- forms when the eruption column is neither buoying material upward by convection or collapsing
- Such deposits can be formed before, after, and during, the formation of pyroclastic flows

Tephra

- When a volcano erupts it will sometimes eject material such as rock fragments into the atmosphere
- The largest pieces of tephra (greater than 64 mm) are called *blocks* and *bombs*
  - Blocks and bombs are normally shot ballistically from the volcano
  - these fragments are so large they fall out near their source
  - Blocks and bombs as large as 8-30 tons have fallen as far away as 1 km from their source
  - Small blocks and bombs have been known to travel as far away as 20-80 km
  - Some of these blocks and bombs can have velocities of 75-200 m/s

Smaller ejecta such as *lapilli* (2-64 mm) and *ash* (<2 mm) will fall out farther from the volcano

- particles greater than a millimeter in size will fall out within 30 minutes of the time they are erupted
- The smallest particles which are less then 0.1 mm can stay in the atmosphere for two or three years after a volcanic eruption
- The distance that ejecta travels away from a volcano depends on:
  - the height of the eruption column
  - temperature of the air
  - wind direction
  - wind speed

Tephra produces a wide range of hazards

- Tephra can destroy vegetation which can result in famine
- ejected material is in the atmosphere it is electrically charged and often produces lightning
- Large ejecta shot ballistically from the volcano are also a hazard to those unfortunate enough to be near the volcano

Other hazards are produced when the ash is deposited on the ground

- disrupt electricity, television, radio, and telephone communication lines
- bury roads and other manmade structures
- damage machinery
- start fires
- clog drainage and sewage systems
- poor visibility and cause respiratory problems
- If ash builds up on the tops of roofs, it will often cause collapse

- Ash is also a great hazard to airplanes
- Volcanic eruption clouds cause rerouting, cancellation, and delays in flights

A Few Final Remarks…

- The main reason scientists study and monitor volcanoes is so that those living near active volcanoes can be aware of the hazards produced by volcanoes. This awareness will hopefully prevent loss of life and property when an eruption occurs.
- It is important that scientists communicate with local government officials and the general public about hazards produced by the volcanoes in their area.
- This interaction and the developement of an emergency plan with established lines of communication will hopefully save lives and encourage better land use planning.


Volcanic phenomena
and associated health
hazards
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Volcanoes health hazard
During eruptions
Inter-eruptive periods
Post-eruption

Inter-eruptive periods can be characterised by:

- strong emissions of potentially harmful gases and particles

Following eruptions

- volcanic mudflows
- debris avalanches
- volcanogenic tsunami

Post-eruption

- famine
- Epidemics
- pyroclastic density currents
- Mudflows
- volcanogenic tsunamis
- lava flows (which usually move sufficiently slowly to permit evacuation though there are exceptions)

490 volcanic events in the 20th century

resulted in human impacts:

- **4–6 million people evacuated**
- **made homelessor otherwise affected**
- **Fatalities occurred in around half of the events, with an estimated total of 80 000–100 000 deaths.**

The risk of catastrophic human losses from future eruptions is significant given the possibility of much larger eruptions than witnessed in the historic period, the increase in human population, and proximity of major cities worldwide to active volcanoes, including Naples and the capitals of Mexico, Japan, the Philippines, Ecuador, Guatemala, and El Salvador.

morbidity associated with volcanism

- destruction of agricultural land
- contamination of water supplies
- sustained or sporadic small-scale eruptions
- community exposures to volcanic air pollution

Tephra and ash falls

Tephra is a general term for any fragmentary material originally emitted from volcanoes

Tephra presents several kinds of health hazard:

- through inhalation and abrasion of skin and conjunctiva,
- through building collapse from loading on roofs
- through impacts on terrestrial and aquatic environments.
- Heavy falls of tephra can damage vegetation, including agricultural crops

- Tephra also typically carries volatiles scavenged from volcanic gases such as fluorine, emitted in large quantities in some eruptions.
- Grazing animals can ingest toxic quantities of fluorine when ash contaminated in this way lies on the ground.
- Drinking water may also become contaminated by fluorine from tephra, although fluorine poisoning in human populations appears rare.

- Ash clouds are associated with explosive eruptions and can pose a risk to aviation through damage to jet engines and abrasion, for example, of cockpit windows. To date there have been no reported air crashes arising from encounters with volcanic clouds, but there have been several near misses

Ash

ash refers to tephra particles <2 mm across

ash contained crystalline silica,

risks of ash exposure:

- silicosis
- chronic obstructive pulmonary disease (COPD)

areas with high levels of airborne ash (daily average total suspended particulates (TSP) of 3000–33 000 μg/m^3) experienced a 2–3-fold increase in hospital admissions and 3–5-fold increase in emergency room visits for respiratory conditions

One of the most deadly effects of a volcano is the ash coming from the eruption, which carries poisonous gases that are harmful to humans, plants, and animals alike

Hazards Of Volcanic Ash

A multitude of dangerous particals and gases, such as aerosols, are carried in volcanic ash. Some of these include;

- Carbon dioxide
- Sulfates (sulfur dioxide)
- Hydrochloric acid
- Hydroflouric acid

These each have different but serious effects on human health if exposed.

In addition, volcanic ash can cause reduced visibility, and it is recommended that precautions are taken when driving

How Volcanic Ash Travels Around The Earth System

Unfortunately, volcanic ash can be very easily transported around the Earth system. The movement of volcanic ash depends on:

- eruption column height
- ash particle size
- amount of ash ejected into the atmosphere
- climatic conditions - wind direction, strength, and humidity

Larger eruptions of ash can travel hundreds to thousands of kilometers downwind from the source, but can effect the climate in places on the other side of the world. Ash carried into the atmosphere and spread far from the epicenter can block the sun's rays, resulting in a cooler Earth. The ash can also return to the Earth's surface by means of precipitation; ash particles caught in clouds in the atmosphere fall back down to Earth with rain, snow, ect.

Impacts on Human Health

inhalation of volcanic ash can be very detrimental to human health, due to the harmful aerosols and poisonous gases the ash is made up of. Health effects inlcude respiratory problems, eye problems, and skin irritiation.

1. Respiratory symptoms (short-term)

- runny nose
- sore throat/coughing
- wheezing/shortness of breath
- possible bronchitus

2. Eye symptoms (short-term)

- may become itchy or bloodshot
- corneal abrasions or scratches

  can result in conjunctivitis
- tearings

One long-term effect of volcanic ash is **silicosis**. Silicosis is a disease resulting in lung impairment and scarring, from exposure to particles of free crystalline silica. Minerals that are associated with silicosis include quartz, cristobalite, and tridymite, all potentially present in volcanic ash. Volcanic ash can also contaminate the water supply.

A picture of silicosis of the lung

A handful of tiny volcanic ash particles

Prevention or Mitigation

there are many ways to avoid and protect yourself against the dangers of volcanic ash. Precautions for the general public as published by the Federal Emergency Management Agency (FEMA) are outlined below:

- wear protective clothing, goggles, and dust masks
- seal buildings
- those with pre-existing respiratory conditions should stay inside or evacuate
  - it is recommended to stay inside in general
- wet any dust and ash particles to prevent movement
- when driving, keep a proper distance in between cars due to reduced visibility
- avoid exertion, since heavy breathing leads to deeper inhalation of particles into the lungs

factors emerged as potentially important predictors of the scale and nature of respiratory effects

- Concentration and size of the ash particles inhaled, particularly the percentage of finer particles (here <4 μm and <2.5 μm) able to penetrate deeply into the lung, and coarser particles (of 4–10 μm) chiefly impacting on the upper airways
- Mineralogic composition, particularly the free silica content
- Surface properties, especially Fe^{2+} content—higher iron resulting in more free radical generation in toxicological studies, with fresh ash generating more radicals than weathered samples

Soufrière Hills volcano, Montserrat

- has been erupting since 1995
- Soufrière Hills ash typically contains 13 –20% inhalable (<10 μm) particles
- crystalline silica (cristobalite, tridymite, and minor quartz) content of these particles has varied between 10 –27 wt% and 4–6 wt%, depending on the style of associated volcanic activity and size of the particles, with smallest particles having the highest concentrations
- Toxicological studies: Montserrat ash to be mildly toxic but less harmful to the lungs than the cristobalite concentration might indicate

Pyroclastic density currents

One of the major hazards to life associated with volcanic eruptions results from exposure to clouds of hot gas and tephra, variously referred to as pyroclastic flows, pyroclastic surges, nuées ardentes

contemporary reports of eruptions showed that PDCs have very high dead:injured ratios of 10:1 or greater —much higher than in any other type of natural disaster.

During an eruption of Mont Pelée on Martinique in 1902, PDCs swept into the town of St Pierre at an estimated speed of 160 km/h, resulting in the deaths of 29 000 individuals within minutes, including all but two of the city's population

The main causes of death:

- heat induced fulminant shock,
- asphyxia due to plugs of ash in the airways
- thermal lung injury
- deep thickness burns

Skeletons of victims found in boat sheds at Herculaneum (killed during the eruption of Vesuvius in AD 79) suggest brief (a few minutes) exposure to temperatures of about 500°C; skull markings suggested boiling of brain tissue.

victims of PDCs from Soufrière Hills volcano

Lower temperature — around 200–300°C

result in a characteristic “pugilistic” attitude of corpses (limbs flexed, spine extended).

Survivors from PDCs tend to have been exposed to more dilute parts of the current or sheltered in some way, but are at risk of respiratory burns resulting in fatal laryngeal or pulmonary oedema, secondary respiratory infections, and complications of deep thickness skin burns. The transient nature of the exposure to hot ash may result in serious burns to respiratory tract and skin while overlying clothing is undamaged

Prior evacuation from areas at risk from PDCs is the only recommended way to minimise fatalities.

Sheltering should only be used in an emergency — the few people that have survived PDCs have reported sheltering in closed rooms, followed by opening of windows as soon as the sensation of heat has passed because of choking sensations. Some have survived out in the open, but only right at the margins of the currents

Volcanic landslides

Because of their slopes and construction from sometimes poorly consolidated materials (rubbly lavas, loose ash), and through the weakening action of acidic groundwaters, volcanoes are prone to gravitational collapses. These may be triggered by seismic events or heavy rainfalls. Even small volcanic landslides can be devastating in populated areas, and they can occur long after volcanic activity, for example, the landslide triggered by sustained and heavy rainfall at Casita volcano, Nicaragua, in 1998. In such cases, the landslides typically evolve into mudflows. The major health sequelae are physical injuries related to burial and property destruction. On volcanic islands, the landslides can initiate tsunami if the displaced material flows into the sea.

Lahars (volcanic mudflows)

Lahar is an Indonesian word for a flowing mixture of rock debris and water that originates on the slopes of a volcano.

They form in a variety of ways including :

- the rapid melting of snow and ice by hot pyroclastic material
- intense rainfall on loose volcanic deposits
- breakout of crater lakes, and as a consequence of debris avalanches.

They can travel at speeds of 50 km/h or more and run out many tens of kilometres. The lahar arising from the eruption of Nevado del Ruíz in 1985 travelled more than 60 km and resulted in the deaths of an estimated 22 800 people. Of the 1000 or so hospitalised after this event, most had lacerations (69%), penetrating wounds (41%) and fractures (37%), and minor eye lesions, with infections a frequent complication.

Volatiles: gases and particles

- Emissions may occur in association with eruptions, but are also common between eruptions at many volcanoes and geothermal areas where they may be vented from the main crater, from fumarole fields, or diffusely through soil. Volatiles emitted include CO and CO_2, SO_2, HCl, HF, H_2S, and radon.
- Volcanoes also emit particles with potential to impact human health, notably sulphate aerosol. Emissions of heavy metals, including lead and mercury, in both gas and particle phase, may also be important.

CO2

CO_2 accumulates in topographical depressions, wells, trenches, basements, etc in some volcanic areas and can result in deaths due to asphyxiation. Such deaths have been reported from a range of countries:

- Vulcano, Lazio and Alban Hills, Italy
- Mammoth Mountain, California

Rarely, CO_2 accumulates in deep water in volcanic areas, such as lakes that are well stratified with little mixing or hydrothermal systems. If the water is saturated with CO_2 under pressure, sudden displacement of the water for whatever reason may cause a sudden release of the gas, like opening a bottle of champagne. The resultant cloud of CO_2 is able to flow under gravity, suffocating people and animals in its path with little warning. For example, release of a quarter of a million tonnes of CO_2 triggered by a landslide into Lake Nyos, Cameroon in 1986 resulted in 2000 deaths.

H_2S

Accumulations of H_2S from volcanic and geothermal sources, including faulty geothermal heating systems, have also resulted in fatalities from asphyxiation

health effects of SO_2 and acid aerosols from eruptions:

- increases in respiratory mortality and morbidity (for those with pre-existing disease), but not childhood asthma prevalence or lung function decrements

Specific occupational health hazards

Groups of workers at particular risk from volcanological hazards due to the nature of their job include:

- working in geothermal power plants
- geologists
- volcano tourism or documentary making.
- workers in construction
- quarrying,
- agriculture and related industries may be exposed to new or ancient deposits of volcanic ash,

potentially giving increased risk of silicosis or even asbestosis and mesothelioma depending on the composition of the ash.

Volcanologists and other geologists working in volcanic or geothermal areas may be exposed to any of the hazards Working in the vicinity of fumarole gases (released in otherwise quiescent volcanic and geothermal areas) without wearing a gas mask may result in exposures to gases (for example, SO_2, HF, HCl, H_2S) and gaseous form metals (for example, Al, Hg, Rb, As) that are higher than in occupational settings. Exposure to acidic gases without wearing respiratory protection, especially if repeated frequently

may lead to irritant induced asthma including reactive airways dysfunction syndrome (RADS) — of which there are anecdotal reports. Geothermal steam from geothermal power plants also contains acid gases and heavy metals — a fatality from accumulation of H_2S within an enclosed space in a

plant has been reported.

volcano tourists and those working in volcano tourism

- cuts and grazes from falls on sharp volcanic rocks,
- respiratory and eye irritation when exposed to fumarole or crater gases.

Other potential impacts on human health

Eruptions that discharge more than a few megatonnes of sulphur gases into the atmosphere, have the potential to cause regional to global scale climate change through complex mechanisms. A now well observed and understood phenomenon is the summer cooling and winter warming of Northern Hemisphere continental regions following large, sulphur-rich eruptions of volcanoes in the tropics. The 1815 eruption of Tambora, Sumbawa island, Indonesia, responsible for the greatest recorded fatalities due to volcanic activity, also released sufficient sulphur into the upper atmosphere to result in widespread cooling during the Northern Hemisphere summer in 1816. This has been linked to epidemic disease in Ireland, the UK, and parts of continental Europe through a combination of socioeconomic factors and the effects of the climatological anomalies on crop yields. In the immediately impacted region, an estimated 61 000 people died during and in the aftermath of the eruption, mostly as a result of famine and epidemic disease.

Risk management

One of the main aims of research assessing and quantifying health risks of volcanoes is to formulate policy on preparations to deal with disasters and on land use planning. *Probabilistic* risk assessment for current and potential future volcanic hazards is a relatively new practice but it is increasingly being used to inform risk management and decision making.

Summary

- Major mortality associated with volcanogenic phenomena in recorded history has resulted from pyroclastic density currents (avalanches of hot ash, gases, and rocks), tsunami, landslides, and debris flows.
- Exposure to volcanic ash may result in acute respiratory morbidity, especially in those with pre-existing respiratory disease, but the long term effects are unclear and may vary from volcano to volcano.
- Eruptions of ash and discharges of aerosols and acid gases may be transported long distances (hundreds of kilometres) and cause health effects remote from the volcano concerned.
- Large eruptions can cause global climate change through entrainment of gas and particles into the upper atmosphere.
- An increasingly multidisciplinary approach is being adopted in research into health hazards of volcanoes and improving management of health risks

Science based evaluation of risks alone is not enough, as painfully underscored by the Nevado del Ruíz tragedy in 1985 (when the town of Armero that was inundated by lahars had already been identified as at risk, but no concrete action was taken to protect the population)

Lahars covered the town of Armero. More than 20,000 people died

It is now widely acknowledged that systematic development and application of policies, strategies, and practices is essential, and that social and economic policies designed to reduce vulnerability are crucial. Communities, and the officials responsible for their protection, need to appreciate not only the nature of risks, but also the uncertainties in the science underpinning the forecasting of volcanic activity and the effectiveness of actions that may be taken to prevent or mitigate the risks. Practicalities of risk management plans also need to be thought through in advance—for example, for successful evacuation, plans need to encompass communications, transport, lodging, medical care, and protection of assets. As a consequence, public awareness programmes, education, and training are increasingly being undertaken as part of volcanic risk management, for example in the communities threatened by Vesuvius

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