Chapter 9

Volcanic Emissions and Health

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Earth 281

Main reference: Chapter 9 from Selinus O., Alloway B., Centeno J.A., Finkelman R.B, Fuge R., Lindh U., and Smedley P., 2005. *Essentials Of Medical Geology: Impacts Of The Natural Environment On Public Health.* p.832. Academic Press.

Outline

- Introduction
- Volcanic Mechanisms
- Remediation Strategies
- Exposure Pathways

geology.com/volcanoes/chaiten

(A) Introduction

- Impacts caused by magma, gases and water being released through volcanic vents and fissures.
- Health impacts are based upon the composition of the volcano and the duration and magnitude of the eruption.
- You do not have to be near a volcano to feel the effects.

mit.zenfs.com/

cdn2.pix.avaxnews.com/

Mount Sinabung erupts February 2014

america.aljazeera.com/

static.guim.co.uk/

- Magma (molten rock), gases and water are released into the ecosystem through volcanic vents and fissures
- Impacts on health are not limited to the “proximal” area surrounding an active volcano

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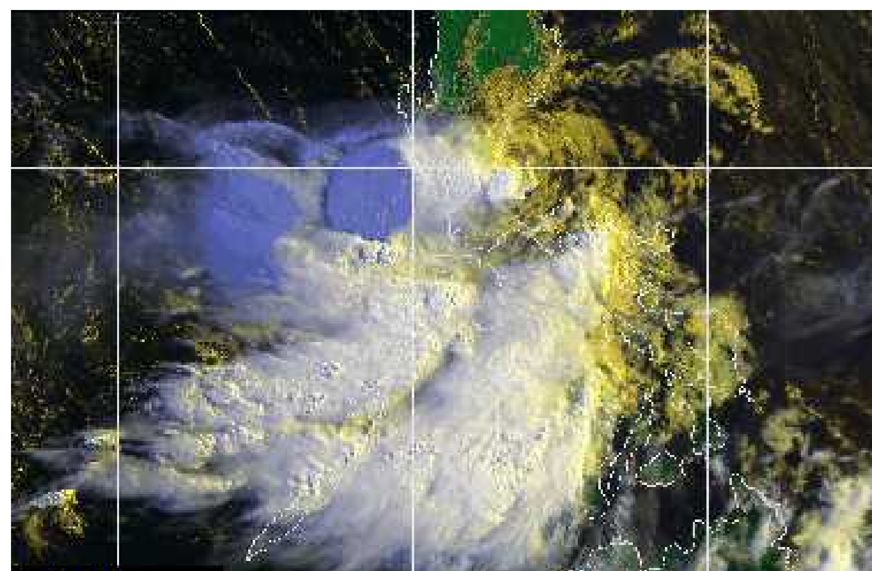

chemcases.com/

Ash Cloud over the Philippines from Mt. Pinatubo - 1991(NOAA)

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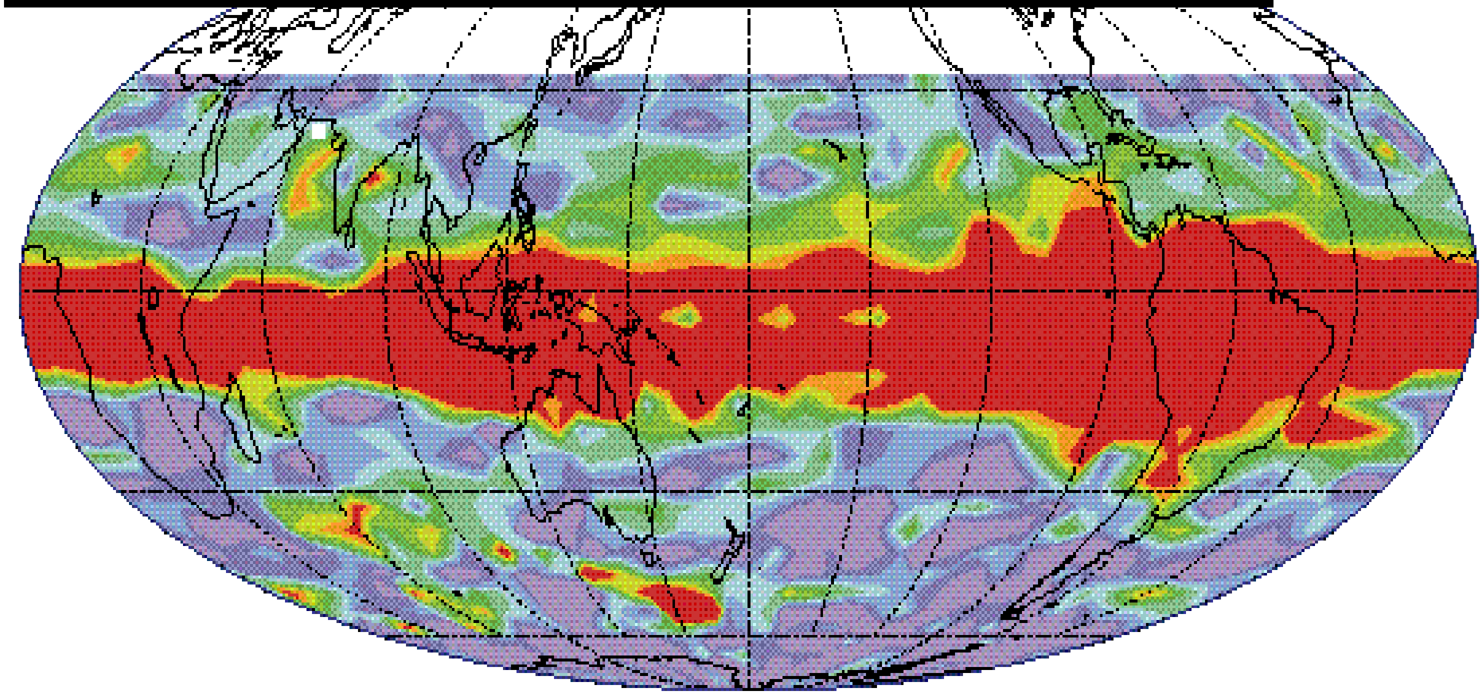
Mount Sinabung

- Health impacts are varied based on the chemical composition of the volcanic eruptions and the magnitude and duration of the eruption

Mt. Pinatubo atmospheric concentrations SO_2



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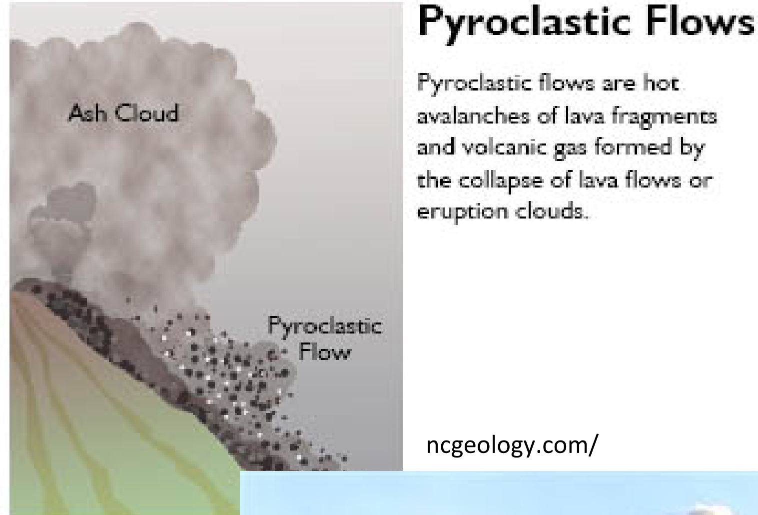
- Pyroclastic flows, lahars, asphyxiation- proximal effects



ncgeology.com/

www.geo.mtu.edu/

Standing wave in a lahar
http://bit.ly/1bkoBWI

3.bp.blogspot.com/

Extreme Pyroclastic Flows At Sinabung Volcano, Indonesia 21st January 2014: http://www.youtube.com/watch?feature=player_embedded&v=95bYATFIOxs

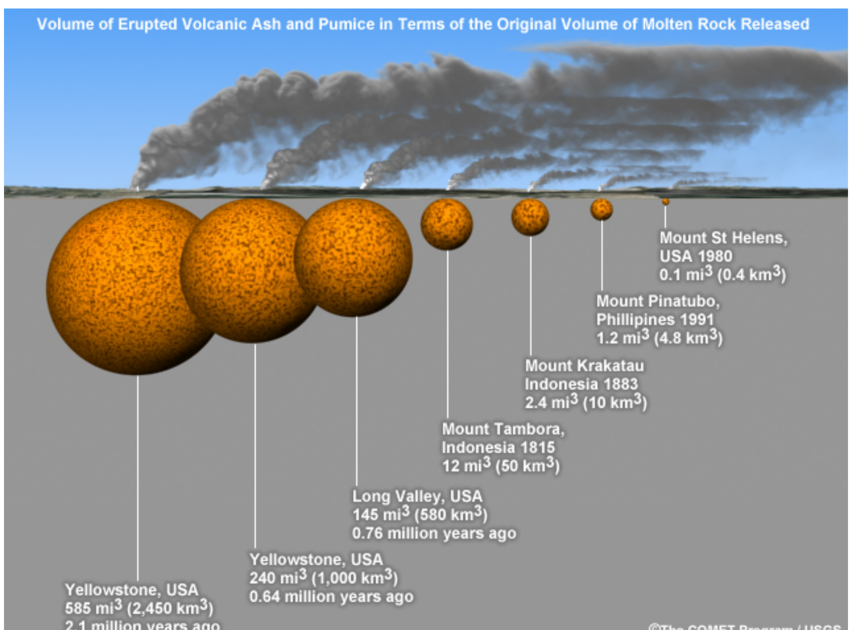
Photo Courtesy: AFP

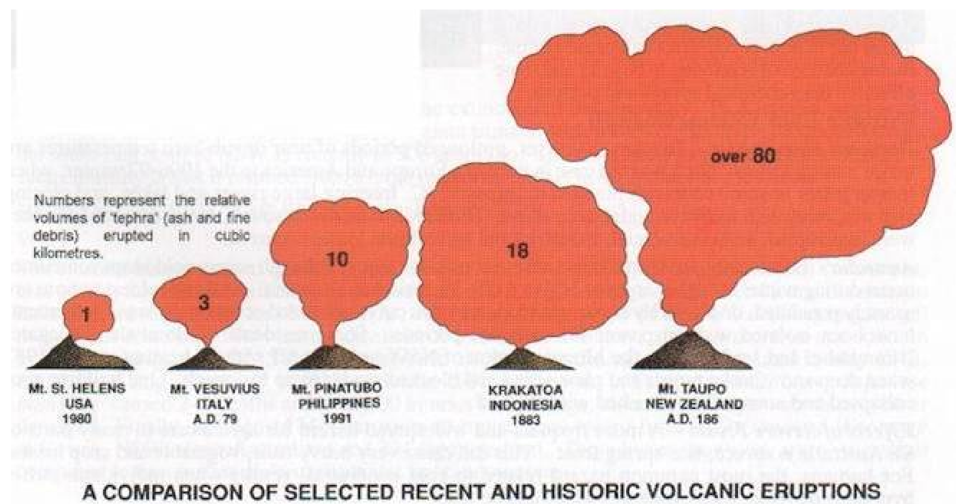
Photo Courtesy: IUGG

- Ash, dust and aerosols-proximal and distal
- Tsunamis-distal

Mechanisms Associated with Volcanic eruptions that may Compromise Health

- Eruptive Variables
    - The nature of the eruption (e.g. explosive, effusive or mixed) influences the duration of the event, hence the release of emissions





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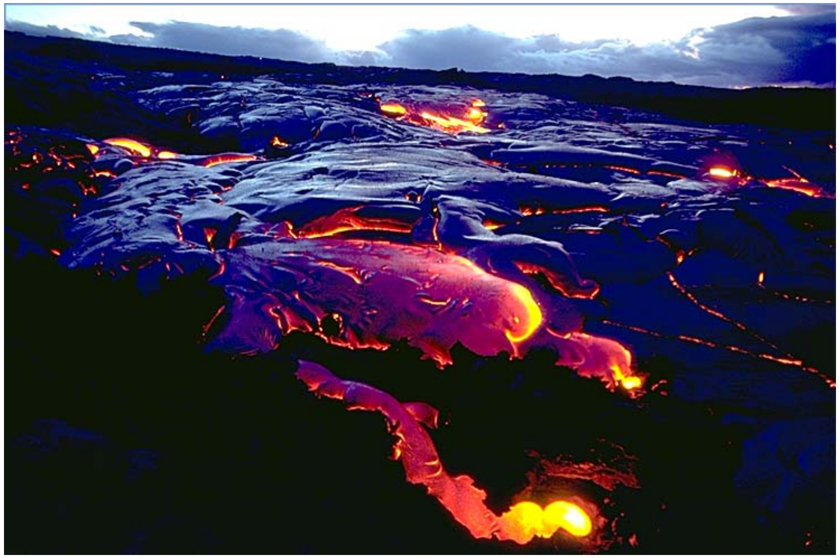
(B) Volcanic Mechanisms

1. Eruptive

   - the type of eruption

Explosive→ large amounts of hot ash, dust and gas (Mt. St. Helens)

Effusive → large lava flows, less gas and dust (Hawaii)



www.swisseduc.ch/

volcanoes.usgs.gov/

(B) Volcanic Mechanisms

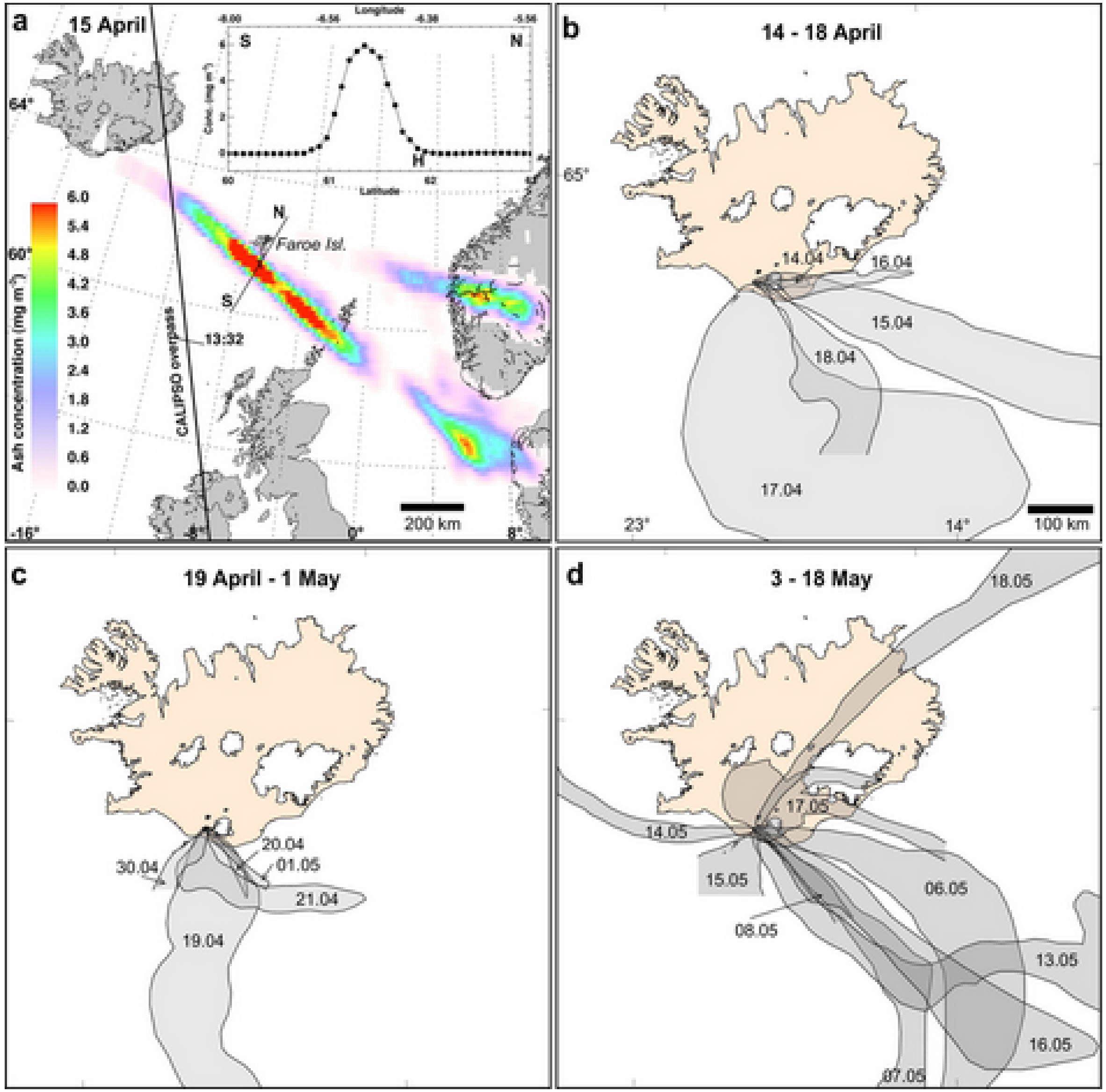
2. Toxic Specific Properties
    - Composition differences in pH, redox and geochemical nature of systems (Mt. St. Helens, Pinatubo, Kilauea)

3. Dispersal Patterns and Persistence
    - Duration of the eruption
    - Location to eruption (near or far)

Volcano (source reference)	Cl:S mass ratio	SO_2:HCl molar ratio	Cl:F mass ratio	HCl:HF molar ratio	Emission rate ($kg\,s^{-1}$)		
					SO_2	HCl	HF
Etna, Italy 14 June 1997 26 October 1997 (this study)	 0.27 0.24	 4.0 4.6	 6.6 3.83	 3.7 2.1	 62.5* 66.2†	 8.9 8.2	 1.3 2.2
Etna‡ July 1987 (ref. 18)	2.32	0.39	8.12	4.35	10.7	15.5	1.9
Kilauea, USA Summit§ Flank‖ (ref. 3)	 0.006 0.004	 66.5 83.1	 n.d. 2.0	 n.d. 0.09	 1.62 1.06	 0.05 0.02	 0.03 0.01
Erebus, Antarctica¶ 1986-91 (ref. 24)	1.4	0.79	3.8	1.1	0.49	0.35	0.17
Masaya 1980 Nicaragua (ref. 25)	0.8	0.87	52	29.2	14.7	9.6	0.18
White Island, New Zealand (ref. 26)	2.4	2.5-2.6	51	24.6-25.7	3.7-4.0	0.8-0.9	0.017-0.02
Mt St Helens, USA# 29 July 1980 (ref. 27)	0.33	5.83	2.1	2.0	14.8	1.44	0.37
Augustine, USA** 1986/97 (ref. 5)	0.86	1.28	34	111	4.39	3.71	0.03
Global volcanism (refs 28, 29)					590	12.6-348	1.90-190
Anthropogenic (ref. 30)					~2,000	95.1	15.8

Etna, Kilauea, Erebus and Masaya are persistently degassing basaltic volcanoes. White Island is an andesitic volcano with persistent hydrothermal fumarolic activity. Mount St Helens and Augustine experienced explosive activity linked to extrusion of dacite lava domes and the emission rates given relate to brief eruptive episodes.
* Simultaneous aircraft measurements.
† Measured on 27 October 1997 by T. Caltabiano. The June Cospec results are more robust because of repetition of traverses and coincident timing with our FTIR measurements; the HF retrievals, however, are less accurate than those for October because concentrations were lower at the more distal observation site.
‡ All chloride calculated as HCl.
§ Average of four analyses. Emission rates for SO_2, HCl and HF calculated from S, Cl, and F budgets.
‖ Average of six analyses. Emission rates for SO_2, HCl and HF calculated from S, Cl, and F budgets.
¶ Average of five analyses.
# Non-explosive degassing.
** Typical non-explosive degassing. Average of three dome fumaroles.

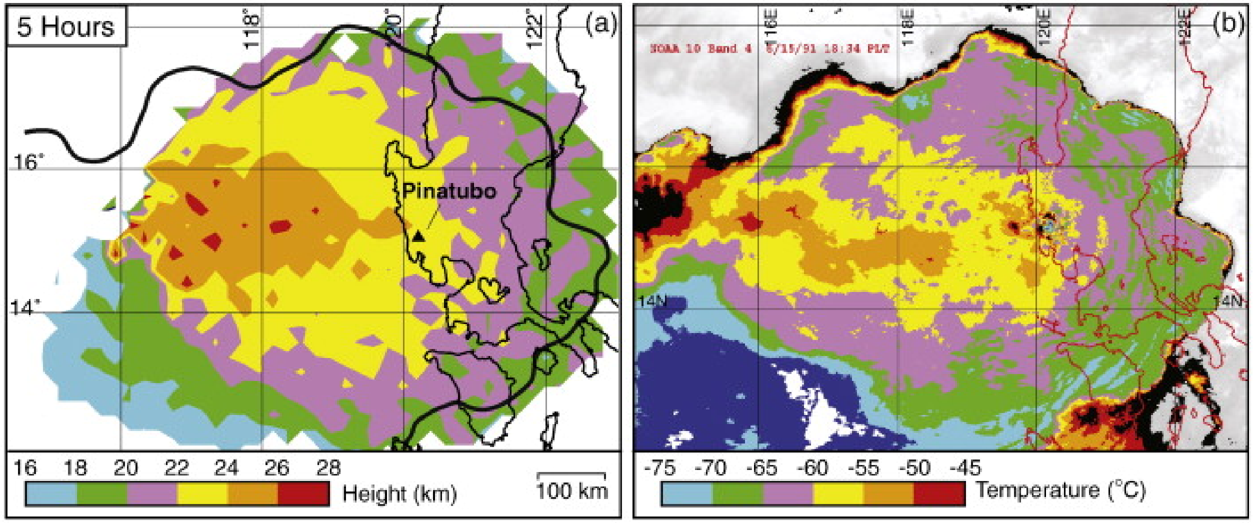
www.nature.com/

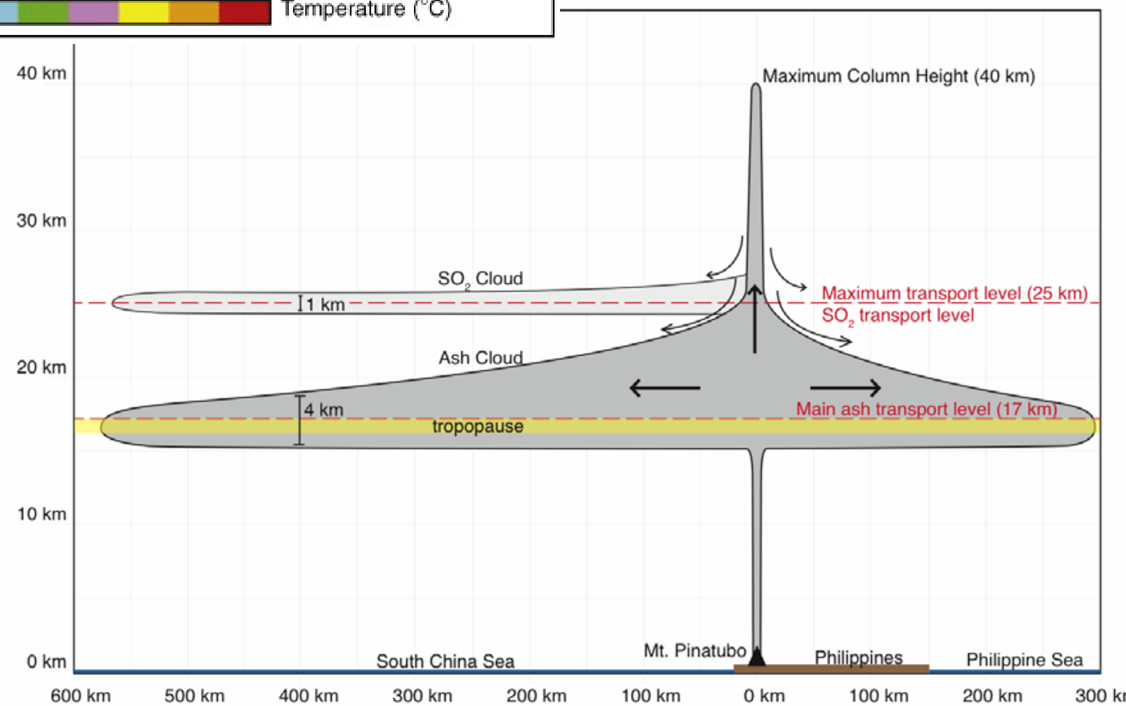


(a) Ash concentrations in a vertical column for 15 April from SEVIRI retrievals. The inset shows the concentration on a section S-N over the Faroe Islands. On the graph H marks the position of the sampling locality at Hoyvik. (b–d) Distribution patterns of the tephra over Iceland and in its vicinity, based on satellite images from MODIS, MERIS and NOAA AVHRR. One image is used per day but data for some days are missing, usually because of unfavorable cloud cover. The sectors identified for each image denote the area over which ash can be detected on the images and no distinction is made between dense and highly diluted clouds.

www.nature.com/

Julie Fero, Steven N. Carey, John T. Merrill, Simulating the dispersal of tephra from the 1991 Pinatubo eruption: Implications for the formation of widespread ash layers, Journal of Volcanology and Geothermal Research, Volume 186, Issues 1–2, 30 September 2009, Pages 120-131,.

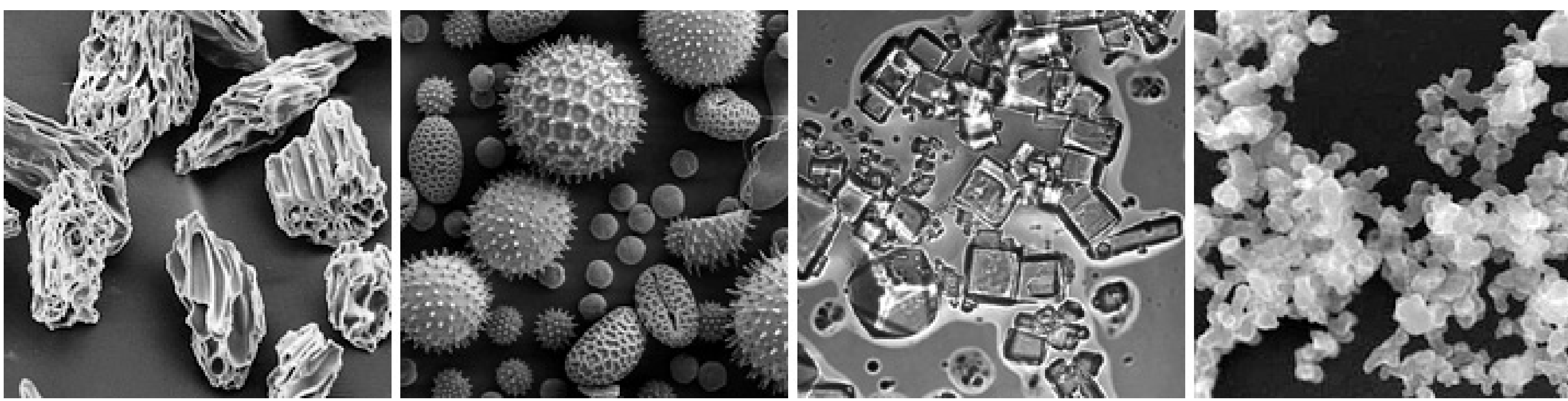




Schematic showing the dominant transport heights of the Pinatubo ash and SO_2 clouds. Distances are scaled to approximately match the cloud-top depicted in top figure (b), (a) denotes a simulation of the dispersal.

Tephra Dispersal

- Tephra is released into atmosphere during eruption (particles are less that 2 mm)
- Most common health impact is irritation of the eyes
- Exposure may cause abrasions of the skin and cornea, or penetrate lungs causing bronchi infections



earthobservatory.nasa.gov/

From left to right: volcanic ash, pollen, sea salt, and soot.

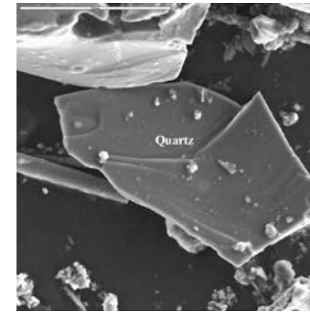
Tephra-Associations

(1) Silica/Talc → acute and chronic inflammation of the lung tissue and pneumoconiosis

(2) Fluoride → depends on concentration: Low (nausea, vomiting, excessive sweating) or High (Death, Gastrointestinal bleeding, cardiovascular convulsions)

→ may also cause sclerosis, development of bony projections (osteophytes and exostoses), calcification of ligaments

(3) Selenium → food-borne exposure (mechanism unknown), causes loss of hair and nails, skin lesions, and nervous system abnormalities



pubs.usgs.gov/

farm9.staticflickr.com/

woelen.homescience.net/science/index.html

Gas Emissions


wodumedia.com/

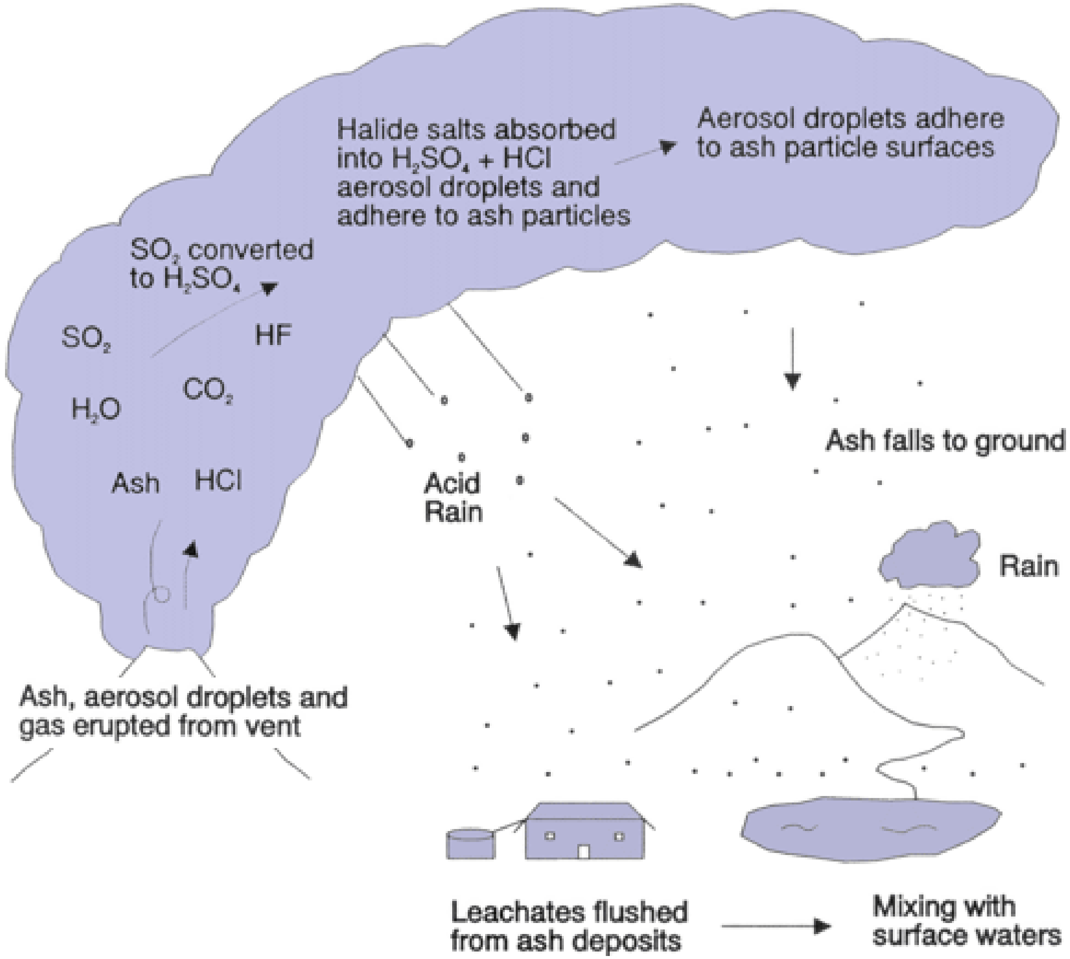
There are a 4 categories of volcanic gases:

(1) Gases and Vapour: gaseous state of the element that normally exists as a liquid or a solid and can revert back to a gaseous state under decreasing temperature or increasing pressure.

(2) Aerosols: droplets or particles suspended in a gaseous medium.

(3) Fumes: aerosols, generally < 0.1 um, usually in the form of volatiles.

(4) Smoke: volatile gases and particles, generally < 0.5 um, formed by combustion.



Volcanic eruptions inject water vapour (H_2O), carbon dioxide (CO_2), sulfur dioxide (SO_2), hydrochloric acid (HCl), hydrofluoric acid (HF) and ash into the atmosphere. HCl and HF will dissolve in water and fall as acid rain whereas most SO_2 is slowly converted to sulphuric acid (H_2SO_4) aerosols. Ash particles may absorb these aerosol droplets onto their surfaces. When ash falls to the ground, the soluble components (leachates) can by washed away by water, potentially resulting in changes to local water chemistry and hence quality. Chemical changes in the underlying soil can occur as a result of leaching of the aerosols coating individual grains and longer term from unstable glass particles (Cronin and others, 1996). Figure 3.3 from Johnston, 1997.

volcanoes.usgs.gov/

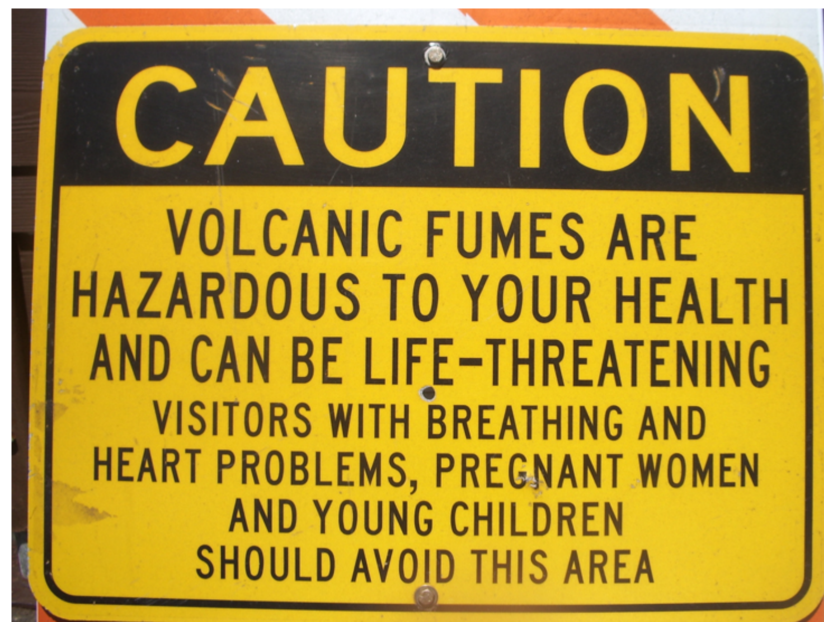
Gas Emissions

- The dangerous gases are those that are heavier than air, which include CO_2 and H_2S, which can cause asphyxiation near the ground.
- Other gases can include HF, HCl, H, He, CO, and Radon
- Three types of gases based on human health:

(1) Irritant effects

(2) Inert asphyxiants

(3) noxious asphyxiants



lovingthebigisland.files.wordpress.com/

Examples of volcanic gas compositions, in volume percent concentrations (from Symonds et. al., 1994)

Volcano	**Kilauea Summit**	**Erta` Ale**	**Momotombo**
Tectonic Style	Hot Spot	Divergent Plate	Convergent Plate
Temperature	1170°C	1130°C	820°C
H_20	37.1	77.2	97.1
$C0_2$	48.9	11.3	1.44
$S0_2$	11.8	8.34	0.50
H_2	0.49	1.39	0.70
CO	1.51	0.44	0.01
H_2S	0.04	0.68	0.23
HCl	0.08	0.42	2.89
HF	---	---	0.26

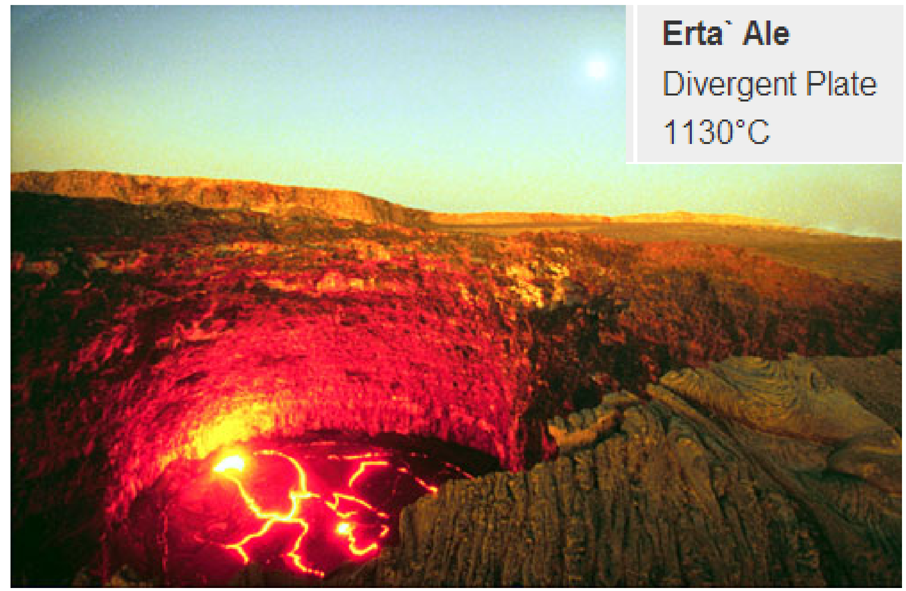
volcanoes.usgs.gov

Kilauea Summit
Hot Spot
1170°C

hvo.wr.usgs.gov/

Momotombo
Convergent Plate
820°C

mw2.google.com/



Erta` Ale
Divergent Plate
1130°C

www.photo-de-vacance.ch/

Irritant Gases

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- Gases include hydrogen halides, HF, HCL, SO_4
- Health impacts:
  - Low Doses: cause throat and eye irritation,
  - High Doses: cause ulcers, corrosive burns when in contact with skin, prevents proper gas exchange (acute respiratory distress syndrome (ARDS)), death due to pulmonary edema
- Environmental Impact: Acid Rain


www.virginmedia.com/

Whakaari

(White Island), Auckland, NZ

Inert Asphyxiants

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- CO_2 is the main inert asphyxiant
- Gases collect in low-lying areas
- Health Impacts:
  - Low Doses: accelerated breathing, headaches and vertigo
  - High Doses: circulatory failure, and death from acidosis

Noxious Asphyxiants

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- H_2S is the most common form
- Health Impacts:
    - Inhibits cytochrome oxidase (aides in cellular metabolism)
    - Low Dose: throat, ocular and nasal irritation, headaches
    - High Dose: death (if over 1000 ppm), or neuropsychological effects

Other Harmful Gases

- Carbon Monoxide (CO) – headache, coma, death
- Nitrogen Dioxide (NO_2) – similar to SO_2, death by pulmonary edema, ARDS, bronchitis
- Carbon Disulfide (CS_2) – headaches, muscular weaknesses, delirium
- Methane (CH_4) – inert asphyxiant, replaces oxygen in the air
- Ammonia (NH_4) – irritant to eyes, skin and airways, burns in high doses

Metals and Elements

- Metal vapours of interest include mercury, arsenic, lead and cadmium
- Metals enter into the soil and groundwater systems
- Arsenic poisoning impacts organic function, causes skin lesions (pigmatation and kertosis), beleived to be carcinogen
- Cadmium causes neurological effects, especially in children and is readily absorbed in plants causing accumulations in the liver and kidneys

Radiation and Other Sources

- Eruptions release ash with concentrated uranium and radon (radioactive gas and known carcinogen)

- Other Sources:
  1. Lava Flows – exposure to toxic chemicals
  2. Pyroclastic flows – hot gas flows of CO_2, SO_2, and H_2S
  3. Crater Lakes – source of toxic chemicals, respiratory illnesses
  4. Lahars – acidic flows of mud, water and debris

(C) Remediation Strategies

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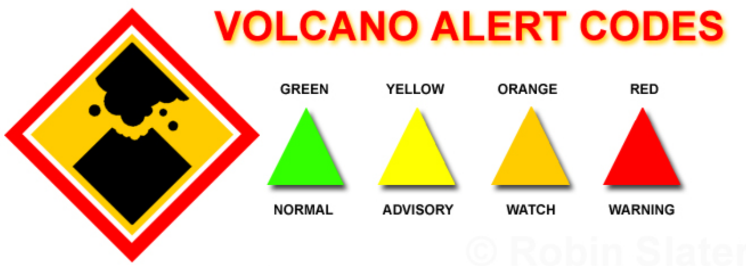
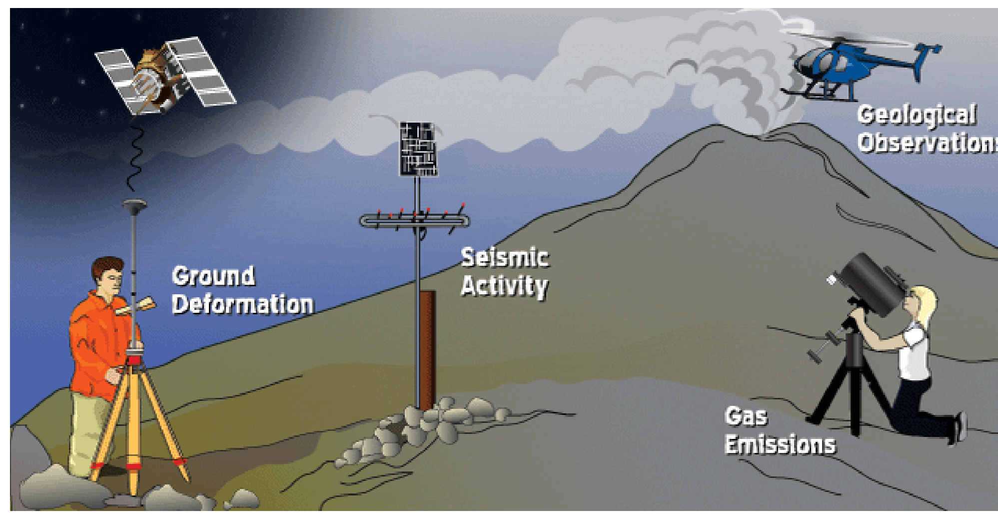


- Involve the creation of warning systems and monitoring before, during, and after an eruption.

- Monitoring would include water and air quality testing, and determining exposure rates.



www.bbc.co.uk/

mail.colonial.net/

- Creating effective evacuation plans

(D) Exposure Pathways

a) Respiratory; b) Gastrointestinal; c)Skin

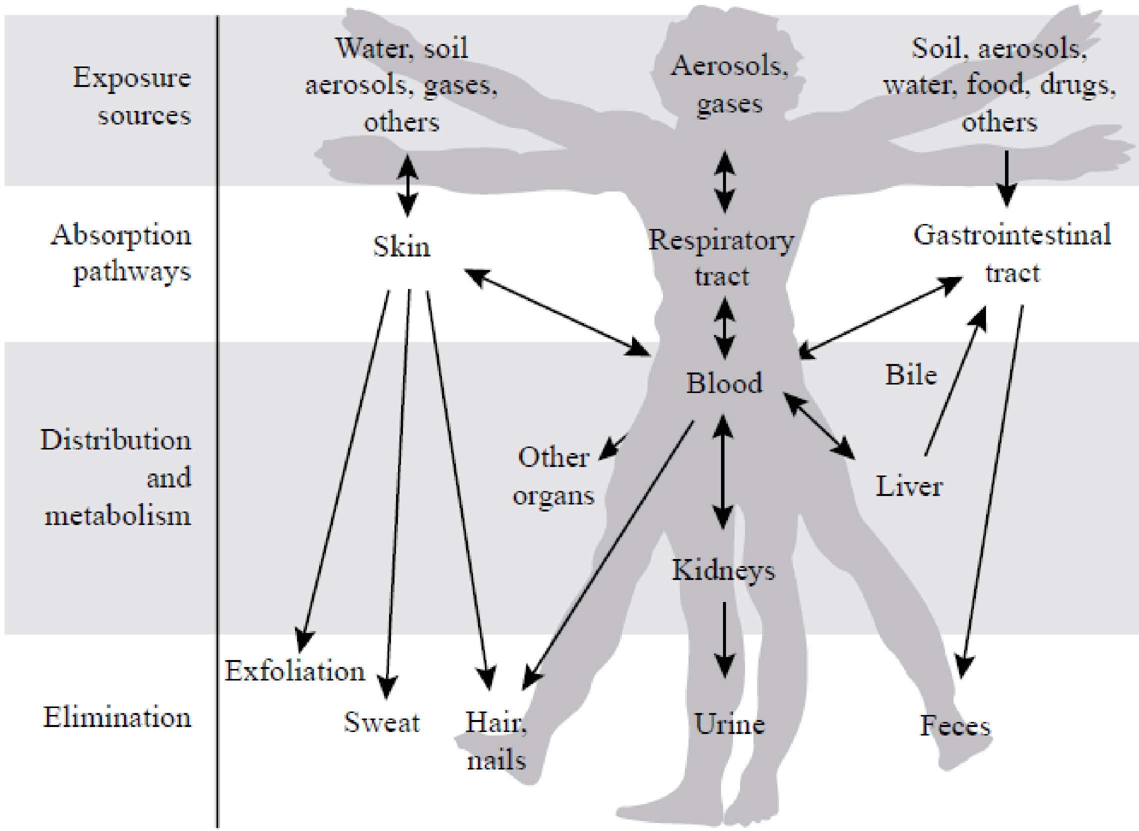


Figure 2 This schematic diagram shows the absorption pathways and systems of distribution, metabolism, and elimination for potential toxins. "Aerosols" include dusts, other solid particulates (such as smoke), and liquid droplets (such as fog, mists, etc.). Distribution may involve deposition of a toxin within a target organ and/or metabolism with or without excretion of the toxin by the target organ (after Goyer and Clarkson, 2001).

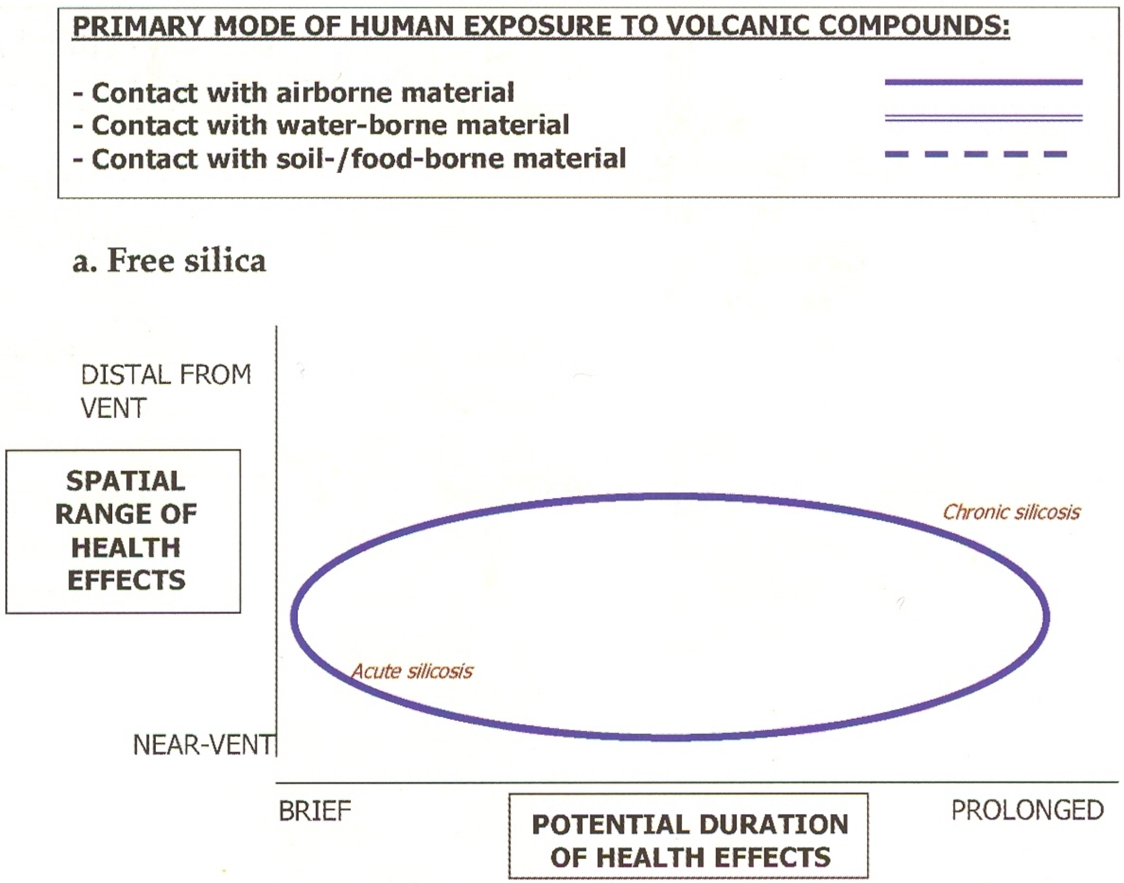
From Plumlee and Ziegler (2005) *in* Vol. 9 *Treatise on Geochemistry*

Metabolism

i. Dose Response: the intensity and duration of the exposure
ii. Route of exposure: pathway
iii. Solubility: Here used as the degree to which the earth's material is solubilized or incorporated in body fluids for a particular exposure route
iv. Toxic Kinetics: how potential toxins are processed in the body, including absorption, metabolism, elimination

- **Bioavailability:** defined as the fraction of an administered dose of a substance that is absorbed via an exposure route and reaches the blood stream.
- **Bioaccessibility:** of a substance is the fraction that can be dissolved by body fluids and therefore is available.
- **Biopersistance:** resistance to all clearance mechanisms
- **Biosolubility:** Extent to which elements/compounds are soluble in body fluids.
- **Bioreactivity:** extent to which an element/compound can modify key body fluid parameters such as pH, concentration of electrolytes and redox

Figure 3: Illustrates the wide range of health impacts, method of exposure and duration



Selinus *et al.* 2005

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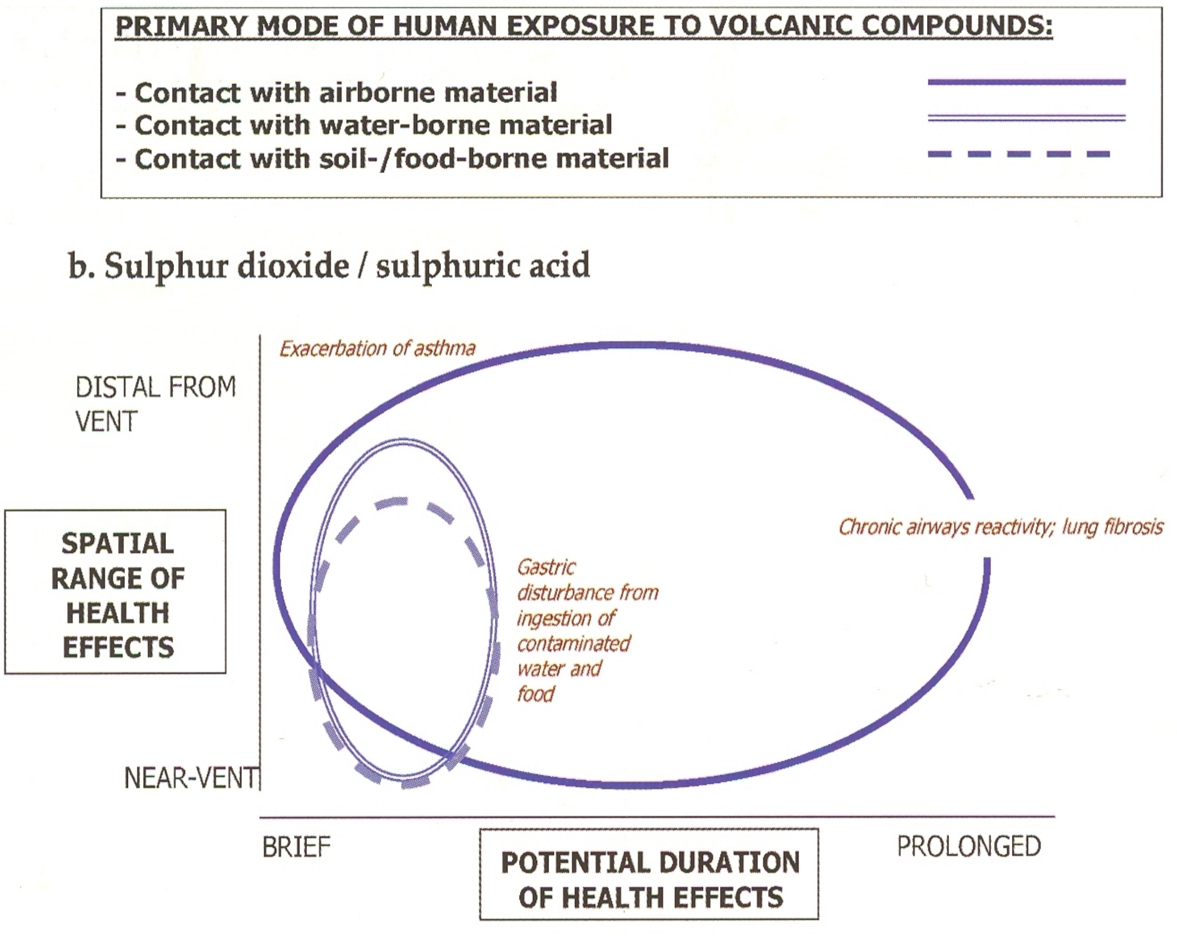

Selinus *et al.* 2005

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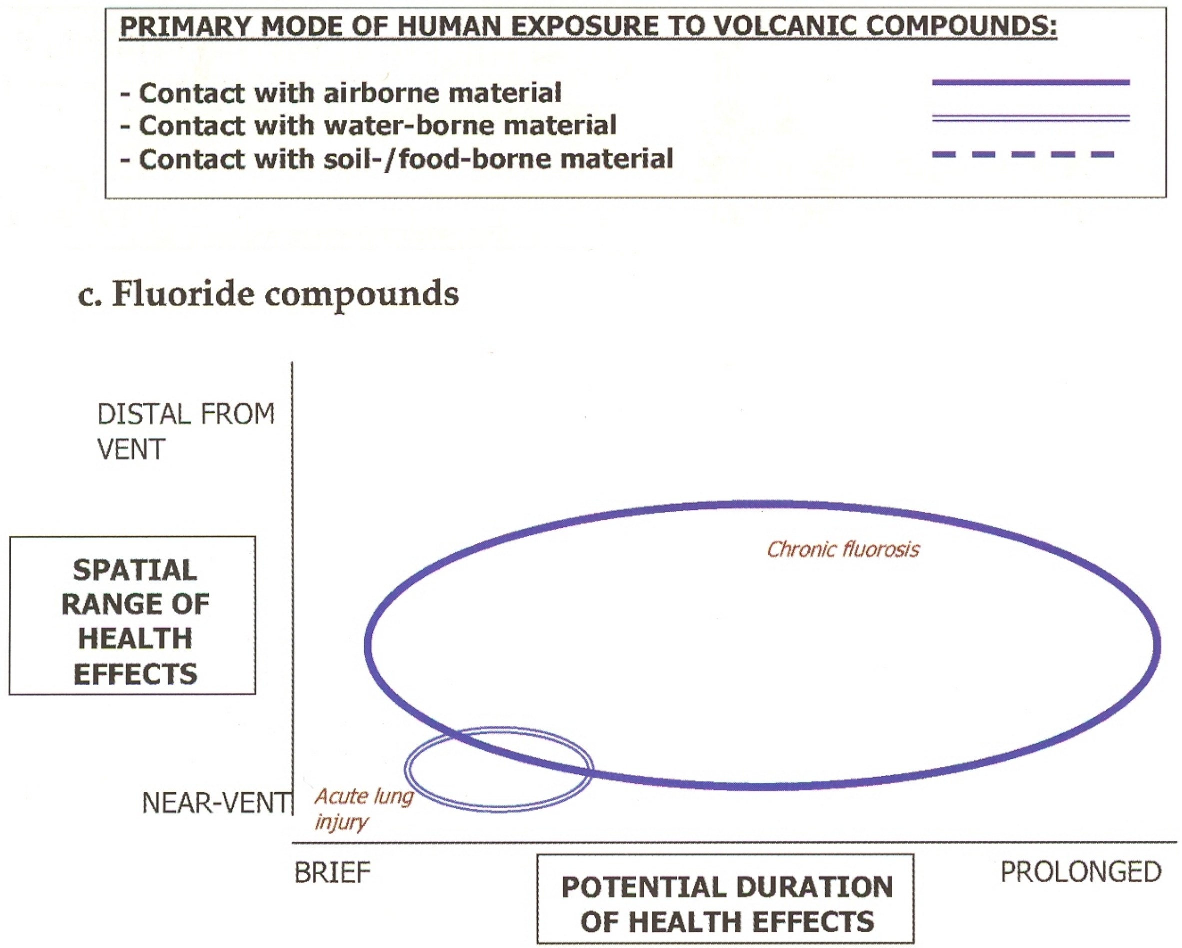

Selinus *et al.* 2005