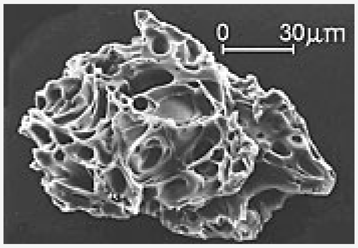
Ash properties & dispersal by wind



Ash particle, 1980 Mount St. Helens eruption, magnified 200 times

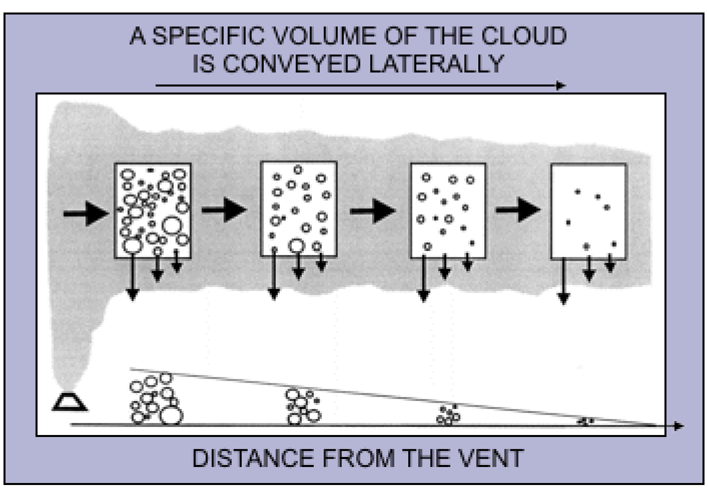
- ash-particle size
- dispersal by wind
- eruption style
- ash thickness
- density & hardness
- physical and chemical components
- post-eruption ash dispersal

Small jagged pieces of rocks, minerals, and volcanic glass the size of sand and silt (less than 2 millimeters (1/12 inch) in diameter) erupted by a volcano are called volcanic ash. Very small ash particles can be less than 0.001 millimeters (1/25,000th of an inch) across. Volcanic ash is not the product of combustion, like the soft fluffy material created by burning wood, leaves, or paper. Volcanic ash is hard, does not dissolve in water, is extremely abrasive and mildly corrosive, and conducts electricity when wet.

Volcanic ash is formed during explosive volcanic eruptions. Explosive eruptions occur when gases dissolved in molten rock (magma) expand and escape violently into the air, and also when water is heated by magma and abruptly flashes into steam. The force of the escaping gas violently shatters solid rocks. Expanding gas also shreds magma and blasts it into the air, where it solidifies into fragments of volcanic rock and glass. Once in the air, wind can blow the the tiny ash particles tens to thousands of kilometers away from the volcano.

Ash particle size

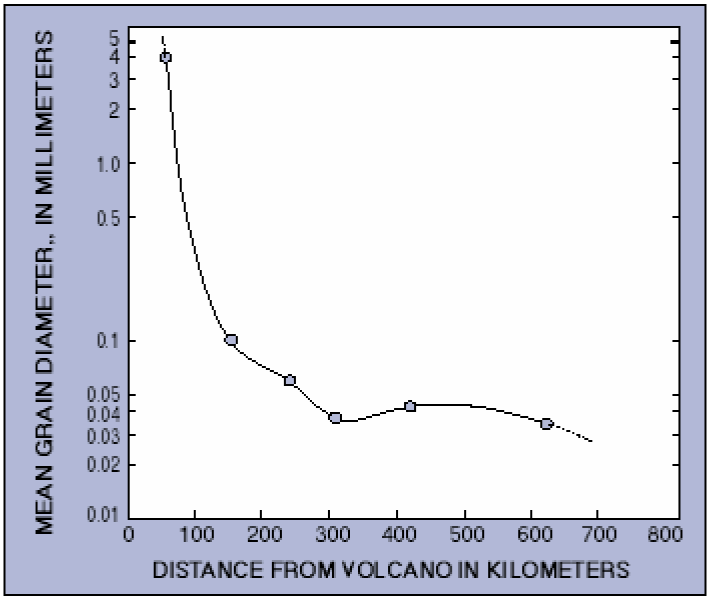
The average grain-size of rock fragments and volcanic ash erupted from an exploding volcanic vent varies greatly among different eruptions and during a single explosive eruption that lasts hours to days. Heavier, large-sized rock fragments typically fall back to the ground on or close to the volcano and progressively smaller and lighter fragments are blown farther from the volcano by wind. Volcanic ash, the smallest particles (2 mm in diameter or smaller), can travel hundreds to thousands of kilometers downwind from a volcano depending on wind speed, volume of ash erupted, and height of the eruption column.



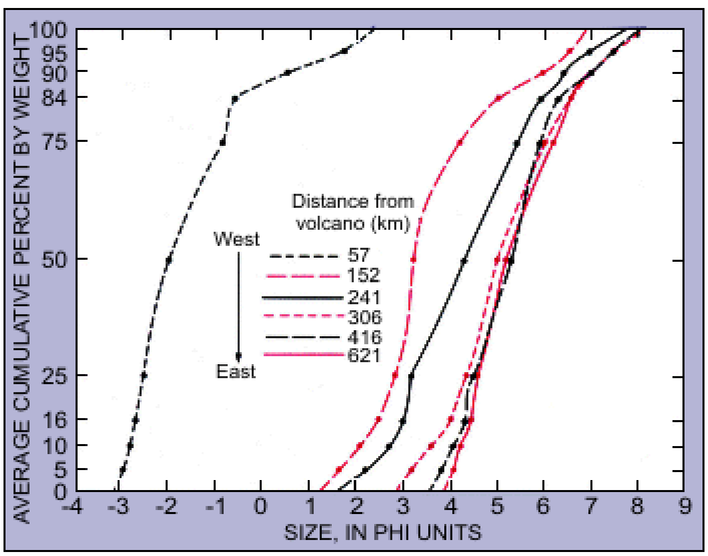
The size of ash particles that fall to the ground generally decreases exponentially with increasing distance from a volcano. Also, the range in grain size of volcanic ash typically diminishes downwind from a volcano (becoming progressively smaller). At specific locations, however, the distribution of ash particle sizes can vary widely (see the Mount St. Helens example below). (Johnston, 1997)

Ash particle size, 1980 eruption of Mount St. Helens, U.S.

The mean diameter of ash particles that fell to the ground downwind of Mount St. Helens during an 8-hour-long eruption on May 18, 1980, is shown below. The volcano ejected a minimum of 1.1 km^3 of uncompacted tephra, which is equivalent to 0.20-0.25 km^3 of magma or solid rock. Peak wind velocity during the eruption varied between 80 and 140 km/hour as measured 400 km downwind of the volcano at about 12 km above sea level.



Graph showing mean diameter of ash particles with increasing distance from Mount St. Helens volcano. Typical of ash-fall deposits, the mean particle size of ash decreased rapidly downwind from Mount St. Helens (Sarna-Wojcicki and others, 1981) for the eruption on May 18, 1980.



Graph showing average cumulative weight percent of ash deposits for different ash sizes (in phi units) at sites with increasing distance from Mount St. Helens volcano. The range of grain size for each site is shown by a different line.

Note that grain sizes become smaller with increasing distance from the volcano (the lines move progressively to the right with corresponding smaller grain size as the distance from the volcano increases). At a distance of 152 km, the ash deposit does not contain particles larger than 2 phi (0.5 mm, equivalent to coarse sand). Beyond about 300 km from vent, the overall grain size distributions of the deposits were similar (compare the right three lines). (Sarna-Wojcicki and others, 1981)

top of page

Dispersal of ash by wind

Wind and eruption style are the two major controls on the dispersal of ash from an erupting volcano. Eruption style affects (1) volume and size of ash produced by varying rates of magma supply; and (2) the range of altitude(s) to which ash is propelled or rises.

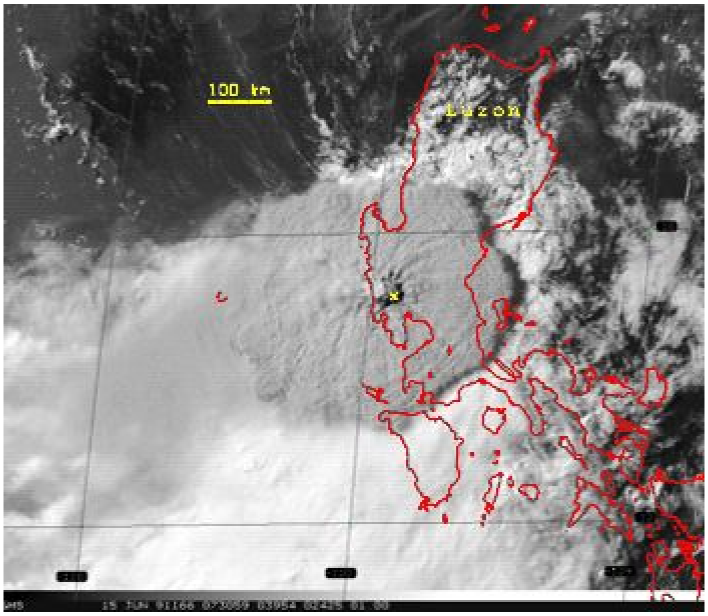
Wind direction and speed above and downwind from an erupting volcano affects the dispersal pattern of volcanic ash in the atmosphere and ash fall on the ground. Both direction and speed typically varies with increasing altitude above the ground and distance from an erupting volcano. Significant change in wind direction and speed may occur during the course of a single long eruption (12-36 hours), which can result in a complex and changing ash-dispersal pattern, especially during cyclones or hurricanes (see Mount Pinatubo, below). During the course of a prolonged series of eruptions that last weeks to months, changing wind patterns will typically blow ash in widely different directions.

Wind typically varies significantly across the boundary between the troposphere and stratosphere (about 10 km above sea level). Air temperature decreases rapidly from the earth's surface up through the troposphere, but remains relatively constant from the base of the stratosphere (10 km) to about 25 km. Temperature then increases from 25 km upwards. The troposphere is dominated by vigorous convection and circulation (weather), with complex wind patterns. Above, the stratosphere has a non-convective, sometimes slightly turbulent, circulation that is not directly connected to wind patterns in the troposphere.

Strong wind generates unidirectional eruption cloud, Mt. Etna, Italy

Satellite image of Mt. Etna eruption cloud (brown steak right of center), July 24, 2001. The volcanic ash was blown by strong northwest winds, resulting in a relatively narrow unidirectional ash cloud.

Image courtesy of NASA/Goddard Space Flight Center, The SeaWiFs Project; http://seawifs.gsfc.nasa.gov/SEAWIFS.html



Typhoon generates disperse ash cloud, Mount Pinatubo, Philippines

Satellite image of Mount Pinatubo eruption cloud about 2.25 hours after the onset of the climactic phase of the eruption, June 15, 1991. The yellow 'x' marks the volcano. The enormous round shape of the eruption cloud resulted from the pass of tropical storm Yunya across the Philippines about 75 km northeast of Pinatubo during the eruption. Typhoon Yunya made landfall at 0800 June 15 then decreased in intensity to a tropical storm.

Owing at least in part to the atypical lower- and mid-level wind regime spawned by the passing storm, ash and larger particles were widely distributed in all directions immediately around the erupting volcano. Most of the ash was blown to the west southwest over a broad area across the South China Sea; ash dusted parts of Indochina, more than 1,200 km away. (Wolfe and Hoblitt, 1997; online report at http://pubs.usgs.gov/pinatubo/oswalt/index.html).

Image courtesy of EOS, from a slide set compiled by R. Holasek, University of Hawai`i.

top of page

Eruption style

The style of eruption that produces ash is controlled by characteristics of the erupting magma (molten rock), including chemistry, crystal content, temperature, and dissolved gases, and also by interaction water, especially groundwater (learn more about magma characteristics). These characteristics and corresponding style of eruption determine the chemistry, particle size distribution, and physical and chemical components of volcanic ash.

Volcanoes display a marked range of eruption styles depending on these characteristics and the rate of magma eruption. For example, volcanic eruptions range from (1) effusion of lava fountains and flows with very little ash erupted, typical of basaltic magma eruptions; to (2) extremely explosive eruptions that inject large quantities of ash high into the stratosphere, typical of rhyolite and dacite magmatic eruptions.

Gentle effusive eruption (basalt magma)
Hawaiian-style eruption

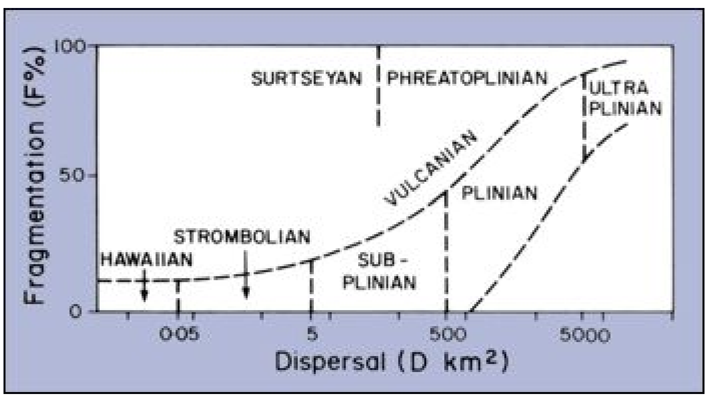
Photo by C. Heliker, 12 September 2003

Basaltic lava erupts from a vent on Kilauea Volcano, Hawai`i, to form row of fountains and lava flows. Basalt magma typically generates very little ash compared to other types (andesite, dacite, and rhyolite).

Explosive eruption (dacite and rhyolite magma)
Plinian-style eruption

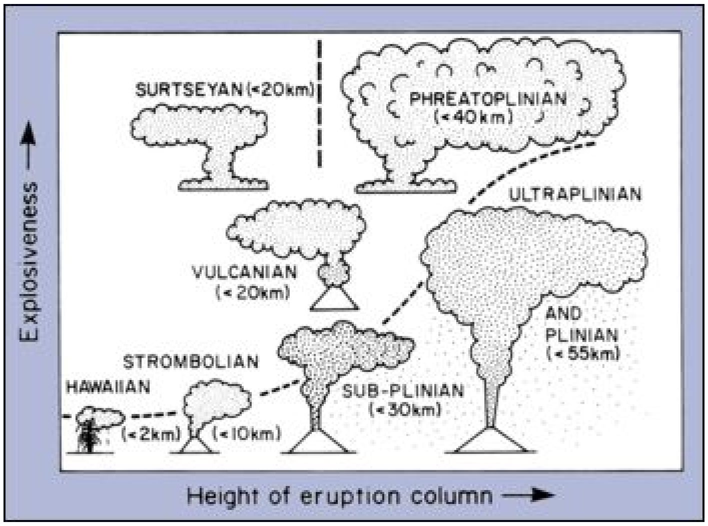
Photo by D. Swanson, 18 May 1980

Dacite magma erupts from the crater of Mount St. Helens to form a Plinian eruption column. Dacite and rhyolite magmas with low concentrations of dissolved gases can erupt as lava flows, producing little or no ash.



Top graph shows the amount of magma fragmentation and resulting dispersal of tephra (ash and larger-sized particles) that typically accompanies different styles of eruption (for example, Hawaiian and Plinian). High fragmentation breaks or shatters the erupting magma into particles, including volcanic ash. Hawaiian-style eruptions do not fragment lava into ash-sized particles typical of larage Plinian-style eruptions (see photos above).

Interaction with water can cause magmas that would normally erupt lava flows to explode into ash particles, or cause normally explosive eruptions into more energetic eruptions. These eruptions are called phreatomagmatic eruptions (Surtseyan or Phreatoplinian, depending on height of eruption column and dispersal). For example, in 1886 Mount Tarawera in New Zealand produced a violently explosive basalt eruption because rising magma interacted explosively with shallow ground water. Substantial thicknesses of basalt ash from this eruption was consequently dispersed hundreds of kilometers downwind.



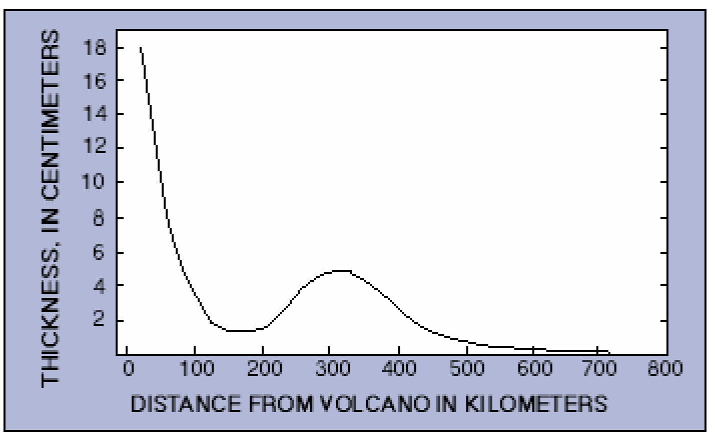
Bottom graph shows the relative explosiveness and resulting height of eruption columns typically associated with different styles of eruption.

Figures from Cas and Wright, 1987; top figure modified from original by Walker, 1973.

top of page

Thickness of ash deposits

Thickness of ash deposits generally decreases exponentially with increasing distance from a volcano. The distribution of ash will depend on the initial particle-sizes of the ejecta (reflecting fragmentation during the eruption), height of eruption column, rate and duration of eruption, and prevailing wind conditions.



Graph shows thickness of ash (and larger-sized particles within 20-40 km) that fell to the ground downwind of Mount St. Helens during the eruption on May 18, 1980. The volcano ejected a minimum of 1.1 km^3 of uncompacted tephra, which is equivalent to 0.20-0.25 km^3 of magma or solid rock. Peak wind velocity during the eruption varied between 80 and 140 km/hour as measured 400 km downwind of the volcano at about 12 km above sea level.

Typical of tephra-fall deposits, the tephra thickness rapidly downwind from Mount St. Helens. Note the increased thickness about 300 km downwind; this unusual increase in tephra thickness is thought to have resulted from the sticking together of individual grains due to moisture in the eruption cloud (Sarna-Wojcicki and others, 1981).

Compaction of ash deposits

Ash particles will compact close together after they fall to the ground. The compaction will increase the bulk density of an ash deposit, sometimes by as much as 50 percent, within a few weeks of an eruption. The thickness of the ash deposit may correspondingly decrease slightly over time.

Density & hardness

Density

The density of individual particles may vary 700-1200 kg/m^3 for pumice, 2350-2450 kg/m^3 for glass shards, 2700-3300 kg/m^3 for crystals, and 2600-3200 kg/m^3 for lithic particles (see table). Pumice fragments may form temporary mats of floating material if deposited on water. Since coarser and more dense particles are deposited close to source, fine glass and pumice shards are relatively enriched in ash fall deposits at distal locations.

Density of individual ash particles, kg/m^3, from Shipley and Sarna-Wojcicki, 1982

Type of ash particle	Density of particle
Pumice fragments	700-1,200 kg/m^3
Volcanic glass shards	2,350-2450 kg/m^3
Crystals and minerals	2,700-3,300 kg/m^3
Other rock fragments	2,600-3,200 kg/m^3

The bulk density of any ash fall deposit can be variable, with reported dry bulk densities of newly fallen and slightly compacted deposits ranging from between 500 and 1500 kg/m^3; bulk density of wet ash ranges between 1,000 and 2,000 kg/m^3 (see table of density and load). Both increasing and decreasing bulk densities with distance from source have been reported, but distal ash falls most commonly show slight increases in bulk density with distance from a volcano. Grain-size, composition (proportions of crystal, lithics, glass shards and pumice fragments), particle shape, and moisture content determines the bulk density of ash deposits. Less spherical particles (more irregular) will pack relatively poorly resulting in higher porosity and lower bulk densities. Particle aggregation prior to deposition will result in higher particle packing and therefore higher densities.

Hardness

The abrasiveness of volcanic ash is a function of the hardness of the material forming the particles are their shape. Hardness values for the most common particles are shown in the table below. Ash particles commonly have sharp broken edges which makes them a very abrasive material.

Moh's scale of hardness (mineral hardness from Deer et. al. 1980)

Scale Number	Mineral	Metal	Minerals in volcanic ash and their hardness
1	Talc		
2	Gypsum	Aluminum Copper	mica (H 2-3)
3	Calcite	Brass	
4	Fluorite	Iron	
5	Apatite	Steel	volcanic glass, pyroxene, amphibole (H 5-6)
6	Orthoclase		plagioclase, alkali-feldspar (H 6-6.5)

	(Feldspar)		
7	Quartz		olivine (H 6.5-7) quartz (H 7)
8	Topaz		
9	Corundum	Chromium	

top of page

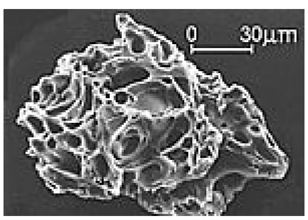
Ash particle components || Chemistry || Soluble components ||

Volcanic ash typically consists of tiny particles composed of varying proportions of:

- Volcanic glass
- Minerals or crystals
- Other rock fragments (lithics)

Volcanic glass

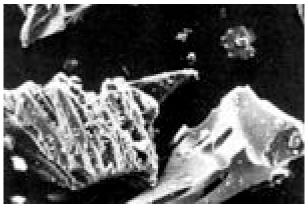
Volcanic glass shards are fragments of the molten part of magma that cooled and solidified during eruption. Glass shards are typically remnants of tiny gas bubbles that developed and grew in size during the final ascent toward the surface; such shards may consist of many gas bubbles or only a portion of a single gas bubble. During eruption, the expanding gas broke the bubbles and surrounding glass into shards of various sizes and shapes. Shards formed by phreatomagmatic eruptions (see eruption style) often have a particularly angular shape resulting from the violent explosive interaction between magma and water. Glass is relatively hard (5 on Moh's scale), and the more angular the glass shards the more abrasive the ash.



Scanning electron micrograph (SEM) of a highly vesicular glass shard of ash measuring just over 0.1 mm long, erupted during the 18 May 1980 eruption of Mount St. Helens.

Sideromelane and tachylite shards collected 12 km from source at Mount Etna, 2002. The width of view is 1 mm. Image courtesy of S. Barnard.

SEM image of phreatomagmatic glass shards > 0.064 mm (Cas and Wright, 1987).



SEM images of phreatomagmatic glass shards > 0.064 mm (Cas and Wright, 1987).

Minerals or crystals (phenocrysts)

Minerals within volcanic ash are primarily derived from the magma. These minerals crystalized and grew within the magma while it was below the earth's surface. The type of minerals within an ash deposit depends upon the chemistry of the magma from which it was erupted. Most minerals in ash have not been shown thus far to cause any long term adverse health effects in humans, but they will affect the composition of soil into which they become incorporated possibly affecting livestock and agriculture. The hardness of individual minerals varies, with the harder minerals being more abrasive.

Typical minerals by magma composition

Magma composition	Minerals typically present
Rhyolite	Quartz, feldspar, +/-mica, +/-orthopyroxene,+/-amphibole
Dacite	Quartz, feldspar, +/-mica, +/-orthopyrocene, +/-clinopyroxene,+/-amphibole
Andesite	Feldspar, clinopyroxene, +/-quartz, +/-orthopyroxene,+/-amphibole
Basalt	Feldspar, clinopyroxene, +/-olivine, +/-orthopyroxene,+/-amphibole

Fine minerals may also grow on the walls of expanding gas bubbles in the magma prior to fragmentation into ash-sized particles. Crystobalite is a type of silica crystal that forms in this way. Crystobalite is known to cause silicosis in humans, which is typically contracted by people working for prolonged periods in industries that expose workers to fine rock dust. See the health section for more information on health effects of ash, including who is most at risk from ash inhalation and how to minimize exposure to volcanic ash.

Other rocks (often called lithics)

Rising magma will incorporate pieces of different types of rocks through which it moves, including rocks located deep beneath a volcano and within the volcano itself. The rapid ascent of magma during explosive eruption will often rip fragments from the walls of the magma conduit, which are ejected and fragmented further by the explosive expansion of volcanic gases. These non-magmatic rock fragments are found in varying abundances within ash deposits and often have a shape and texture distinctly different than glass shards.

Chemistry

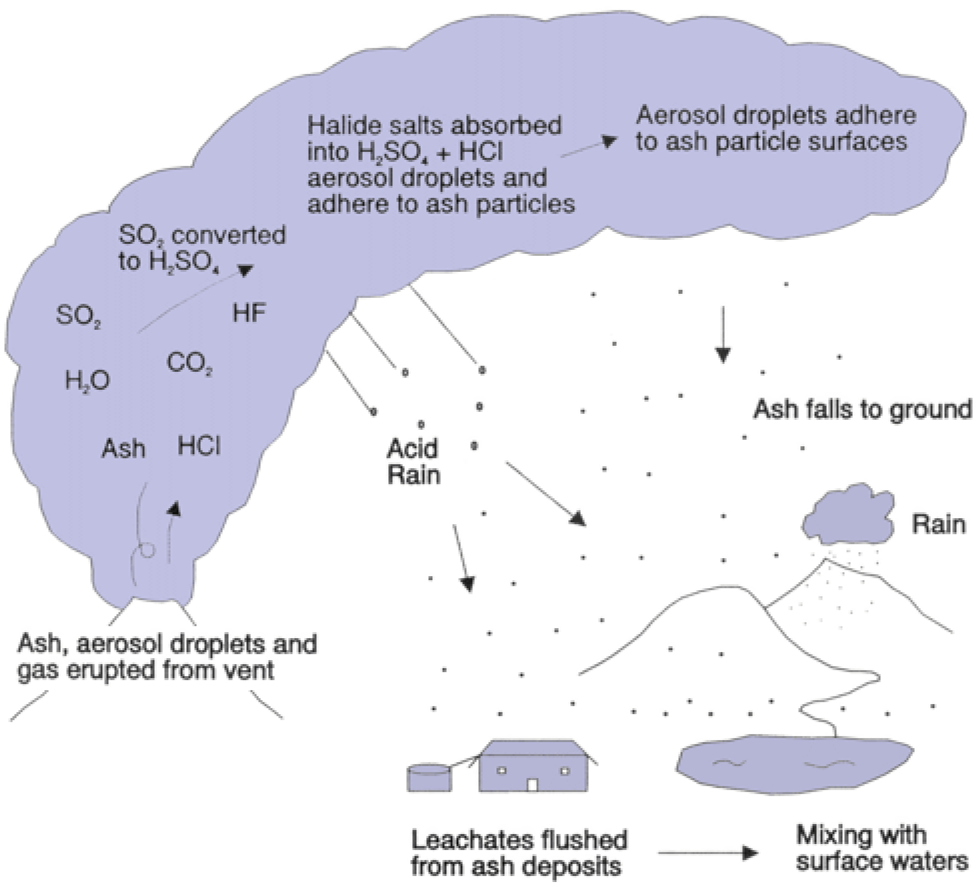
Ash chemistry is directly related to the chemistry of the source magma. Learn more about magma characteristics.

Volcanic glass is relatively high in silica compared to mineral crystals, but relatively low in non-silica elements (especially Mg and Fe). Both glass and most minerals almost always contain Si, Al, K, Na, Ca, Mg and/or Fe.

Soluble components

Freshly fallen ash grains commonly have surface coatings of soluble components (salts) and/or moisture. These components can make ash mildly corrosive and potentially conductive. The soluble coatings are derived from the interactions in an eruption column between ash particles and volcanic-gas aerosols, which may be composed of sulphuric and hydrochloric acid droplets with absorbed halide salts. The amount of available aerosols varies greatly between eruptions of similar size and volume.

Diagram showing formation of soluble components on ash particles.



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.

Table showing concentrations of leachable constituents in ash fall from historic eruptions (all concentrations in mg/kg).

	Fuego, Costa Rica		**Pacaya, Guatemala**		**Santiaguito, Guatemala**		**Mt. St. Helens, USA**		**Ruapehu, New Zealand**	
Element	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Median	Max
Al	5.2	26.8	12.8	21.2	5.2	19.6	-	-	42.8	1160

B	0.088	0.044	0.06	0.108	1.08	3.92	-	-	-	-
Ba	0.296	1	0.68	1.12	0.132	0.348	0.152	0.24	-	-
Br	-	-	-	-	-	-	-	-	1.6	13.6
Ca	400	1040	196	304	600	2240	440	800	1890	6760
Cd	0.008	0.04	0.056	0.128	0.056	0.256	0.0052	0.0252	-	-
Cl	124	232	204	840	440	1400	392	668	248	2020
Co	0.0036	0.0328	0.0072	0.024	0.132	0.6	0.0196	0.072	-	-
Cu	0.324	2.52	1.24	2.36	1.56	2.8	0.164	0.48	-	-
F	21.2	88	28.8	44	14.4	23.2	7.2	12	25.8	95.6
Fe	2.08	22.4	2.8	9.2	1.56	3.6	0.376	0.48	5.74	92.8
K	-	-	-	-	-	-	-	-	36.1	253
Li	0.044	0.116	0.0036	0.064	0.4	1.88	0.208	0.52	0.5	1.45
Mg	22	44	19.6	52	96	400	48	84	235	1200
Mn	1.48	3.12	1	2.88	19.6	92	7.6	13.2	-	-
Na	128	184	156	440	400	1760	264	440	292	1150
Pb	0.104	0.96	0.014	0.044	0.0096	0.048	0.0092	0.072	-	-
Si	7.2	12.4	9.2	15.2	7.6	11.2	40	56	-	-
Sr	2	5.2	1.64	2.6	1.48	4.4	1.76	2.88	-	-
U	0.00108	0.0028	0.00008	0.00048	0.0012	0.006	0	0	-	-
V	0.06	0.128	0.0248	0.068	0.0364	0.08	0.0012	0.0264	-	-
Zn	0.144	0.56	5.6	18.8	2.04	8.4	2.04	26.8	-	-
Nitrate									21.9	88.9
Sulphate							1000	1800	5190	24530

Concentration values have been derived by Johnston and others (2004) both from data specific to Mt Ruapehu (Cronin and others, 1998; Neild and others, 1998; Cronin and others, 2003, Christenson, 2000) and from data on ash fall composition from historic eruptions. Smith and others (1982 and 1983) present data on leachable matter in ash fall for a range of volcanic systems: basaltic (1974 eruptions of Fuego and Pacaya) and dacitic (1969, 1975 and 1976 eruptions of Santiaguito, Guatemala, and 1980 eruption of Mount St. Helens, U.S.A.).

top of page

Post-eruption disturbance of ash deposits || running water || wind ||

Explosive eruptions that destroy vegetation and deposit volcanic rocks and ash over wide areas create conditions that (1) promote increased rates of surface runoff during rainstorms; (2) dramatically increase the availability of loose debris that can be eroded and transported into river valleys; and (3) typically result in persistent airborne "ashy" conditions due to wind and human activities. The destruction of vegetation combined with deposition of ash on hill slopes reduces the amount of water that normally soaks into the ground or is transpired by plants. The increased overland flow of water erodes rock debris from hill slopes and carries it into river valleys. There, sediment can accumulate and change the normal hydrology of river valleys.

The net effect of such changes to watersheds is that post-eruption stream velocities and peak discharges during rainstorms are temporarily much higher than during pre-eruption conditions. Streams typically respond more quickly to a given amount of rainfall and produce higher flows as rainfall is quickly flushed through a watershed.

For realtively thin ash deposits on non-paved surfaces, the ash will be progressively stabilized by a range of processes. Movement of water through an ash layer is capable of transporting grains downwards into cracks, root casts, animal burrows and soil macropores below. These processes are accelerated by frost action because freezing and thawing helps to disagregate the ash grains. In parts of eastern Washington State, USA, the ash layer from the 1980 eruption of Mount St. Helens (as thick as 4 cm) has been incorporated by these processes into a silty soil.

Running water

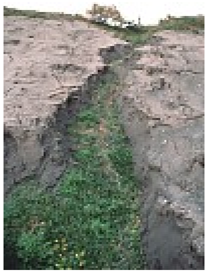
Significant ash fall can lead to acclerated rates of erosion on hillslopes and in valleys, above normal streamflow in rivers during rainstorms, and increased deposition of sediment along riverbeds and valley floors. For example, monitoring of the post-1980 eruption streamflow hydrology and sediment transport at Mount St. Helens has shown that peakflow water discharges were temporarily amplified by tens of percent and that persistent sediment yields in rivers draining the volcano can remain elevated above pre-eruption yields by as much as 100-fold for decades. Comparative studies with other volcanoes show that such extraordinary sediment delivery commonly leads to drastic aggradation of riverbeds and valley floors; for example, see consequences of erosion of pyroclastic flow deposits at Mount Pinatubo, Philippines.

Such extraordinary aggradation typically buries or severely damages infrastructure, triggers channel instability, reduces the ability of channels to convey water, and leads to substantially increased flood hazards. The magnitude and duration of such extraordinary post-eruption sediment transport varies mainly with the nature of volcanic disturbance, but also by interannual and interdecadal hydrologic fluctuations. Sediment delivery is greater and more persistent from basins with severely disturbed channels from lahars (volcanic debris flows) and pyroclastic flows than from watersheds mainly blanketed with ash-fall deposits.

These photographs show what happened during the first rainy season after the explosive eruption of Mount St. Helens in 1980. The eruption generated a large pyroclastic surge and tephra fall that deposited loose gravel-sized and sand-sized rock debris to a thickness of about 1 m and leveled nearly all vegetation in this area, about 8 km northeast of the volcano.

29 September 1980

30 September 1981



30 September 1980

Close view of a gully eroded into new volcanic deposits within 3 months of the eruption. The underlying soil layer, topped with pre-eruption vegetation and roots, prevented running water from eroding into even thicker tephra deposits erupted by the volcano hundreds of years ago. In many locations, however, these older deposits were also carried away by surface runoff during intense rainstorms and transported tens of kilometers downstream.

Within a few years of the eruption, much of the ash was eroded from slopes of 50 percent or steeper, with redisposition nearly always local and immediate. It was during severe rainstorms that the ash was readily eroded from the steep slopes and swept into streams and rivers. Such erosion is similar to the behavior of soils on non-vegetated land during severe rainstorms.

Wind

When dry ash falls onto areas without vegetation cover or on paved surfaces it is easily stirred up by wind and human activities (for example, moving vehicles and agricultural practices). Wet ash, however, usually exhibits cohesive properties that can dramatically decrease such reworking and disturbance. The resistance to wind erosion of compacted ash will increase as grains nest more tightly together.

Mount St. Helens' 1980 ash showed initial resistance to wetting as water beaded on its surface. However, this resistance lasted for only a few hours in light rain and was eliminated by heavy rain in minutes. After initial wetting, an undisturbed ash layer may remain persistently wet. This is due to the inefficient water drainage from between the surfaces of ash grains, which are particularly angular. Raindrops impacting on an ash layer contribute to rapid compaction through decreasing porosity. Pore space saturation will then occur relatively rapidly during heavy rain.

In the 1964 Irazu eruption in Costa Rica fine-grained soft, loose ash formed a hard impervious surface crust thought to be a result of precipitation of soluble salts by evaporation.

top of page

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