USGS

Volcano Hazards Program

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Volcanic Gases and Their Effects

Volcanic gases are the driving force of eruptions

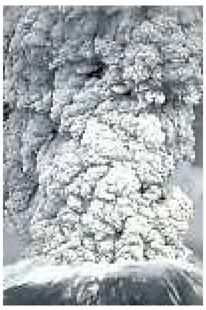
Sulfur dioxide gas creates air pollution in Hawai'i

Carbon dioxide gas kills trees in California

Magma contains dissolved gases that are released into the atmosphere during eruptions. Gases are also released from magma that either remains below ground (for example, as an intrusion) or is rising toward the surface. In such cases, gases may escape continuously into the atmosphere from the soil, volcanic vents, fumaroles, and hydrothermal systems.

At high pressures deep beneath the earth's surface, volcanic gases are dissolved in molten rock. But as magma rises toward the surface where the pressure is lower, gases held in the melt begin to form tiny bubbles. The increasing volume taken up by gas bubbles makes the magma less dense than the surrounding rock, which may allow the magma to continue its upward journey. Closer to the surface, the bubbles increase in number and size so that the gas volume may exceed the melt volume in the magma, creating a magma foam. The rapidly expanding gas bubbles of the foam can lead to explosive eruptions in which the melt is fragmented into pieces of volcanic rock, known as tephra. If the molten rock is not fragmented by explosive activity, a lava flow will be generated.

Together with the tephra and entrained air, volcanic gases can rise tens of kilometers into Earth's atmosphere during large explosive eruptions. Once airborne, the prevailing winds may blow the eruption cloud hundreds to thousands of kilometers from a volcano. The gases spread from an erupting vent primarily as acid aerosols (tiny acid droplets), compounds attached to tephra particles, and microscopic salt particles.



Explosive eruption, Mount St. Helens

Volcanic gases undergo a tremendous increase in volume when magma rises to the Earth's surface and erupts. For example, consider what happens if one cubic meter of 900°C rhyolite magma containing five percent by weight of dissolved water were suddenly brought from depth to the surface. The one cubic meter of magma now would occupy a volume of 670 m^3 as a mixture of water vapor and magma at atmospheric pressure (Sparks et. al., 1997)! The one meter cube at depth would increase to 8.75 m on each side at the surface. Such enormous expansion of volcanic gases, primarily water, is the main driving force of explosive eruptions.

Types of volcanic gases

The most abundant gas typically released into the atmosphere from volcanic systems is water vapor (H_20), followed by carbon dioxide ($C0_2$) and sulfur dioxide ($S0_2$). Volcanoes also release smaller amounts of others gases, including hydrogen sulfide (H_2S), hydrogen (H_2), carbon monoxide (CO), hydrogen chloride (HCL), hydrogen fluoride (HF), and helium (He).

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

Volcano Tectonic Style Temperature	**Kilauea Summit** Hot Spot 1170°C	**Erta` Ale** Divergent Plate 1130°C	**Momotombo** Convergent Plate 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

Potential effects of volcanic gases

The volcanic gases that pose the greatest potential hazard to people, animals, agriculture, and property are sulfur dioxide, carbon dioxide, and hydrogen fluoride. Locally, sulfur dioxide gas can lead to acid rain and air pollution downwind from a volcano. Globally, large explosive eruptions that inject a tremendous volume of sulfur aerosols into the stratosphere can lead to lower surface temperatures and promote depletion of the Earth's ozone layer. Because carbon dioxide gas is heavier than air, the gas may flow into in low-lying areas and collect in the soil. The concentration of carbon dioxide gas in these areas can be lethal to people, animals, and vegetation. A few historic eruptions have released sufficient fluorine-compounds to deform or kill animals that grazed on vegetation coated with volcanic ash; fluorine compounds tend to become concentrated on fine-grained ash particles, which can be ingested by animals.

Sulfur dioxide (SO_2)

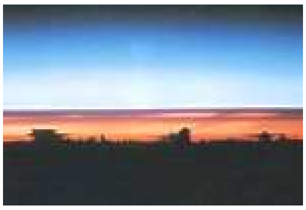
The effects of SO_2 on people and the environment vary widely depending on (1) the amount of gas a volcano emits into the atmosphere; (2) whether the gas is injected into the troposphere or stratosphere; and (3) the regional or global wind and weather pattern that disperses the gas. Sulfur dioxide (SO_2) is a colorless gas with a pungent odor that irritates skin and the tissues and mucous membranes of the eyes, nose, and throat. Sulfur dioxide chiefly affects upper respiratory tract and bronchi. The World Health Organization recommends a concentration of no greater than 0.5 ppm over 24 hours for maximum exposure. A concentration of 6-12 ppm can cause immediate irritation of the nose and throat; 20 ppm can cause eye irritation; 10,000 ppm will irritate moist skin within minutes.

Emission rates of SO_2 from an active volcano range from <20 tonnes/day to >10 million tonnes/day according to the style of volcanic activity and type and volume of magma involved. For example, the large explosive eruption of Mount Pinatubo on 15 June 1991 expelled 3-5 km ^{3} of dacite magma and injected about 17 million tonnes of SO_2 into the stratosphere. The sulfur aerosols resulted in a 0.5-0.6°C cooling of the Earth's surface in the Northern Hemisphere. The sulfate aerosols also accelerated chemical reactions that, together with the increased stratospheric chlorine levels from human-made chlorofluorocarbon (CFC) pollution, destroyed ozone and led to some of the lowest ozone levels ever observed in the atmosphere.

At Kilauea Volcano, the recent effusive eruption of about 0.0005 km^3/day (500,000 m^3) of basalt magma releases about 2,000 tonnes of SO_2 into the lower troposphere. Downwind from the vent, acid rain and air pollution is a persistent health problem when the volcano is erupting.

SO_2 causes air pollution

Volcanic smog
Eruptions of Kilauea Volcano release large quantities of sulfur dioxide gas into the atmosphere that can lead to volcanic air pollution on the Island of Hawai`i. Sulfur dioxide gas reacts chemically with sunlight, oxygen, dust particles, and water to form volcanic smog known as vog. **Details.**



SO_2 effects Earth's surface temperature

Global cooling and ozone depletion
Measurements from recent eruptions such as Mount St. Helens, Washington (1980), El Chichon, Mexico (1982), and Mount Pinatubo, Philippines (1991), clearly show the importance of sulfur aerosols in modifying climate, warming the stratosphere, and cooling the troposphere. Research has also shown that the liquid drops of sulfuric acid promote the destruction of the Earth's ozone layer. **Details.**

Hydrogen sulfide (H_2S)

Hydrogen sulfide (H_2S) is a colorless, flammable gas with a strong offensive odor. It is sometimes referred to as sewer gas. At low concentrations it can irritate the eyes and acts as a depressant; at high concentrations it can cause irritation of the upper respiratory tract and, during long exposure, pulmonary edema. A 30-minute exposure to 500 ppm results in headache, dizziness, excitement, staggering gait, and diarrhea, followed sometimes by bronchitis or bronchopneumonia.

Carbon dioxide (CO_2)

Volcanoes release more than 130 million tonnes of CO_2 into the atmosphere every year. This colorless, odorless gas usually does not pose a direct hazard to life because it typically becomes diluted to low concentrations very quickly whether it is released continuously from the ground or during episodic eruptions. But in certain circumstances, CO_2 may become concentrated at levels lethal to people and animals. Carbon dioxide gas is heavier than air and the gas can flow into in low-lying areas; breathing air with more than 30% CO_2 can quickly induce unconsciousness and cause death. In volcanic or other areas where CO_2 emissions occur, it is important to avoid small depressions and low areas that might be CO_2

traps. The boundary between air and lethal gas can be extremely sharp; even a single step upslope may be adequate to escape death.

When a burning piece of wood is lowered into a hole that has a high concentration of CO_2, the fire goes out. Such a condition can be lethal to people and animals.

Burning cloth...

CO_2 puts fire out...

CO_2 kills small mammal...

Air with 5% CO_2 causes perceptible increased respiration; 6-10% results in shortness of breath, headaches, dizziness, sweating, and general restlessness; 10-15% causes impaired coordination and abrupt muscle contractions; 20-30% causes loss of consciousness and convulsions; over 30% can cause death (Hathaway et. al., 1991).

Comparison of CO_2 emissions from volcanoes vs. human activities.

Scientists have calculated that volcanoes emit between about 130-230 million tonnes (145-255 million tons) of CO_2 into the atmosphere every year (Gerlach, 1999, 1991). This estimate includes both subaerial and submarine volcanoes, about in equal amounts. Emissions of CO_2 by human activities, including fossil fuel burning, cement production, and gas flaring, amount to about 27 billion tonnes per year (30 billion tons) [(Marland, et al., 2006) - The reference gives the amount of released carbon (C), rather than CO_2, through 2003.]. Human activities release more than 130 times the amount of CO_2 emitted by volcanoes--the equivalent of more than 8,000 additional volcanoes like Kilauea (Kilauea emits about 3.3 million tonnes/year)! (Gerlach et. al., 2002)

Historical examples of the effects of carbon dioxide gas

- Mammoth Mountain in Long Valley Caldera, California kills trees near Mammoth Mountain, California

Hydrogen Chloride (HCl)

Chlorine gas is emitted from volcanoes in the form of hydrochloric acid (HCl). Exposure to the gas irritates mucous membranes of the eyes and respiratory tract. Concentrations over 35 ppm cause irritation of the throat after short exposure; >100 ppm results in pulmonary edema, and often laryngeal spasm. It also causes acid rain downwind from volcanoes because HCl is extremely soluble in condensing water droplets and it is a very "strong acid" (it dissociates extensively to give H^+ ions in the droplets).

Hydrogen Fluoride (HF)

Fluorine is a pale yellow gas that attaches to fine ash particles, coats grass, and pollutes streams and lakes. Exposure to this powerful caustic irritant can cause conjunctivitis, skin irritation, bone degeneration and mottling of teeth. Excess fluorine results in a significant cause of death and injury in livestock during ash eruptions. Even in areas that receive just a millimeter of ash, poisoning can occur where the fluorine content of dried grass exceeds 250 ppm. Animals that eat grass coated with fluorine-tainted ash are poisoned. Small amounts of fluorine can be beneficial, but excess fluorine causes fluorisis, an affliction that eventually kills animals by destroying their bones. It also promotes acid rain effects downwind of volcanoes, like HCl.

Secondary Gas Emissions

Another type of gas release occurs when lava flows reach the ocean. Extreme heat from molten lava boils and vaporizes seawater, leading to a series of chemical reactions. The boiling and reactions produce a large white plume, locally known as lava haze or laze, containing a mixture of hydrochloric acid and concentrated seawater.

Acid-rich plumes

Lava haze or laze
Hydrochloric acid forms when lava enters the ocean boiling and vaporizing the sea water. Chloride in the sea salt combines with hydrogen in the water to form hydrochloric acid in the plume. This is a short-lived local phenomenon that only affects people or vegetation directly under the plume. **Details.**

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