

# Atmospheric Processing, Environmental Effects, and Climate Change: on the Role of Climate Signaling by Volcanic Sulphate and Volcanic Ash vs Mineral Dust

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## Abstract

There is widespread consensus that volcanic sulphate aerosols in the stratosphere can restrict solar energy reaching the earth's surface for years, so reducing surface temperatures, modifying global circulation patterns, and generally changing the global climate system. Global climate models struggle to replicate the observed variability of the earth system after massive volcanic eruptions up to this point, and the reaction of the climate system to large volcanic eruptions is not fully understood. For geological periods, it has been proposed that volcanic ash influences climate in addition to the stratospheric climate forcing caused by volcanic sulphate aerosols by altering the global carbon cycle by fertilising the surface ocean with iron and promoting the growth of phytoplankton. Following the eruption of the volcano Kasatochi on the Aleutian Islands in the summer of 2008, this mechanism was also recently noticed. This review paper outlines the formation processes and atmospheric life cycles of volcanic sulphate and volcanic ash, contrasts their effects on climate, and highlights current gaps in our knowledge in order to spark further investigation into the impact of volcanic ash on the climate system via ocean iron fertilisation.

This article compares volcanic ash and mineral dust in terms of their sources, atmospheric loads, deposition mechanisms, atmospheric processing, and effects on the environment and climate. It also compares their chemical and physical properties. Although there are significant differences between the histories of volcanic ash and mineral dust particles before they are released into the atmosphere, there are many similarities between how the atmosphere is processed at ambient temperatures and the effects on the environment and climate. This review paper seeks to encourage future combined research methods to advance our existing understanding through close collaboration between mineral dust and volcanic ash experts by outlining the similarities and contrasts between the processes and consequences of volcanic ash and mineral dust.

**Keywords:** Volcanic; Climate

## Introduction

Ashes, particles, and gases in the atmosphere are all produced by volcanic emissions when magma and the surrounding rock inside volcanic vents fragment. Following H<sub>2</sub>O are CO<sub>2</sub>, SO<sub>2</sub>, H<sub>2</sub>S, HCl, HF, and other substances in order of importance in the magma's volcanic gas emissions. Secondary products, such as volcanic sulphate aerosols, are produced as a high- and low-temperature chemical transformation reactions in the conduit, the volcanic plume, and the cloud [1].

Before being eliminated from the atmosphere by gravity settling and moist deposition, volcanic emissions that are discharged into the free troposphere or stratosphere are first carried by the dominant winds and then photochemically and microphysically altered. Another source for volcanic ash in the atmosphere is the post-eruptive remobilization of its deposits.

The significance of volcanic ash for the climate has been viewed as minor since the volcanic eruptions of El Chichón in 1982 and Mt. Pinatubo in 1991, but the climate forcing of volcanic sulphate has drawn increasing attention. Since sulphur species are released into the stratosphere by explosive volcanic eruptions, it is now well acknowledged in the fields of climate and volcanology research that these eruptions have a significant climate-forcing influence. Usually, they take the form of SO<sub>2</sub>, but they can also include H<sub>2</sub>S [2]. Within weeks, they undergo oxidation and become sulphate aerosols. For years, stratospheric volcanic sulphate aerosols can block sunlight from reaching the earth's surface. This lowers surface temperatures and has an impact on global circulation patterns and the overall global climate system.

The effects of volcanoes on the climate, for instance, are covered in a number of earlier reviews. All of these studies, however, concentrate on the impact of volcanic sulphate aerosols on the climate. According to, the climatic effects of volcanic ash and tephra are quite minor and only last as long as these particles are present in the atmosphere. Volcanic ash, as opposed to volcanic gases and aerosols, leaves the atmosphere more quickly following an eruption [3]. Following large volcanic eruptions, only submicron volcanic ash particles have been seen for several months in the lower stratosphere. The enormous atmospheric load of volcanic ash near to the source region may have an impact on the amplitude of the diurnal cycle of surface air temperature over a period of up to a few weeks. Do not, however, disregard the effect that volcanic ash has on the biogeochemistry of the ocean; volcanic ash may activate the "biological pump," a mechanism that converts CO<sub>2</sub> to organic carbon and permits organic matter particles to sink to the deep ocean, reducing atmospheric CO<sub>2</sub>. Recent studies have demonstrated that volcanic eruptions' airborne debris, particularly volcanic ash, alters the biogeochemical processes in the surface ocean, directly influencing

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climate [4]. Before the eruption of the Kasatochi volcano in the Aleutian Islands in August 2008, these dynamics were, however, generally ignored by the community of volcano-climate researchers. Following this eruption, the NE Pacific's favourable atmospheric and oceanic conditions allowed for the production of a massive phytoplankton bloom, which was seen across a vast area by satellite sensors, in situ observations, and modelling studies. The first time that volcanic ash was effectively used to fertilise the ocean's surface, this event proved that it could do so and potentially alter the climate. Volcanic ash can consequently function similarly to mineral dust, which is frequently believed to be the primary external source of iron for the open ocean.

This time, the report the climatic impacts of volcanic ash to those of volcanic sulphate and sheds new information on how volcanic eruptions affect the climate. The study intends to spark fresh debates and collaborative, interdisciplinary research initiatives among communities of researchers with expertise in ocean biogeochemistry and biology, volcanology, geochemistry, meteorology, atmospheric chemistry, and climate [5]. Even in the age of anthropogenic climate change, a better comprehension of natural climate change drivers, such as volcanic eruptions, is essential for interpreting natural climatic variability. The fate of volcanic ash and sulphate is discussed in the following Sections 2 and 3 in chronological order from the generation processes through the atmospheric burden to postatmospheric deposition. Section 4 presents climate forcing. Section 5 gives a forecast of upcoming research requirements.

A key by-product of volcanic explosions is volcanic ash. It is created by the magma and the surrounding volcanic vent rock fragmenting during the formation process. Volcanic ash is thrown into the free troposphere or possibly the stratosphere, depending on the intensity of the eruption, where it is carried by the dominant winds until it is cleared from the atmosphere by gravity settling and wet deposition [6]. It is also known that volcanic ash can be moved by wind from deposits that have built up after eruptions on land along the main transport directions of the volcanic cloud, which can travel hundreds to thousands of kilometres depending on the wind speed, size, density, and size of the ash particles, as well as the size and frequency of the eruption. Compared to mineral dust in the atmosphere.

Numerous studies have been conducted on the global cycle of mineral dust and how it affects the Earth's climate. Mineral dust aerosols act as cloud condensation or ice nuclei, which have a direct and indirect impact on the radiative forcing of the atmosphere. Mineral dust particles also affect the photochemistry of the ozone layer and provide nutrients to ecosystems on land and in the sea. Through changes to precipitation, vegetation cover, and wind, climate variability also has an impact on the amount of mineral dust in the sky.

This review compares the effects of mineral dust versus volcanic ash on the ecosystem and climate. The characterization of volcanic ash is given more attention, but the impacts of mineral dust are covered less in depth but with references to a large body of literature [7]. Similarities and distinctions will be highlighted to help the numerous science neighbourhoods studying volcanic ash and natural resource dust to take lessons from each other in a take into account the fact, to consider future joint research and development projects, and to address the crucial, difficult, and compelling questions that are still open, such as the following:

(i) What physical-chemical processes in long-distance atmospheric transport alter the surface chemical structure of volcanic ash and mineral dust?

(ii) How significant is the concentration of volcanic ash from land-based deposits for future changes in climate and the environment?

What causes the extreme variation in the fluxes of hazardous and nutritious elements from volcanic ashes as well as mineral dust to the surface ocean?

(iii) How significant is mineral dust-induced enrichment of the surface ocean by volcanic iron and the accompanying changes to atmospheric CO<sub>2</sub>?

(v) How significant is the impact of volcanic ash and/or mineral dust on the climate of the Earth?

## Material and Methods

### Formation Processes and Chemical and Physical Characteristics

#### Frequency of Volcanic Eruptions

Around 20 volcanoes erupt at any given time during the course of the year's 50–70 worldwide volcanic activity, which can last anywhere from a few hours to years. The most frequent volcanic eruptions have a Volcanic Explosivity Index (VEI) of less than 4, which is a relative indicator of how explosive the eruption is. These minor eruptions are thought to emit 20 Tg/yr of volcanic ash into the atmosphere. The limited ability to observe remote volcanic eruptions prior to the satellite era, however, has constrained our understanding of volcanic eruptions with VEI 4. However, due to the ash emissions' quick deposition back into the ground, they are only of local interest.

Sulphur-containing gases, with values of 14–21 Tg/yr for SO<sub>2</sub> and 1–37 Tg/yr for H<sub>2</sub>S, typically constitute 2–35% of the volcanic gas emissions. Despite contributing only 14% of all natural and human-caused sulphur emissions globally, volcanic sulphur emissions have a far greater relative impact on radiative and climate consequences. Volcanic emissions have longer lives than sulphur compounds generated by humans since they are primarily released above the atmosphere's boundary layer because of the height of volcano peaks.

#### Chemical and Mechanical Processes below the Earth Surface

Volcanic ash's chemical makeup is mostly influenced by the erupting magma, which has a silica content of between 45 and 75 weight percent [50] and melts at temperatures between 650 and 1200 °C. The 1989 Stronghold eruption in Alaska's volcanic ash was examined, and it was discovered that the ash was composed of 70% silica glass and 30% minerals. In a sequential solidification process, which is fueled by cooling and depressurization during the rise of the magma through the earth's crust, volcanic ash minerals including feldspar, olivine, pyroxene, hematite, biotite, magnetite, and ilmenite have their beginnings.

Volatiles detach from the magma in the form of gas bubbles when it rises through the earth's mantle and crust into the conduit. This separation eventually leads to an explosive eruption. Magma fragmentation during explosive volcanic eruptions involving rhyolitic magma is typically prevalent. However, andesitic volcanoes, like Shiveluch in Kamchatka, also have plinian (extremely explosive) volcanic eruptions.

The varying levels of volcanic SO<sub>2</sub> emissions from violent volcanic eruptions as determined by petrological techniques and remote sensing are a topic of continuous discussion. The term "excess sulphur" was created to refer to the much lower dissolved sulphur content in magmas compared to the total quantity of SO<sub>2</sub> emitted during an eruption as

determined by remote sensing methods. The melt droplets that are part of the magma and are analysed to determine the pre-eruptive sulphur content do not take into account any chemical conversion that occurs during the eruptive phase, so the petrological data provide a minimal estimate of the sulphur that was erupted.

### Chemical and Mechanical Processing in Volcanic Plumes

The volume above the vent that is up to the point of neutral buoyancy, which is indicated by the predominant updraft motion, is referred to as the volcanic eruption plume. By entraining ambient atmospheric water vapour into the plume and creating buoyancy, turbulent motion dilutes the gas-particle mixture emitted from the vent. Energy in the plume of a volcanic eruption is also redistributed changes in the state of water aggregation. Volcanic ash and gases cool in this volume from around 1000°C to less than 0°C in just a few minutes, and significant volcanic ash fragmentation processes take place. The parameters of the eruption have a significant impact on the size distribution of volcanic ash.

According to, H<sub>2</sub>S oxidation can occur at the hot core ( $T > 600^{\circ}\text{C}$ ) of a volcanic plume, which is where SO<sub>2</sub> injection into the atmosphere can occur. However, H<sub>2</sub>S oxidation is not primarily produced directly from shallow or deep magma systems. The heated core of volcanic plumes is thought to be the primary factor causing variations in sulphur speciation. shown that the redox status of magma as measured at depth does not always correspond to that of its fleeing gases. Depending on the initial state of oxidation, the heated core of a volcanic plume can act as a reactor for SO<sub>2</sub> synthesis and transform an originally SO<sub>2</sub>-poor mixture into a SO<sub>2</sub>-rich mixture. Consequently, these investigations offer yet another justification for the variations in atmospheric SO<sub>2</sub> measurements following volcanic eruptions. The dew point for sulfuric acid in the eruption plume was estimated to be 338°C due to further chemical transformations of sulphur-containing gases and particles in the mid- and low-temperature zones of volcanic plumes. However, because this dew point temperature only applies to very high sulphuric acid concentrations at atmospheric pressure, it is only partially a reliable estimate for volcanic plumes. showed that T 150°C and 50°C are more accurate predictions for the dew points of volcanic plumes of sulphuric acid and water, respectively. At T 150°C, when sulphuric acid condensation begins, the concentration of sulphuric acid droplets rises until it reaches a plateau at a temperature just below 50°C.

### Atmospheric Burden, Residence Time, and Deposition

In terms of space and time, volcanic activity, the location of an eruption, and the patterns of atmospheric dispersion upwind from the volcano all influence the atmospheric concentrations of volcanic ash and sulphate. From daily mean near-surface concentrations of 400 g/m<sup>3</sup> in Scandinavia to maximum ash concentrations of roughly 4000 g/m<sup>3</sup> in the volcanic ash cloud transported over Europe, volcanic ash mass concentrations measured in the troposphere during the eruption of Iceland in 2010 varied. In Iceland, the daily average near surface concentration during the active eruption and also subsequently during resuspension events approached 1000 g/m<sup>3</sup>. Detailed information on the resuspension of volcanic ash following different volcanic eruptions is available here.

A sulphate aerosol layer was found in the lower stratosphere in undisturbed conditions, with a global sulphate load of about 0.15 Tg Sulfur. Over a few years, volcanic sulphate aerosols greatly increase this stratospheric background sulphate concentration. Approximately one year passes during the e-folding decay of stratospheric sulphate. Particles of SO<sub>2</sub> and sulphate are swiftly advected around the world

after being introduced or generated in the stratosphere. Sulphate aerosols circled the globe two weeks after the Krakatau eruption in 1883.

### Climate Forcing

During volcanic eruptions or remobilization events, volcanic ash is discharged into the atmosphere, which lowers visibility and solar irradiation reaching the earth's surface and cools the surface. The majority of volcanic ash has a short atmospheric residence time, which limits its direct radiative impacts to the vicinity of the eruption and along the main transport pathways in the atmosphere. However, the direct radiative effects of volcanic ash may be overwhelming in these areas.

The main worldwide direct radiative impacts following volcanic eruption are caused by stratospheric sulphate aerosols, though.

### Chemical and Physical Properties

According to the "Glossary of Atmospheric Chemistry Terms," dust is made up of tiny, solid, dry particles that are discharged into the atmosphere by mechanical or human-made activities as well as by natural factors like wind and volcanic eruptions. Gravity causes dust particles, which typically range in size from 1 to 100 μm, to slowly fall from the atmosphere. Thus, a small portion of all dust that has been observed may consist of volcanic ash and mineral dust. The definitions below are used to differentiate between volcanic ash and mineral dust: In contrast to volcanic ash, which is a loose, unconsolidated material with particle sizes less than 2 mm that is either distributed in the atmosphere or is deposited above the surface, atmospheric mineral dust is derived from a suspension of minerals that make up the soil.

Volcanic ash is formed through one of three different processes: explosive volcanic eruption, phreatomagmatic eruption, or pyroclastic density current. The production process has a significant impact on the size distribution of volcanic ash. In addition, secondary volcanic ash clouds are produced when volcanic ash depositions on land are resuspended; these clouds shouldn't be confused with coignimbrite clouds, which will be covered later. Magma that contains dissolved volatiles rises in the conduit, resulting in explosive volcanic eruptions. By means of the exsolution of volatiles, gas bubbles are created, and they expand via diffusion, decompression, and coalescence. The pressure lowers as the magma-gas combination rises, causing the mixture to accelerate in the face of frictional and gravitational forces until it bursts out of the vent explosively as a continuous gas stream containing magma clots and clasts.

### Density and Surface Area

In mineral dust modelling, for instance, it is possible to assume that the particle morphology of mineral dust particles is spherical with a commonly used particle density of 2650 kg/m<sup>3</sup>. From one eruption to the next and even during an eruption, the density of the individual volcanic ash particles changes. Depending on the porosity, crystallisation level, and basaltic or rhyolitic composition, it typically ranges between 2000 and 3000 kg/m<sup>3</sup>. Volcanic ash often consists of vesicular particles with an undifferentiated surface texture because to the expansion of magmatic gases such H<sub>2</sub>O, CO<sub>2</sub>, SO<sub>2</sub>, H<sub>2</sub>, CO, H<sub>2</sub>S, HCl, and HF during an explosive and phreatomatic volcanic eruption. Typically, volcanic ash has a specific surface area less than 2 m<sup>2</sup>/g. But there have also been reports of levels as high as 10 m<sup>2</sup>/g.

### Emissions into the Atmosphere, Atmospheric Load, and Subsequent Deposition

The term "emission" refers to the discharge of material into the atmosphere from a location outside the atmosphere, which serves as the atmosphere's source. Mineral dust source sites are typically found in semiarid or arid regions with minimal vegetation and dry surfaces. The wind can gather and move fine-grained particles into the atmosphere in this area. The areas where dust emission occurs are often defined by numerical models for mineral dust mobilisation based on factors including soil moisture, soil texture, and vegetation influences. The emission of mineral dust into the atmosphere is a complex, nonlinear function of both the soil surface qualities and the weather (wind friction velocity and precipitation). When the wind friction velocity surpasses a certain threshold, mineral dust emissions happen from an erodible surface. During explosive volcanic eruptions, phreatomagmatic eruptions, or pyroclastic density currents, volcanic ash is produced. Around 20 volcanoes erupt on average per hour around the planet, 50–70 volcanoes erupt annually, and at least one big eruption with a Volcanic Explosivity Index of at least 4 occurs each year. When assuming a particle density of 2000 kg/m<sup>3</sup>, the total annual emissions of volcanic ash into the troposphere by modest volcanic eruptions with VEI 4 are predicted to reach 20 Tg. This equates to 10 km<sup>3</sup>.

There is a lot of temporal and spatial variation in the concentrations of volcanic ash and mineral dust in the atmosphere. Mineral dust load in the atmosphere is largely influenced by seasonal fluctuation, such as rainy and dry seasons, whereas volcanic ash load is primarily influenced by the occurrence of sporadic and typically unpredictable volcanic eruptions.

Gravitational settling, turbulent dry deposition, and wet deposition, sometimes known as wet scavenging by rain, are the methods used to remove mineral dust and volcanic ash from the sky. By definition, the removal mechanisms for dry and wet deposition include the dry and wet aggregation of volcanic ash. However, due of their area of expertise, they are covered individually subsequently. According to estimations from mineral dust models, the amount of wet deposition over the ocean varies from 30 to 95 percent of the overall amount of mineral dust deposition, with the ratio of dry to wet deposition being very different. It should be highlighted that the distribution and magnitude of deposition fluxes represent the sum of all uncertainties associated with the global mineral dust cycle, including emissions and movement in the atmosphere.

### Atmospheric Processing

Before meteorological processes take place at ambient temperatures, volcanic ash experiences enormous temperature gradients (from roughly 1000°C to less than 0°C) in the volcanic eruption plume, which is spreading vertically into the atmospheric from the origin to the level of neutral buoyancy. In addition to the fragmentation processes that take place here, quenching is a crucial step in the formation of the minerals created by incomplete condensation reactions and the glass material found in volcanic ash.

Due to vertically divided zones of negatively and positively charged volcanic ash particles, intense lightning is a frequently seen occurrence in the volcanic eruption plume. The charged volcanic ash particles may influence how volcanic ash aggregates. The temperature and ionising effects of lightning strikes on the chemical composition of volcanic ash have not yet been studied. Without taking into account lightning, several potentially significant processes for physical-chemical alterations of volcanic ash surfaces are explored in the literature, as summarised below. Volcanic eruption plumes undergo a variety of homogeneous and heterogeneous chemical and microphysical alterations on the

ash surfaces as they climb from around 1000°C at the vent to ambient temperature.

Large quantities of volatiles and volcanic ash are emitted into the atmosphere during volcanic eruptions. It is assumed that soluble compounds are produced on the volcanic ash surfaces through the interaction of these gases and secondary aerosols produced from these gases with volcanic ash within the eruption plume, scavenging up to 30%–40% of the sulphur and 10%–20% of the chlorine released from volcanic eruptions. The hypothesis that three temperature-dependent zones are involved in the scavenging of volatiles by ash inside eruption plumes: (1) the "salt formation zone," which represents the hot centre of the eruption plume, where sulphate and halide salt aerosols, which were created at close to magmatic temperatures, are adsorbed onto ash particles; (2) in the "surface adsorption zone," where halogen gases directly react.

### Environmental and Climate Impacts

#### Human Health

Due to elevated air concentrations, aeolian dust events pose a serious threat to human health. Due to its propensity for combining with pollution aerosols in urban areas of Asia, mineral dust events are becoming an increasing threat to ecosystems and human health. Asthma, allergic alveolitis, eye irritations, and common chronic respiratory and lung disorders have all been linked to increased levels of exposure. Similar health consequences to those caused by mineral dust may be experienced by anyone exposed to large levels of volcanic ash. Small ash particles do, however, have extra mechanical impacts due to their sharp surface patterns. For instance, in windy conditions, they can abrade the front of the eye and, in the worst case scenario, cause silicosis.

#### Aviation

Due to limited vision, strong mineral dust storms primarily hinder takeoff and landing of aircraft. Aircraft can, however, fly in areas with large concentrations of mineral dust without experiencing any engine issues. When mineral dust is fed into jet engines, which generally melts at temperatures of roughly 1700°C, it does not melt. However, due to the melting temperatures being at or below the working temperatures of high-performance jet engines, which are roughly 1400°C, volcanic ash may cause issues for jet engines. When temperatures rise over their glass transition point, the molten material that is deposited on the cooler parts of the engines can produce flame-outs, which can also be brought on by glass shards. Volcanic ash interfered with 129 flights throughout the course of the last 60 years.

#### Soil Fertilisation

Vegetation and soil are entirely buried by deposits of heavy volcanic ash or mineral dust. The likelihood of a plant surviving depends on the thickness, chemistry, compaction, rainfall, and length of burial of the deposit. Both positive and negative effects on flora and soil might result from the slight deposition of mineral dust and volcanic ash. Buried plants may live, despite thin volcanic ash fall inhibiting transpiration and photosynthesis and changing growth. Mineral dust from the Sahara desert, which is frequently transported across the Atlantic Ocean and is asserted to serve as the primary mineral fertiliser of the Amazon region, is credited with having a beneficial effect. Mulching has a good impact on agricultural production of the deposition of volcanic ash.

### Discussion

Numerous causes of generational climate change have been

discussed in the literature, including volcanism, orbital changes, silicate weathering in orogens, changes in cosmic ray fluxes, and tectonic motion. Recently, the topic of volcanic forcing on weather on geologic periods has expanded to include additional indirect impacts as well as the radiative effects of stratosphere sulphate. Despite the fact that the presence of volcanic glass in deep-sea rocks has been recognised as a sign of volcanic activity, ocean fertilisation by volcanic ash was not thought to be a factor in millennium climate change.

It is currently unknown, though, whether even a mega-volcanic eruption could bring about climatic cooling on a timescale of at least a century merely through the radiative effects of stratospheric sulphate. About 75 ka ago, a massive ignimbrite eruption occurred near Toba, Sumatra. 2500 km<sup>3</sup> DRE were erupted by Toba. Although the Toba eruption-related cooling persisted for nearly 1000 years, recent studies point to a weaker temperature response. The stratospheric sulphate burden, its residence period, and climate forcing are now under dispute. Ocean iron fertilisation has not yet been thought to be a factor in the Toba eruption's impact on climate variability, despite the fact that majority of the Toba ash was deposited in the Bay of Bengal, an area where marine primary production is not now constrained by the availability of iron.

Through millennial-scale analysis of Antarctic ice cores, it was discovered that, in addition to the effects of volcanic sulphate on the planet's albedo, volcanic ash may increase the amount of soluble iron in sizable surface areas of the nutrient-limited Southern Ocean, promoting the growth of phytoplankton and influencing the global carbon cycle. Geochronologic and biogeochemical data indicate that iron fertilisation by volcanic ash offers a feasible mechanism for atmospheric CO<sub>2</sub> drawdown during the Cenozoic climatic transition, both in terms of timing and biogeochemical mass balance. These two effects together are thought to have caused cooling during the last millennium.

Since mineral dust has long been believed to be the primary factor in the atmospheric deposition of minerals into the open ocean, studies on the fertilisation of the ocean by mineral dust have been extensive. In paleorecords like ice cores, dust and climate indicators show a considerable link. For instance, the supply of iron from dust sources occurs sporadically in the NE Pacific Ocean and is influenced by the frequency of dust storms and atmospheric circulation. A significant multiproxy dataset for the Southern Ocean was recently reported from a marine sediment core in the sub-Antarctic Atlantic. Iron input and marine export production were found to be closely correlated, suggesting that the process of iron fertilisation on marine biota was a recurrent activity taking place in the sub-Antarctic zone. Another, relatively unexplored external source of iron is the oceanic deposition of volcanic ash. Although it has long been regarded as having little significance or impact on the climate. It is widely believed that volcanic sulphate aerosols reduce solar radiation, which is what causes the significant climate forcing impact that follows volcanic eruptions. Volcanic ash is expelled from the atmosphere far more quickly after an eruption than volcanic gases and aerosols are. But recent research has demonstrated that volcanic ash changes the biogeochemical processes in the surface ocean, directly impacting climate.

Volcanic ash carried by the air may release trace species when it comes into contact with seawater and settles on the ocean's surface. Thus, volcanic ash, despite its intermittent discharge, may function similarly to mineral dust. Other trace elements found in volcanic ash, such zinc or copper, may be either harmful or fertile to phytoplankton.

Following the eruption of the Aleutian Islands' Kasatochi volcano

in August 2008, the first conclusive proof of volcanic ash fertilising an HNLC ocean area with iron was discovered. The interchange of trace gases between the ocean and atmosphere, which is important for regulating climate, may be impacted by ocean iron fertilisation. An increase in the MPP is associated with the release of dimethylsulphide (DMS), which is oxidised to sulphate in the atmosphere, as well as an increase in the amount of organic carbon (OC) that is contributed to submicron marine aerosols. Additionally cooling the Earth's surface, OC and sulphate aerosols can serve as effective cloud condensation nuclei and have a substantial impact on cloud characteristics through indirect aerosol effects.

## Conclusion

There are observations of the volcanic stratospheric sulphate burden and distribution following recent large volcanic eruptions like El Chichón (1982) and Pinatubo (1991), as well as, for example, changes in atmospheric CO<sub>2</sub>, solar radiation, and atmospheric temperature. These observations are made using ground-based and satellite-based technologies. These unambiguously demonstrate the significance of volcanic stratospheric sulphate in cooling the earth's surface, which has a number of other indirect effects on climate due to nonlinear reactions and feedbacks in the climate system, the prior theory that volcanic ash particles suspended in the atmosphere are responsible for volcanic climate forcing has been modified, and research on the climate impacts caused by volcanic ash has shifted away from this theory. The majority of interpretations of the impacts of volcanic eruptions on the climate are based on simulations of climate models driven by stratospheric volcanic sulphate forcing. Global climate models have struggled up until this point to replicate the observed variability of the earth system following big volcanic eruptions. Either crucial feedback mechanisms have gone unnoticed, or processes like the fertilisation of the ocean by volcanic ash have not been considered because they are currently unavailable. Therefore, it will be required to revisit past volcanic eruptions and their effects on the climate, especially the potential for volcanic ash to fertilise oceanic iron. This is based on a volcano's geographic position, the amount of volcanic ash that is dumped into the water immediately following an eruption or by post-eruptive remobilization of ash form deposits, the availability of macronutrients,

In general, it is necessary to conduct a more thorough assessment of the usually ignored role that ocean fertilisation plays in the variability of volcanic climate. In order to comprehend natural climatic variability on geological timeframes, it is also important to compare the role of volcanic ash in ocean fertilisation to that of mineral dust. This study aims to stimulate multidisciplinary research including volcanology, geochemistry, meteorology, atmospheric chemistry, and climate research teams as well as ocean biogeochemistry and biology. The processing of iron in volcanic plumes and during long-range transport will need to be better understood by modelling studies, observations in the field, and laboratory. Only then will we be able to improve our understanding of the volcanic ash fertilisation potential of the surface ocean. Additionally, it is important to understand how volcanic ash, a component of the marine ecosystem that has received little attention, affects species composition and marine productivity, two important aspects that have an impact on marine carbon cycling and consequently, the global climate.

Mineral dust and volcanic ash particles have very different histories before they are released into the atmosphere, but they also have a lot in common when it comes to how the atmosphere is processed at ambient temperatures and how it affects the environment and the climate. Therefore, the goal of this review is to encourage

increased collaboration among the scientific community looking into the atmospheric chemical effects and changes of volcanic ash and mineral dust. Model parameters for the remobilization of volcanic ash from its land-based deposits are based on techniques for mobilising mineral dust. However, due to the restricted availability of ash in its deposits, updated techniques will be required taking into account mass conserving parameterizations, where the movement of deposits is also included. Researchers who study mineral dust may also be interested in these parameterizations.

It has been difficult to gain a comprehensive knowledge of the crucial processes up to now because of the harsh circumstances for multiphase chemistry found in volcanic plumes with regard to temperature and its gradients, acidity, lightning, and particle load. Despite these challenges, multiphase volcanic plume chemistry offers the potential to shed light on mechanisms that may be crucial for mineral dust atmospheric chemical processing under less extreme settings. The production of bioavailable iron on volcanic ash and mineral dust surfaces for ocean fertilisation is particularly highlighted in this study. Our imperfect understanding, especially from leaching studies, might be significantly increased through collaborative experimental and modelling research efforts involving mineral dust and volcanic ash experts. Even while leaching experiments are crucial to our current understanding, they may become even more crucial if uniform methods were established and followed. This would enable comparisons to be made between studies carried out at various laboratories. Additionally, as tiny particles are prone to long-distance transmission, particle size distributions and mineralogy for diameters significantly lower than 2  $\mu\text{m}$  should be extensively explored. This is especially true for volcanological researchers.

In order to more accurately analyse the climate effects of volcanic ash vs mineral dust during the geological past, from terrestrial and

marine environmental archives, including ice, peat, sea, and ocean sediment cores for mineral dust and volcanic ash deposition, must be put together. However, until we have a thorough grasp of current processes, we won't be able to effectively address these processes in the palaeo-records or with regard to the potential effects of mineral dust on the climate in the future, as opposed to volcanic ash.

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## Conflicts of Interest

The author has no known conflict of interest associated with this paper.

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