# VOLCANISM AND GLOBAL ENVIRONMENTAL CHANGE

The 2010 eruption of Eyjafjallajökull resulted in unprecedented disruption to global air travel and caused major flooding in Iceland, highlighting the importance of understanding how volcanic processes affect the Earth's surface and atmosphere.

Covering a key connection between geological processes and life on Earth, this multidisciplinary volume describes the effects of volcanism on the environment by combining present-day observations of volcanism and environmental changes with information from past eruptions preserved in the geologic record. The book discusses the origins, features and timing of volumetrically large volcanic eruptions; methods for assessing gas and tephra release in the modern day and the palaeo-record; and the impacts of volcanic gases and aerosols on the environment, from ozone depletion to mass extinctions. The significant advances that have been made in recent years in quantifying and understanding the impacts of present and past volcanic eruptions are presented and review chapters are included, making this a valuable book for academic researchers and graduate students in volcanology, climate science, palaeontology, atmospheric chemistry and igneous petrology.

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# Preface

*Linda T. Elkins-Tanton*
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On the 8th June in 1783 CE a fissure on Iceland opened and the devastating Laki eruption began. Seemingly a simple basaltic fire-fountaining event, it defied common assumptions about basaltic volcanism by emitting vast amounts of halogens and sulfur species to the atmosphere. The eruption caused severe environmental and climatic changes in the northern hemisphere that lasted for several years. Even with the fidelity of human recordkeeping at the time, scientists today are still investigating why and how the Laki eruption affected the environment.

The geologic record reveals that volcanism has occurred on a wide range of scales throughout Earth history, from the formation of small cinder cones to giant flood basalt provinces. Coeval sedimentary records indicate that some of these past eruptions, continental flood basalts in particular, may have caused dramatic changes to the global environment, affecting climate, environmental chemistry, and perhaps triggering mass extinctions. One of the largest of these continental flood basalt eruptions occurred 252 million years ago in present-day Siberia. Much of the lava is thought to have been produced in fissure eruptions, such as Laki in Iceland, and death ensued, not only from starvation. The coeval end-Permian extinction of species was global and came close to eliminating multicellular life in the oceans and, to a lesser extent, on land.

Not every volcanic eruption causes significant environmental change, however, and the mechanisms driving different modes of volcanism and their variable environmental impact are areas of ongoing research. Eruption volume, magnitude and explosivity are obvious indicators of the potential for environmental effects. Large erupted volumes and high explosivities indicate large volatile mass fluxes and increase the chance of volatile species being lofted high into the atmosphere. Once in the stratosphere, gases and aerosol particles can circulate the globe, affecting climate and the environment on global scales. Beyond this simple beginning, however, is a landscape of complex physical and chemical interactions that still remain to be explored and understood.

Methods for assessing the effects of volcanism on the environment are increasingly diverse as new technology and techniques enable measurements that were previously unattainable. Today, scientists can actively monitor eruptions with instrumentation on the ground and on satellites to measures plume sizes, dispersion rates, and plume compositions, including sulfur, carbon and halogen compounds. We can measure global temperature changes in the years following an eruption as well as changes to surface water chemistry and primary productivity due to ash deposition and ash-leachate dissolution. Although advances have been made in recent years, many questions remain regarding issues such as the production and dispersion of ash and its effect on airplanes. Understanding the effects of volcanism on climate and environment is limited, however, in the small slices of time and styles of volcanism experienced during human history.

To understand the full range of styles and impacts of volcanism, we must look to the geologic record. In the palaeo-record, traditional petrography and physical volcanology are supplemented with pressure and chemistry estimates from fluid inclusions, with nanoprobe measurements of volatiles in melt inclusions and with disaggregation and grain-size measurements and magnetic conglomerate tests in volcaniclastics, to determine palaeo-eruption dynamics, explosivity and volatile content. A variety of isotope and geochemical proxies are used to understand the impact of volcanism, in the geologic past, on global temperature and other environmental conditions.

Previously, the voluminous flood basalts in the geologic record were thought to contain low levels of climate-changing volatiles. Recent work on the Siberian flood basalts, however, indicates that the eruptions mobilized vast amounts of carbon and sulfur-bearing species, along with ozone-depleting chlorofluorocarbons. Similarly, recent work provides estimates of the volatiles released by the Deccan Traps and the Central Atlantic Igneous Province, indicating their potential to severely affect the environment and life on Earth. Given the impacts of volcanic activity in the past and the similarity in composition between volcanic volatiles and anthropogenic emissions, a better understanding of how volcanic volatiles contributed to past global environmental change has direct application to both volcanic and anthropogenic climate change today.

The richest discoveries and most important advances in science can often be made in interdisciplinary work. This volume brings together geologists, atmospheric scientists, climate scientists, volcanologists, palaeobiologists and modelers, to find a fruitful path forward in better understanding how solid Earth processes affect the atmosphere, and thus result in global environmental change affecting habitability on Earth, both in the present day and the geological past.

The chapters in *Volcanism and Global Environmental Change* are divided into three sections. In Part One, 'Large volume volcanism: origins, features, and timing', Ukstins Peate and Elkins-Tanton highlight a specific aspect of large igneous provinces, their common inclusion of explosive basaltic volcanism producing in some cases tremendous volumes of volcaniclastic deposits. In some cases, these volcaniclastics were produced by interaction with ground water but, in others, they were driven from depth with an explosive force that indicates a far greater potential for environmental change than has been supposed. Oppenheimer and Donovan discuss the poorly understood phenomena dubbed 'super-eruptions', perhaps the greatest single volcanic threat to modern humankind.

Large igneous provinces hold our fascination not only because of their immense size and their lack of modern analogs, but also because their physical origins are still debated (discussed here by Torsvik and Burke). The apparent link between large igneous provinces and global extinction events is being demonstrated with smaller and smaller errors as laboratory geochronology techniques improve and as fieldwork continues; the state of this art is described by Burgess, Blackburn and Bowring. With increasing geochronology fidelity comes better knowledge of the duration of these eruptions (which in many cases may have been far less than the commonly quoted million years). Palaeomagnetism offers a method for examining the rapidity of emplacement of packets of flows, as they record the continuous gradual movement of the magnetic pole, and, in conjunction with ages for the whole province, for assessing the total length of non-eruptive intervals. This technique is demonstrated for the Siberian Traps by Pavlov and co-authors.

In Part Two, 'Assessing gas and tephra release in the present day and palaeorecord', the state of the art of present-day gas and ash measurements by ground-based, satellite and aircraft instruments are discussed by Aiuppa, Prata, Platt and Bobrowski, and Pieri. Sophisticated ground-based instrumentation is becoming more common and will continue to expand in coming years as population growth puts more and more people at risk of volcanic hazards; gas monitoring is becoming as standard as seismometers on volcanoes around the world. Meanwhile, instrumentation on satellites and aircraft can target both volcanoes near population centers and those that are more remote.

Measuring the gas release rates, degrees of explosivity, and climatic effects of eruptions from the geologic record is more challenging. The following four chapters concern gases emitted by flood basalts and their link to extinctions. Sobolev and co-authors describe a model for the source of volatiles in the Siberian flood basalts, while Self and co-authors discuss plume heights, composition and timescales of flood basalt eruptions, and Svensen and co-authors discuss the potential for volatiles baked from country rocks by the heat and mass transfer of the flood basalts.

The final part of the book, ‘Modes of volcanically induced global environmental change’, contains chapters on atmospheric and climate change caused by volcanism by Schmidt and Robock and by Mather and Pyle. Courtillot *et al*. summarize the decades of work done at the Institut de Physique du Globe on defining and addressing this broad topic. Finally, the specific effects of halogens emitted to the atmosphere are discussed by Krueger and co-authors, while Jones covers the environmental effects of ash deposition. Schaal and co-authors describe the evidence for ocean anoxia and its relation to volcanism, specifically during the end-Permian, and, Cui, Kump and Ridgwell present models of ocean acidification induced by carbon release from various sources including volcanic $CO_2$, and the link to the end-Permian extinction. The book is completed by Black and co-authors, who evaluate proposed environmental effects using a global model of atmospheric chemistry and climate for the end-Permian.

The interactions that occur between volcanism and the environment on global scales are numerous and complex. Past and present eruptions provide natural experiments on the environmental impact of volcanism that could never be created in the laboratory. Flood basalt volcanism associated with mass extinctions, in particular, offers end-member constraints on the extent to which Earth’s ecosystems can adapt to an abrupt shift in atmospheric composition. The compositions of some past volcanically released gases are frighteningly evocative of anthropogenic emissions, and these episodes of past volcanism may offer clues to the ways that humankind is currently affecting the Earth’s ecosystems. Ultimately, volcanic processes from the present day and geologic record provide scenarios through which we may begin to understand the implications of anthropogenic activities, such as fossil-fuel burning, natural-resource utilization and landscape modification.