Volcanoes and the Environment

Volcanoes and the Environment incorporates contributions from some of the foremost authorities in volcanology from around the world to form a comprehensive and accessible text. This book is an indispensable guide for all those interested in how volcanism has affected our planet's environment in the past and will continue to do so in the future. Spanning a wide variety of topics from geology to climatology and ecology, it also considers the economic and social impacts of volcanic activity on humans.

Chapters cover the role of volcanoes in shaping our planet's environment through the eons, and their effect on the geological cycle; the impacts on atmosphere and climate; impacts on the health of those living on active volcanoes; the role of volcanism on early life; effects of eruptions on modern plant and animal life and implications from these studies; links between large eruptions and mass extinctions; relationships between contrasting human societies and volcanic disasters; how volcanoes can provide heat energy and supply precious base metals, as well as raw material, for our industries; and impacts of volcanic disasters on the economy.

This book is intended for students and researchers interested in environmental change from the fields of earth and environmental science, geography, ecology, and social science. It will also interest and inform policy-makers and professionals working in natural hazard planning and mitigation.

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Preface

Volcanic eruptions are among the most fascinating natural phenomena and can have significant impacts upon the environment. One only has to think of the 1883 eruption of Krakatau or of the 1980 eruption of Mount St. Helens to get a sense of the awesome power and wide-ranging impacts of eruptions. Some readers will remember hearing or reading about the loss of life and devastation around those volcanoes, while others will remember how even larger eruptions than these cooled the Earth's climate and affected the ozone layer. Most will recall controversial discussions about how volcanoes may have eradicated the dinosaurs some 65 million years ago or about how super-eruptions may have nearly wiped out our human ancestors some 75 000 years ago. We like to think it is fortunate that they did not, but what will happen when the next super-eruption strikes? Most recently, eruptions at ocean island volcanoes have even been proposed as triggers for catastrophic, massive volcano failure and the generation of tsunami waves of unimaginable proportion. The 26 December 2004 Banda Aceh tsunami; off Sumatra, which devastated coastal areas in SE Asia, killing 300000 and precipitating several million people into a state of absolute poverty, is a small event in comparison. Volcano-related mega-tsunamis represent a very great risk to many coastal cities around the world and to their populations, and no doubt to the world economy. Moreover, it has now been demonstrated that periods of severe cooling lasting 1000 years are unambiguously correlated with eruptions. This will no doubt fuel heated debates as to whether eruptions can indeed trigger glaciations on that timescale.

Eruptions arguably have the potential to have all these impacts and many more upon their surroundings and, in some cases, upon the global environment. This is a sobering thought, especially when considering that there are still a large number of potentially hazardous volcanoes of which we know next to nothing. For example, about 80% of active volcanoes, most of which are located in developing countries where local populations are the most vulnerable to natural hazards, remain largely unstudied. In this age of supercomputers, nanotechnology and space exploration, we know very little about these volcanoes of our own planet, most of which are not monitored to any extent, or about the impacts they could have in future. Changing this situation needs to be one of the highest priorities of volcanological efforts in coming decades.

Volcanoes also contribute positively to the environment. They have brought much to "life" in the past, and represent, at present, an important source of benefits for humanity. For example:

- Volcanoes have decisively contributed to the origin of life and Earth's atmosphere, and are often regarded as directly responsible for the existence of highly fertile soils in many parts of our planet. Uplift related to volcanism in easternmost Africa, starting millions of years ago, and associated climatic and vegetation changes, have been related to the emergence of our direct ancestors in the Rift Valley some 2–3 million years ago.
- The volcano-derived heat that may have fueled the emergence of life in the oceans is now being mined as geothermal energy on several continents. Volcanoes are also the source of ore deposits and an important source of material for industry.
- By studying the dispersal of giant clouds produced by explosive volcanic eruptions, atmospheric scientists have made great advances in understanding how the atmosphere works, and particularly in understanding its energy balance and the complexity of atmospheric circulation. Each time a large eruption happens, it is a natural experiment on the scale of our planet as a whole, enabling atmospheric scientists to put to challenging tests their models predicting our current and future climate.
- Thick volcanic ash layers from powerful eruptions have also buried and preserved the records of ancient civilizations worldwide. In Europe, this is illustrated by the late Bronze

Age towns on the Island of Thera (Santorini, Greece; arguably the legendary Atlantis or part of it), which have provided profound insights into the early development of European art, from the study of its beautiful paintings on walls and pottery. Two thousand years later, another large eruption buried the Roman town of Pompeii (near Naples, Italy), again providing invaluable clues into what made a great civilization. Of course, these buried civilizations are also a stark reminder of the extraordinary destructive power of the largest of eruptions, for which we have either no or only limited historical records.

- Studying the origin of life at hot vents on deep submarine volcanoes can also shed light on whether life may exist on other planets such as Europa, a satellite of Jupiter; and on whether life may have thrived on Mars in the past.

The list of benefits derived from volcanoes and their study extends much beyond this short list of examples as will become clear during the reading of this book.

In this textbook we have taken the broadest possible view of the environment. We have considered not just the impacts of eruptions on the atmosphere and climate, and on the flora, fauna and humans around volcanoes but also the impacts on human health, human societies, and the local and national economies. We have also considered the role of volcanism in generating precious base metal resources, the use of volcanic materials in industry and the recovery of volcano-derived thermal energy, the contribution of volcanic eruptions to past mass extinctions, and the role of volcanism and volcano-derived hydrothermal venting on the emergence of the earliest forms of life on Earth and on the development of the primitive atmosphere and ocean. We have also included a treatment of the role of volcanism in the geological cycle.

In order to enable discussions of all these interrelated impacts to be easily followed it has been necessary to introduce a basic treatment on the physical understanding of volcanic eruptions, as well as on volcanic hazards and on how eruptions can be anticipated. These topics are fascinating aspects in their own right and set the scene for the discussions that follow.

This wide coverage of topics related to the impacts of volcanism and volcanic eruptions upon the many interrelated aspects of the environment considered in the widest sense is what makes this book unique. A few years ago we came to realize that many of the aspects now discussed in this new text were covered only in part and only in scattered texts. There was not a single text attempting to present an integrated treatment. Many of the discussions appeared in specialized journal articles and books, making them inaccessible to amateur environmentalists and to most undergraduates and postgraduates. We felt that what was needed was a text that would be not only comprehensive in its treatment of the subject but also accessible to a wide audience of naturalist amateurs, undergraduate and postgraduate students in the environmental, geographical and earth sciences as well as an easy-to-carry reference text for all our research and teaching colleagues across many scientific disciplines.

Seventeen of our colleagues among the leading authorities on the subject enthusiastically shared our vision and together we started preparing what was to become this book, the very first textbook extensively discussing most aspects of the impacts of volcanic eruptions upon the environment.

We hope that like all the contributors to this book the readers will be irresistibly enthused by this exciting subject. The following paragraphs introduce the successive chapters in more detail, outlining some of the basic questions, which are discussed by the contributors.

Chapters 1–3 are foundation chapters needed before the diverse effects of volcanism can be studied. Chapter 1, by Steven Carey, a senior physical volcanologist at the University of Rhode Island, sets the scene by reviewing our understanding of volcanoes and of the physical processes associated with volcanic eruptions. Some of the questions considered include: where is volcanic activity concentrated and why? What are the main contrasting types of volcanic settings and how do they differ in the styles of the eruptions which occur there? How variable is the composition of magma and how does this come about? How are magmas generated? In what way do volcanic eruptions contribute to the development of the landscape (or the "seascape") – mountains and topographic depressions?

Volcanic hazards can affect humans and the environment. But what are the main types of hazards and how can humans cope with them? How can we assess them? Can we predict the onset of eruptions? What are the techniques used? Is it sufficient to anticipate where and when eruptions will occur to anticipate potential disasters, either environmental or human in character? These are some of the crucial questions considered, in Chapter 2, by Robert Tilling, a veteran of volcano monitoring and volcano disaster response with the US Geological Survey. Tilling discusses some of these questions by comparing the cases and responses to two classic eruptions, the eruptions in 1985 at Nevado del Ruiz, Colombia and in 1991 at Mt. Pinatubo, Philippines. He concludes by summarizing some of the key lessons that have been learnt by those who have lived through volcanic crises and volcanic disasters such as these.

Chapter 3, by Joan Martí and Arnau Folch, both experienced volcanologists and modelers at CSIC (Consejo Superior de Investigaciones Científicas, i.e., the Spanish National Research Council) in Barcelona, builds up on Chapters 1 and 2. It focuses specifically on how we can anticipate volcanic eruptions. It discusses what techniques are used in the wide variety of volcanic settings and corresponding volcano types. It also discusses how theory and laboratory work can help by providing invaluable insights and understanding. The chapter shows along its different sections that the best way to anticipate a volcanic eruption and its effects is by combining a good knowledge of the volcano's eruptive behavior (physical volcanology) and of the level of its current activity (volcano monitoring).

These three chapters are fundamental to understanding the character of volcanic perturbations, which can impact on humans and their activities or the environment at large. Chapters 4–5 explore in turn the relationships between volcanism and a specific aspect of the "environment." Chapters 4–5 are related, respectively, to the relationship of volcanism with geological time and space, and with a specific aspect of the physical environment of our planet, namely its atmosphere. Some of the key questions discussed include: what has been the contribution of volcanoes in shaping our planet and its environment through the history of the Earth? Are eruptions becoming more or less frequent now than millions of years ago? What is the role of plate tectonics and when did plate tectonics start to act as a major driving force in the evolution of our planet? What was, and what is now the contribution of volcanic degassing and volcanic eruptions to the atmosphere? – to the oceans? – to life? These questions are discussed in Chapter 4 by Ray Cas, a veteran volcanologist at Monash University who has studied volcanoes first-hand in many parts of the world.

In recent years there has been a growing realization that volcanic degassing and eruptions of a range of styles can impact upon both the chemical composition of the atmosphere and upon its radiative energy balance. This, in turn, changes the temperature distribution on the Earth and thus the weather and climate that we experience. In Chapter 5 Stephen Self, a leading volcanologist at the Open University and pioneer of research in this area, introduces the main mechanisms by which contrasting styles of eruptions can affect atmospheric composition and climate. Through a few key examples that include super-eruptions and flood basalt volcanism, he illustrates that we are increasingly able to document how large eruptions affected the atmosphere and climate in the past. This effort is crucial to help us foresee the impacts that future eruptions will have.

Chapters 6–9 explore in turn several key aspects of the relationship between volcanism and life, both in the past and at present. One of the most fascinating aspects of our relationship to volcanism is in how volcanic activity may have played a major role in our ultimate origin. That is the origin of ancestral forms of life that evolved into increasingly complex forms and eventually some 4 billion years later or so, to us *Homo sapiens*. In Chapter 6, Karl Stetter, a senior researcher at the University of California–Los Angeles and the University of Regensburg and a leading authority on the subject, considers some of the following questions: what are the most primitive forms of life still in existence today? How do they relate to volcanism? How can we describe their relationships with other species in an evolutionary tree? How diverse are these primitive forms of life and how have they survived the competition for almost 4 billion years? Professor Stetter considers these fascinating questions and more, and places them in the framework of the history of life on our planet.

An area of heated debate has been whether or not the dinosaurs were wiped out by an asteroid that fell over the Yucatan Peninsula in Mexico, or whether longer-term volcanic activity covering the largest part of India with layer upon layer of lava has anything to do with it. In Chapter 7, Paul Wignall, a geologist and paleontologist leading work in this area at the University of Leeds, seeks evidence to resolve this issue. Wignall does not limit the discussion to the great extinction of the dinosaurs and other species at the K–T boundary, but considers a variety of well-documented mass extinction events, which may be related to massive outpourings of lava on a continental scale. The chapter closes by balancing the evidence in favor and against a major role of volcanism in the mass extinction scenarios.

In Chapter 8, Virginia Dale, Johanna Delgado-Acevedo, and James MacMahon, all volcano botanists and ecologists, from the Oak Ridge National Laboratory, the University of Puerto Rico, and Utah State University, respectively, discuss how plant life is affected by volcanic eruptions. These scientists, also at the forefront of their field, consider recent eruptions of contrasting styles ranging from those emitting lava flows to those involving pyroclastic flows. What determines plant life survival? How does plant life recover after a major volcanic eruption? The chapter also summarizes the physical impacts of eruptions and their impacts on vegetation around volcanoes worldwide. They also compare the patterns of the surviving floral composition, vegetation re-establishment, and plant succession after each specific type of volcanic disturbance.

In Chapter 9, John Edwards, a leading volcano zoologist and ecologist at the University of Washington, discusses how animals may or may not survive volcanic eruptions and in the case where the eruptions are so strong that they wipe out all life forms, how and in what order the animals are observed to recolonize a barren volcanic area. The chapter not only emphasizes survival and revival of animal communities but also stresses that eruptions are a major process on evolutionary timescales of millions of years. The discussion includes the effects of ash dispersal on insects, the issue of animal survival after eruptions, the processes of recolonization by animals in six case studies, the recolonization in the zone destroyed by the "ash hurricane" at Mount St. Helens and later events in animal recolonization. One important finding is that arthropods are key players, as primary colonizers. Another key finding is that recolonization appears extremely rapid compared to evolutionary times. A largely unresolved question which deserves more attention is the "refugia question" – whether or not some animals may be able to survive extreme volcanic disasters and how this could come about? The chapter concludes by highlighting three key areas where research is much needed in order to make further advances in understanding.

Chapter 10 considers the effect of recent eruptions on human health. Over half a billion people now live in the immediate vicinity of active volcanoes, the majority of them in developing countries and highly vulnerable to volcanic emissions and eruptions. Therefore, a very important concern is to discover how volcanic degassing and eruptions can affect the health of a proportion of those people and to explore what could be done to monitor and mitigate any adverse effects on human health. What are the health effects of being exposed to volcanic gases? What are the effects of eruptions of a range of styles? Peter Baxter, a medical scientist at the University of Cambridge and the leading authority in the field of volcano medicine, has studied first-hand the effects of volcanic activity and eruptions worldwide and draws from case studies at many volcanoes to discuss these fundamental questions.

Chapter 10 also makes recommendations for good practices during volcanic crises and raises concerns for the future where appropriate.

Chapters 11–13 discuss in turn three valuable by-products of volcanism which are extensively used by humans: volcano-derived heat, precious metals, and raw materials for industry. The presence of hot magmas, below the surface in association with volcanoes, offers the prospect of harnessing a huge amount of thermal energy that can be used in our homes, both for heat or to provide electricity. This so-called geothermal energy is an important source of renewable energy and the implications for the environment are significant if we can successfully recover it. Where does geothermal energy originate? What does it take for a geothermal deposit to be economical? How do we estimate reserves? Are there any adverse effects for the environment as geothermal energy is tapped and recovered, in comparison with other types of energy? These are some of the key questions considered in Chapter 11 by Wendell Duffield, a veteran US Geological Survey scientist and volcanologist. Geothermal energy is already important and is bound to become even more so, as the reserves of fossil fuels run out and as the cost of cleaning up adverse environmental impacts can no longer be avoided in energy cost calculations.

One of the many benefits of volcanism comes from the exploitation of valuable ore deposits, which are related to the presence of volcanoes in the Earth's crust. But what do we mean when we speak of ore deposits? How do we determine whether an ore body is exploitable? What are the different types of ore bodies associated with volcanism? How can we use our understanding of volcanoes and ore deposit formation to discover the new resources that will be needed in the future. In Chapter 12, Harold Gibson, an economic geologist and volcanologist expert on this subject at Laurentian University, considers these questions and describes the volcanic environments and processes which hold the key to the formation and location of volcano-derived ore deposits.

A key area of the impact of eruptions on our environment and activities is through providing materials that can be used in industry. The exploitation of these volcanic materials in turn has a direct impact on the environment. What are the different types of materials that can be used and to what purposes? Chapter 13, by Grant Heiken, a veteran volcanologist at the Los Alamos National Laboratory, describes these different types of materials and goes on to analyze their past and current uses. In particular, pumice and scoria, which are both produced by a variety of types of explosive eruptions, have many uses ranging from raw material in the preparation of abrasives, building-blocks for cathedrals, cat litter, cement, and concrete, etc. But where can we find these materials? What problems are we faced with as we try to identify the most economical varieties of rock types, and how is this related to the processes that deposited the materials in the first place? The chapter is not limited to pumice and scoria but encompasses the whole range of volcanic materials.

Chapters 14–15 discuss additional aspects of the relationship between eruptions and humans – namely the relationship of volcanism with human societies and the impact of eruptions on the human economies. Human societies have had to respond to the many types of volcanic disasters that have occurred and continue to occur worldwide. In Chapter 14, David Chester, a geographer and volcano sociologist at the University of Liverpool and researcher leading this field, considers the relationship between contrasting human societies and volcanic disasters. The chapter starts by discussing the relationship between volcanoes and society in time and space from a historical perspective. It then moves on to review the interface between social theory and eruptions. How have societies responded to eruptions in the past? What is the modern response of contrasting societies to volcanic disasters? The chapter challenges the dominant approach that has been adopted almost up to the present and proposes more radical alternative societal responses. It concludes by highlighting areas of research that will have to be developed in the future.

It is clear that eruptions have direct and indirect effects on the economy. Do they impact only local economies, or can there be effects on a national or even global level? How big are these effects, and how is the cost of a volcanic disaster estimated? What are the key determinants of whether an eruption will or will not impact an economy? In Chapter 15, Charlotte Benson, a volcano disaster economist who has been pioneering research on this topic at the UK Overseas Development Institute, draws from documentation on the economic impacts of volcanic activity. She clearly demonstrates that this is an increasingly important and fascinating new area of research and one where much more research is needed.

We hope that you, the readers, will enjoy reading this book as much as we enjoyed putting it together. We will have succeeded in our endeavor if reading this textbook inspires some of you to pursue unanswered or poorly understood aspects of the fascinating, "volcanoes and environment" problems. More importantly, we hope that this book will enhance public awareness of our rapidly changing and evolving environment and of how volcanic eruptions contribute to the changes.

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