GLACIOVOLCANISM ON EARTH AND MARS

Products, Processes and Palaeoenvironmental Significance

The study of volcano–ice interactions, or 'glaciovolcanism', is a field experiencing exponential growth. Explosive eruptions in Iceland at Gjálp (1996) and more recently at Eyjafjallajökull (2010), the latter of which caused major economic disruption across Europe, illustrate the importance of assessing possible future hazards associated with ice-clad volcanoes. Subglacial volcanoes are also thought to exist on other bodies in the Solar System, especially on Mars.

This comprehensive volume presents a discussion of the distinctive processes and characteristics of glaciovolcanic eruptions, and their products and landforms, with reference to both terrestrial and Mars occurrences. Supported by abundant diagrams and photos from the authors' extensive collections, this book outlines where eruptions have occurred and will occur in future on Earth, the resulting hazards that are unique to volcano–ice interactions, and how the deposits are used to unravel planetary palaeoclimatic histories. It has a practical focus on lithofacies, glaciovolcanic edifice morphometry and construction, and on applications to palaeoenvironmental studies. Also available online are a series of expertly illustrated and annotated lecture slides that can be incorporated into teaching materials.

Providing the first global summary of past and current work, this book also identifies those areas in need of further research, making this an ideal reference for academic researchers and postgraduate students in the fields of volcanology, glaciology, planetary science, and palaeoenvironmental studies.

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Preface

Nature and scope of the volume

This book is the first monograph on glaciovolcanism to be published. One of its principal intentions is to revivify the topic by celebrating 15 years of burgeoning research following the first international conference on volcano–ice interactions on Earth and Mars. That conference took place in 2000 in recognition that glaciovolcanism was a unique and new research area in its own right (Chapman et al., 2001). Also known as subglacial volcanism, glaciovolcanism has largely been omitted from current textbooks because of its youth. Although the study of interactions between volcanoes and glaciers dates back about a century, publications of scientific studies of glaciovolcanism before the 1990s were few. GeoREF searches (http://www.agiweb.org/georef/) show that prior to 2000, fewer than 30 literature citations were linked to studies of glaciovolcanism, subglacial volcanism, or volcano–ice interactions. However, the publication rate for articles on volcano–ice interactions has risen by almost an order of magnitude in the past decade, signalling the rapidly increasing interest in the topic. Major reasons for the rise in interest globally are threefold: (1) the occurrence, in 1996, of a spectacular and exceptionally well-documented glaciovolcanic eruption in Iceland (Gjálp) and associated huge glacial outburst flood (jökulhlaup) which wiped out a large part of the transport infrastructure in southern Iceland, followed by the Eyjafjallajökull eruption in 2010 which had a major economic impact across much of Europe; (2) the dawning realisation during the past decade that Mars is a water-rich planet hosting numerous glaciovolcanic edifices, a discovery that greatly enhances Mars' potential for future human colonisation and as an exobiological target; and (3) the development and rapidly growing importance of glaciovolcanic studies as a powerful new palaeoenvironmental proxy for reconstruction of planetary ice sheets. Although that importance is still largely unacknowledged by mainstream palaeoenvironmental scientists, glaciovolcanic deposits are currently the most holistic repositories of information that can be used for determining *and quantifying* critical parameters of past ice sheets. In regions that have experienced glaciovolcanism, studies of the volcanic rocks should be at the core of any palaeoenviromental investigations. It is also now thought that glaciovolcanic centres may have played a pivotal role in enabling terrestrial species to survive and repopulate Earth's polar regions after multiple glacial periods. Glaciovolcanism is therefore not only of interest to multiple disciplines but it is also highly topical, and this book is the first to be published that describes and examines the eruptive

processes and products involved, with reference to occurrences mainly on Earth but also on Mars.

Terrestrial glaciovolcanic deposits are globally widespread. However, the three most important geographical regions are Antarctica (the largest and longest-lived glaciovolcanic province, extending back at least 28 million years), Iceland (with the greatest concentration of glaciovolcanic edifices and largest number of observed historical eruptions) and British Columbia (where amongst the most insightful and earliest glaciovolcanic models and terminology were devised). Snow- and ice-capped volcanoes, found throughout much of the Pacific ring of fire including New Zealand, Japan, Russia (Kamchatka), Alaska, western Canada, western USA and South America, also potentially have a glaciovolcanic history and have a long history of hazards from glaciovolcanism. Indeed, every country with volcanoes and ice is potentially a glaciovolcanic province, even if glaciovolcanic products have not yet been recognised. One estimate puts the number of potentially active snow- or ice-covered volcanoes at more than 400. Mars is also now considered to have a large number of putative glaciovolcanic edifices, which have been used to document the water budget of the planet, and their discovery has led the way for postulating formerly extensive glacial surface ice and for identifying potential targets for exobiology investigations.

Glaciovolcanic eruptions can be devastating in fatalities and economic costs. For example, the 1985 eruption of Nevado del Ruiz volcano in Colombia produced snow/ice-generated lahars that killed c. 25 000 people. The 2010 eruption beneath the small ice cap on Eyjafjallajökull (Iceland) caused losses of several billion euros due to disruption of flights across the whole of Europe, whilst the meltwater flood associated with the 1996 eruption at Gjálp (also Iceland) was, for a period of a few hours, the second largest freshwater discharge on Earth, peaking at approximately four times the discharge of the Mississippi and exceeded only by that of the Amazon. The associated floodwaters caused some US$19 000 000 of economic damage principally to the Icelandic transport infrastructure which, for a country with a small population (c. 250 000 persons), is a traumatic and costly outcome.

This book is intended as a standalone monograph, and it is illustrated by line drawings and numerous photographs culled from the authors' extensive and unique collections, together with tables, graphs, maps and other figures as appropriate, many reproduced from the original papers. Its primary goal is to educate current and future earth, environmental, planetary and engineering scientists actively working in glaciovolcanic terrains about the distinctive characteristics of glaciovolcanic eruptions, their products and landforms. Throughout the writing of this book our preferred modus operandi was to use the best-described examples of glaciovolcanic sequences available and to present the published and some unpublished information in a simplified manner to illustrate how those sequences may have formed and the varied processes involved. In every case, we urge readers to go back to the original referenced descriptions to glean all of the available information, some of which we will have omitted for space considerations and which may ultimately prove to be more important than our current understanding suggests. We also include a glossary of the sometimes difficult-to-understand glaciovolcanic and related terminology in current use

(often based on Native American and Icelandic terms unfamiliar to many scientists); abundant photographic illustration of the different constituent lithofacies; diagrammatic depiction of the eruptive and depositional processes; and evaluation of the distinctive sequence architectures and edifice morphometries. A special feature, available at www.cambridge.org/glaciovolcanism, is a series of expertly illustrated and annotated digital lectures that can be adapted or incorporated wholesale into existing university undergraduate and graduate teaching programmes. The inclusion of ready-made teaching materials is intended to substantially increase the outreach possibilities of the volume, to enhance the teaching of glaciovolcanism as a mainstream subject and considerably enlarge its profile in tertiary education worldwide. Currently, traditional curricula largely overlook glaciovolcanism. This is especially true in countries that lack the means to readily acquire and teach such knowledge, particularly in developing countries where many of the world's most dangerous glaciovolcanic systems occur.

Finally, the study of glaciovolcanism, like all scientific research, is like standing before a building facing a locked door. You unlock the first door and there is another, then another. The doors never end, *but you are further into the building.* This book is the key to the first few doors. What you do and where you go in the building after that is up to you. We wish you luck.

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