Eruptions that Shook the World

In April 2010 Eyjafjallajökull volcano on Iceland belched out an ash cloud that shut down much of Europe’s airspace for nearly a week. Although only a relatively small eruption, this precipitated the highest level of air travel disruption since the Second World War and it is estimated to have cost the airline industry worldwide over two billion US dollars.

But what does it take for a volcanic eruption to really shake the world? Did volcanic eruptions extinguish the dinosaurs? Did they help humans to evolve and conquer the world, only to decimate their populations with a super-eruption 73,000 years ago? Did they contribute to the ebb and flow of ancient empires, the French Revolution, and the rise of fascism in Europe in the nineteenth century? These are some of the claims made for volcanic cataclysm.

In this book, volcanologist Clive Oppenheimer explores rich geological, historical, archaeological and paleoenvironmental records (such as ice cores and tree rings) to tell the stories behind some of the greatest volcanic events of the past quarter of a billion years. He shows how a forensic approach to volcanology reveals the richness and complexity behind cause and effect, and argues that important lessons for future catastrophe risk management can be drawn from understanding events that took place even at the dawn of human origins.

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The largest volcanic salvo of the last century took place in a remote part of the Alaska Peninsula in 1912. The eruption of Mount Katmai expelled around 28 cubic kilometres (nearly seven cubic miles) of ash and pumice, projecting roughly two-thirds of it into the air and the remaining third as ground-hugging hurricanes of dust and rock. The only event to have come close to it in more recent times is the 1991 eruption of Mt Pinatubo in the Philippines. Had an eruption the size of Katmai’s 1912 outburst occurred in more densely populated regions of the ‘lower 48’ or, say, in Italy, Indonesia or the Caribbean, the event would be much better known outside of the volcanological coterie. In case you are wondering how to envisage 28 cubic kilometres of volcanic rock, it is sufficient to form a blanket seven centimetres thick (nearly three inches) over California, or 11 centimetres across the UK!

However, the Katmai eruption was a fairly trivial demonstration of volcanic fury viewed from either geological or human evolutionary perspectives. Around 7700 years ago, an eruption twice the size did strike the conterminous USA (in Oregon). Remarkably, the memory of the eruption, which formed the magnificent landform known as Crater Lake, lingers in the oral traditions of the Klamath native American tribe. Another eruption, more than twice as large again, struck the eastern Mediterranean only 3600 years ago. It may have had a devastating ‘slow-fuse’ impact on the Minoans, one of the great early civilisations. Stretching back 73,000 years ago, a volcanic cataclysm more than 200 times larger than Katmai’s blast left a hole up to 80 kilometres across, in northern Sumatra. Some claims suggest that the event almost exterminated our ancestors! These comparisons demonstrate why we need to examine the records of much larger historic and prehistoric eruptions, if we wish to anticipate the full spectrum of possible future volcanic activity. What is more,
the deep time perspective sheds light on the gamut of societal responses to volcanic disasters, again providing vital clues to assist preparation for future volcanic catastrophes. It also reveals the creative responses to both the resources and threats associated with volcanism, which have promoted positive developments in human society and culture.

Probing into Earth’s past environmental changes has always been a primary objective of geology but geologists today work increasingly alongside climatologists, palaeo-oceanographers, ice-core specialists, dendrochronologists, anthropologists and archaeologists to understand how climate change and natural disasters have shaped human origins, migrations, replacements and the growth of society and culture. A recurring theme is the quest to understand how abrupt changes in the environment influenced human behaviour. Why, for instance, did ancient societies abandon their territory or start to decline?

Theories to explain such issues display cycles of popularity and disdain. Catastrophism, environmental determinism and the narratives of ‘dark nature’ have long pedigrees rooted in philosophy, geography, evolutionary biology, religion and popular fiction. In the Western tradition, the Creation story and Noah’s battle with the Flood are especially significant. In the nineteenth century, however, catastrophism’s pre-eminence diminished as the geologists of the day began to view ‘the past as the key to the present’, arguing that natural processes acting over very long periods of time constructed mountain ranges, ocean basins, deserts and ice caps.

However, catastrophism has never truly gone out of fashion – a cursory look at the television schedules of natural history channels proves the point. Among the ‘documentaries’ on excruciating toxins, dirtiest jobs, weirdest sharks and deadliest asteroid impacts, shows on volcanoes surface frequently. Often, they portray worst-case scenarios, encouraged surely by the recurrent publication of academic papers reporting volcanic catastrophes, both ancient and anticipated (see table). A primary aim of this book is to examine the claims that volcanism shaped prehistoric and historic social trajectories. To do this, we need to look at how volcanoes act on a very large scale, and how often they do it. Lifespans of volcanoes are variable but can exceed a million years, far in excess of the time that the species Homo sapiens has lived on Earth. Even an individual volcano might exert an intermittent influence on human ecology, demography and migration.
Such enquiry into the record of past volcanism and its impact is not only of interest to understanding archaeology and ancient environmental change. In considering the full range of risks posed by future volcanic activity it is vital to recognise that volcanoes can unleash disasters of a scale not seen for generations. In the field of flood defence, for instance, neglecting the effects of the one-in-a-hundred-year event has led to very substantial losses. What are the chances of a ‘super-volcano’ such as Yellowstone in the USA producing another ‘super-eruption’ in the next decades, and what would its impacts be? Might global climate change actually trigger volcanic eruptions? Could artificial volcanoes be used to control climate change? As well as considering these questions, this book also delves into the deeper geological record to explore the links between volcanism and mass extinctions identified in the fossil record.

Chapter 1 sets the scene by reviewing the most pertinent concepts of volcanology. It reviews the kinds of volcanoes and eruptions that are capable of ‘shaking the world’ and how often they do it. Then, the broad structure of the book is as follows: Chapters 2 and 3 provide the necessary background for understanding how volcanoes can abruptly change the environment and impact human societies across a spectrum of spatial and temporal scales. Some hazards are obvious – a glowing pyroclastic current entering through the back door for instance – but others are more insidious and potentially far more pervasive. These include the cold summers experienced after certain large eruptions due to the associated emissions of chemically reactive gases into the atmosphere. These two chapters thus distinguish between the immediate (but lasting), local-to-regional scale impacts of an eruption, and the hemispheric- to global-scale repercussions of eruption-induced climate change. One rather common (and useful) element – sulphur – turns out to be behind some of the most extravagant and far-reaching claims for volcano catastrophism. Chapters 4 and 5 provide further preparatory reading by explaining how we can reconstruct past volcanic events, environments and human responses.

Chapters 6 through 13 supply the main case studies. They are arranged to provide a time travelling experience, embarking in the deep geological past (why did the dinosaurs perish?) and ending in the second decade of the nineteenth century, when the largest and deadliest known historic eruption (of a volcano in eastern Indonesia) apparently contributed to social unrest and outbreaks of epidemic disease in Europe. In between, I review cases of eruptions that had
major repercussions on human societies, reaching back to the first migrations of modern humans out of Africa, and the prehistory of Europe, Asia, Oceania and the Americas.

One reason for this progression through time is to aid reflection on lessons for the future. The final chapter builds from an understanding of the human ecology of natural disasters, and highlights key issues for managing volcanic catastrophe risks in the world to come. Human society might be more technologically advanced than it was a millennium ago but that does not in itself bring greater security in confronting potential environmental catastrophes. Indeed, the trivially sized Eyjafjallajökull eruption in Iceland in 2010 dramatically exposed some of the specific vulnerabilities of a globalised world.

I wrote this book because I became fascinated by the intersections of geology, climatology, ecology, archaeology and anthropology. In fact, it is this plexus of themes that makes volcanology such a great subject – just about anyone can get involved: mathematicians, physicists, architects, atmospheric scientists, civil protection managers, health professionals, risk analysts, engineers, archaeologists, oceanographers and planetary scientists, among others. This reflects the relevance of the subject to an equally wide range of academic, practical and vital issues and topics, including the origins of life, human evolution, climate change, food security, geothermal energy and worldwide aviation … It has been a challenge to synthesise such a diverse and complex field. I hope that, notwithstanding the errors and omissions I have surely made, and the inevitable revisions of hypotheses that will emerge in the light of forthcoming data and models, that at least the book will convey the excitement of volcanology, and help to stimulate further research that overruns traditional disciplinary boundaries. My overall message is that, beyond the attention-grabbing claims of volcano catastrophism, what we actually know is far more nuanced (and speculative) but much more interesting.

For the sake of the forests (and the cover price), referencing has been minimised but a thorough listing of (hyperlinked) sources, plus a selection of colour images from the book, can be found at http://www.geog.cam.ac.uk/research/projects/eruptions.
Notable eruptions and some of the more extreme claims made for their effects.

<table>
<thead>
<tr>
<th>Eruption(s) and date(s)</th>
<th>Magnitude ($M_0$)</th>
<th>Impact scale</th>
<th>Extreme claims</th>
<th>Chapter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siberian Traps, 250 million years ago</td>
<td>(11.9) 3 million km(^3) lava</td>
<td>Global</td>
<td>Mass extinction</td>
<td>6</td>
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<tr>
<td>Deccan Traps, 65.5 million years ago</td>
<td>(11.6) 1.5 million km(^3) lava</td>
<td>Global</td>
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<td>6</td>
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<tr>
<td>East African Rift Valley, repeated eruptions over last millions of years</td>
<td>7-8</td>
<td>Regional</td>
<td>Migrations of archaic and modern humans</td>
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<td>Toba, 73,000 years ago</td>
<td>8.8</td>
<td>Hemispheric-continental</td>
<td>Severe global climate change and near extinction of <em>Homo sapiens</em></td>
<td>8</td>
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<tr>
<td>Campanian Ignimbrite, 39,300 years ago</td>
<td>7.4-7.7</td>
<td>Continental-regional</td>
<td>Acceleration of the European Palaeolithic Transition, demise of the Neanderthals</td>
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<td>Mystery eruption, 17,000 years ago</td>
<td>?</td>
<td>Regional-local</td>
<td>Extinction of <em>Homo floresiensis</em> ('the Hobbit')</td>
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<td>Laacher See, 10,970 BCE</td>
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<td>Migration and cultural de-evolution of populations</td>
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<td>Kikai, c. 5480 BCE</td>
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<tr>
<td>Eruption(s) and date(s)</td>
<td>Magnitude (log)</td>
<td>Impact scale</td>
<td>Extreme claims</td>
<td>Chapter</td>
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<tr>
<td>Arenal, last thousands of years</td>
<td>~4</td>
<td>Local</td>
<td>Adaptation and continuity</td>
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<td>Popocatépetl, c. 50 CE</td>
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<td>6.9 (if Ilopango)</td>
<td>Hemispheric-regional</td>
<td>Justinian plague, fall of Teotihuacán</td>
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<tr>
<td>Mystery eruption, 1258 CE</td>
<td>?7/C1508</td>
<td>Hemispheric</td>
<td>Famine and pestilence in Europe, religious fervour</td>
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<tr>
<td>Laki, 1783-4</td>
<td>6.6</td>
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<td>Famine, heat wave, severe cold, flooding, air pollution, crop damage</td>
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<td>Tambora, 1815</td>
<td>6.9</td>
<td>Hemispheric</td>
<td>Famine, poor harvests, social unrest in Europe, rise of extremism and introduction of social reforms in Europe</td>
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<tr>
<td>Yellowstone, 2100</td>
<td>7.8</td>
<td>Global</td>
<td>Transfer of human civilisation to a safer place in the Solar System</td>
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1. Introduced in Chapter 1.
Acknowledgements

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