1-30-2023

# Looking backward and forward: volcanology in the years 2000, 2010, 2020, and beyond

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## Citation Details

Fink, J., Cashman, K., & Sigmundsson, F. (2023). Looking backward and forward: volcanology in the years 2000, 2010, 2020, and beyond. Bulletin of Volcanology, 85(2), 13.

Bulletin of Volcanology (2023) 85:13
https://doi.org/10.1007/s00445-022-01604-1

PERSPECTIVES

# Looking backward and forward: volcanology in the years 2000, 2010, 2020, and beyond

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Received: 2 August 2022 / Accepted: 14 August 2022


**Keywords** Volcanology · History of science · Volcanic eruptions · Volcanic processes · Hazards · Climate change

Figuring out how volcanoes work is one of the geoscience's most complex puzzles. Clues of all sizes, shapes, and colors are scattered across every continent, the bottom of the ocean, in the atmosphere, and on the surfaces of other planets. Generations of geologists, geophysicists, geodesists, and geochemists have used field observations, laboratory measurements, and theory to fill gaps left by their predecessors. Yet critical uncertainties remain. Why do eruptions begin? What determines their intensity? What controls their frequency and style of activity? What causes them to end? These unsolved issues leave society increasingly vulnerable to volcanic disruptions. Hundreds of published papers supplemented by dozens of review articles and compendia like the *Encyclopedia of Volcanology*[1] each offer a snapshot showing steps volcanologists have taken to piece together answers to these fundamental questions.

The essays in this new collection offer a complementary, more dynamic view of how volcano science has evolved over the past two decades, while also speculating on how it might advance in the years ahead. Each article places a subfield of volcanology along a timeline from 2000 to 2030 and looks at the lessons learned from the steady improvements of technology, coupled with the less predictable but often more consequential insights gained from the study of individual eruptions. Many of the authors also highlight how these observations fit into broader theoretical frameworks. The result is a unique, kaleidoscopic view of how a stream of disparate fragments can come together to form a more coherent picture of volcanic processes and impacts.

This project began with a multi-session symposium at the American Geophysical Union's Fall 2000 annual meeting, at which a dozen leading volcano scientists were challenged to forecast how each of their subdisciplines would change in the coming decade. In a follow-up session in 2010, many of these same individuals were invited to look back and report on the accuracy of their informed guesses. They and a new cohort were also asked to look ahead to 2020. A third AGU session in December 2020 extended the exercise out a decade further, combining original and new participants. Links to all 15 of the pre-recorded oral presentations from the 2020 AGU session, along with an introduction, 3-min summaries of each, and a discussion about volcanology and climate change can be found in Appendix A. In 2021, the *Bulletin of Volcanology* agreed to publish this set of articles in their "Perspectives" format, which was established to "provide roadmaps for future development, directions, and needs." Most of the entries in this collection include this evolutionary framing, looking both backward and forward across a timespan of more than a quarter century.

Most sciences advance through a combination of incremental improvements in technology, punctuated by conceptual breakthroughs and emerging societal imperatives. Perhaps singularly, volcanological understanding requires an additional component—the collective attention of the global community focused on signature eruptions. Thus, while new observational techniques ranging from satellite-based remote sensing to high-resolution GPS to seismic networks

[1] Sigurdsson, Haraldur, Bruce Houghton, Steve McNutt, Hazel Rymer, and John Stix, eds. *The encyclopedia of volcanoes*. Elsevier, 2015.

Editorial responsibility: A. Harris

This paper constitutes part of a topical collection: Looking Backwards and Forwards in Volcanology: A Collection of Perspectives on the Trajectory of a Science.

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Published online: 30 January 2023

to analytical tools and model capabilities have all had major impacts on our understanding of volcanoes, the truly transformative moments have come serendipitously from the study of specific eruptive events. These include the 1980 debris avalanche, pyroclastic surge, and dome growth at Mount St. Helens (Washington, USA); 1991's deadly combination of ashfall, mudflows, and climate-altering sulfur injection at Mount Pinatubo (Philippines); 2002's rapidly advancing ultramafic lava flow from Mount Nyiragongo into the city of Goma (Democratic Republic of Congo); Eyjafallajökull's major disruption of North Atlantic air travel in 2010; and the unprecedented explosivity of the Hunga Tonga-Hunga Ha'apai (Tonga) eruption in 2022 (Fig. 1). These eruptions are not necessarily the largest—what matters is that their intense study from multiple vantage points reveals new physical processes and/or societal responses. What they also share is that the insights they provide could not have been anticipated.

The pieces in this set combine these predictable and unexpected elements under four broad headings: (1) components of volcano-magmatic systems, (2) methods of monitoring, (3) scales of observation and collaboration, and (4) societal interactions with volcanoes.

Topics related to fundamental aspects of magmatic systems range from the structure of subvolcanic systems to controls on eruptive processes. Importantly, all illustrate ways in which field observations can be combined with new analytical techniques. These include high-resolution compositional measurements and increased accuracy of morphologic analysis in both two and three dimensions, improved experimental approaches and increased modeling capacity to improve understanding of conditions in upper crustal magma reservoirs, eruption triggers, and controls on eruption style, particularly magma fragmentation.

The articles on monitoring methods and characteristics are the most dependent on technological innovations and in many ways were the easiest topics to predict. Traditional seismic monitoring, now extended by broadband instruments and ultrasound, can be used to track magma migration, ascent, and eruption. Satellite-based remote sensing allows global monitoring of volcano deformation, thermal signals, and gas

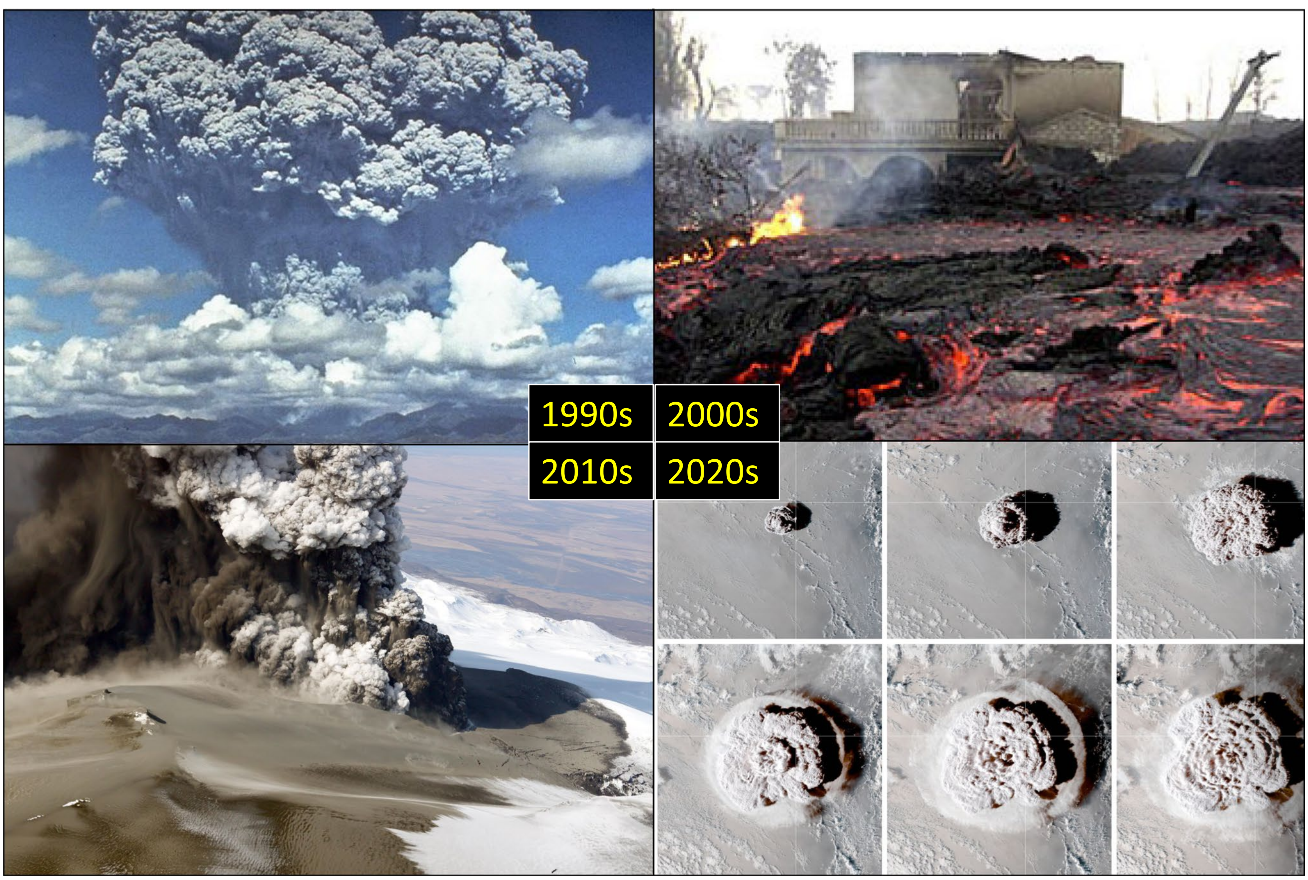


**Fig. 1** Images of eruptions that taught important lessons to the field of volcanology in each of the past four decades: Pinatubo, Philippines (1991) [credit USGS]; Nyiragongo, Democratic Republic of Congo (2002) [AP]; Eyjafjallajökull, Iceland (2010) [Magnus Tumi Gudmundsson]; and Hunga Tonga-Hunga Ha'apai, Tonga (2022) [NASA]

emissions, raising the possibility of identifying awakening volcanic systems years to decades in advance of eruptive activity.

In its early days, volcanology was dominated by men and women who could spend decades mapping and monitoring individual volcanoes. Others surveyed the world's active volcanic fields to find and test examples of physical and chemical processes. Still others, mostly in remote areas of developing countries, set up and ran volcano observatories. With the emergence of information technologies and the cheapening of international air travel in the 1990s, volcanology became more collaborative, making it possible for large global teams of scientists to work together. Several articles in this collection document the quickening of these trends and the shifting of methodologies. Scientifically, challenges include coordination and funding for large international projects, management of massive and diverse datasets, as well as the goal of better aligning the demographics of the volcanological workforce with the makeup of the communities it serves.

All studies of volcanoes are ultimately motivated by the need to monitor and mitigate the dangers these systems pose to society. The scale of risks can vary greatly, from the local impacts of explosive and effusive eruptions to global interactions between volcanoes and climate. Increasingly, volcanologists are also recognizing that the simultaneous occurrence of climate-related disasters like typhoons, floods, and wildfires with eruptive activity will require new multi-agency response strategies and more interdisciplinary training.

This collection seeks to illustrate how volcanology is responding to combinations of predictable and unexpected natural, technological, and societal phenomena. Hopefully, it can serve as a model for how other sciences can track their own development and improve their forecasting ability. These papers also lay the groundwork for assessing how volcano science will continue to advance in the 2020s and beyond. Interested readers should consider participating in the next iteration, in fall, 2030.

**Supplementary Information** The online version contains supplementary material available at https://doi.org/10.1007/s00445-022-01604-1.

**Acknowledgements** Thanks to Brooks Hanson and his publications team from AGU for access to the video recordings of presentations from the 2020 Fall AGU session.