COMMENTARY

The sun of Rome is set! Volcanic dust veils and their political fallout

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Within a year of the slaying of Julius Caesar, Okmok volcano in the Aleutian Islands (Fig. 1) begat one of the greatest eruptions of the past 2,500 y, according to research in PNAS (1). The study explores the repercussions of climatic change induced by the eruption for the unstable Roman Republic.

Since the 1991 eruption of Mt. Pinatubo, large eruptions have been widely recognized as a leading driver of natural climate variability (2–4). Their study has also revealed many insights into the nature of magmatic processes of the Earth's interior. However, lately, a renewed research focus on major volcanic episodes has been motivated by passion for world history.

One of the first scientists to delve deep into this topic was the British meteorologist Hubert Lamb. In a landmark paper published in 1970, he formulated the dust veil index (DVI) to characterize the climate-forcing potential of volcanic eruptions, and compared his multicentennial time series of DVI values against climate proxies (5). What particularly interested Lamb were the influences of climatic change on societal trajectories, and his research laid the modern foundations of historical climatology (6). The importance of his work was quickly recognized by climate scientists, such as Stephen Schneider, who used the DVI in models to investigate the scale of climatic influence due to volcanism (7).

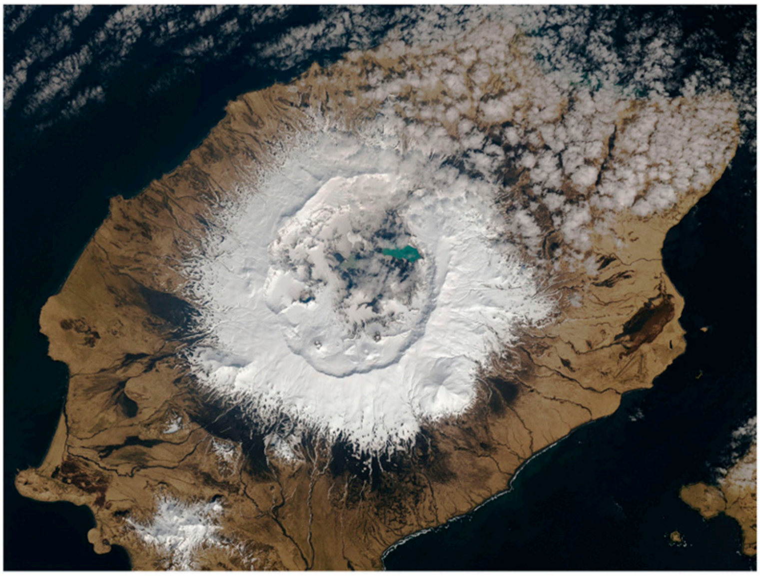

Fig. 1. The 10-km-diameter caldera of Okmok volcano dominates the northeastern end of Umnak Island in the Aleutian archipelago. It was formed partly by a paroxysmal eruption now dated to early 43 BCE. Okmok's last eruption was an explosive affair in 2008. Image credit: NASA Earth Observatory/Joshua Stevens, using Landsat data from the US Geological Survey.

In 1977, the economic historian John Post combined these themes of volcanism changing climate, and climatic change impacting society, in a compelling book with the provocative title *The Last Great Subsistence Crisis in the Western World* (8). In it, Post argued that the "The Year without a Summer" that followed the 1815 eruption of Tambora, conspired with the devastating economic legacy of the Napoleonic Wars to usher in a period of profound social, demographic, and political change.

Oddly perhaps, up until this point in time, volcanologists' own efforts to understand the record of global volcanism were largely confined to a coordinated program of cataloging the active volcanoes of the world. Between 1951 and 1980, more than 20 volumes were published. Worthy as they are, they do not make for light reading. However, renewed curiosity concerning past volcanism was provoked in the early 1980s, when it emerged that an extraordinary archive of information on past global volcanism lies locked in the polar ice sheets (9).

The signature of volcanism in the ice cores derives primarily from the deposition of volcanic sulfate aerosol that forms and disperses in the atmosphere in the days, weeks, and months following an eruption. Although a minor constituent of magmas, sulfur is the main protagonist in the climate change brought about by larger eruptions. Leaving the vent as a gas

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Author contributions: C.O. wrote the paper.

The author declares no competing interest.

See companion article, "Extreme climate after massive eruption of Alaska's Okmok volcano in 43 BCE and effects on the late Roman Republic and Ptolemaic Kingdom," 10.1073/pnas.2002722117.

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www.pnas.org/cgi/doi/10.1073/pnas.2011054117

(e.g., sulfur dioxide), it is transformed over time in the atmosphere into submicron-sized particles. Depending on the volcano's location and the eruption's season, intensity, and sulfur yield, this aerosol can spread widely in the stratosphere, potentially veiling the entire planet and cooling the Earth's surface for several years. The stratospheric haze also causes spectacular sunsets (that some recognize in works of J. M. W. Turner, Caspar David Friedrich, and other artists, painted after the Tambora eruption). A fraction of the dust may deposit across the polar regions forming layers with elevated sulfur concentrations. Were it not for this process, our knowledge of the timing and climatic effects of past eruptions would be very limited.

The sulfur alone cannot identify the source volcano, but sometimes it is accompanied by accumulations of volcanic ash particles. These grains can be analyzed geochemically, enabling, in some cases, correlation with the source volcano; this potential was recognized in the late 1970s (10). However, to push inquiry into the climatic impacts of volcanism further back in time than the instrumental era of meteorology, improved proxy records with absolute chronological fidelity were needed. This need was met thanks to tree ring studies, with their application to understanding volcanic forcing of climate progressively recognized from the 1980s (11, 12).

Over the past decade, these diverse techniques have been applied in concert, increasingly in collaboration with historians, to investigate the entangled biographies of volcanoes and humankind (13–15). Climate proxies and chronological accuracy have improved (16, 17), and isotopic analysis of the volcanic sulfur fallout in ice cores (18) has been shown to discriminate between tropospheric and stratospheric transport of the volcanic aerosol. This is significant since stratospheric aerosol veils are, in general, more likely to perturb climate at the large scale. The work by McConnell et al. (1) applies all of these tools to probe the volcano–climate–society connection, but in an astonishingly ancient context—the Mediterranean world in the immediate aftermath of the assassination of Julius Caesar in 44 BCE.

That some unusual volcanic activity had occurred at this time was first suggested by Dick Stothers and Mike Rampino nearly 40 y ago (19). Drawing on Plutarch and other sources, they highlighted evidence for a stratospheric aerosol veil in the year following Caesar's murder:

> ...among events of divine ordering, there was the ... obscuration of the sun's rays. For during all that year its orb rose pale and without radiance, while the heat that came down from it was slight and ineffectual, so that the air in its circulation was dark and heavy owing to the feebleness of the warmth that penetrated it, and the fruits, imperfect and half ripe, withered away and shrivelled up on account of the coldness of the atmosphere. (Plutarch, *Caesar*, 69)

In this light (or rather the lack of it), Titinius's tribute to Cassius (after his death in 42 BCE) in Shakespeare's *Julius Caesar*, "The sun of Rome is set!" takes on both metaphorical and literal meaning. Stothers and Rampino suspected Mount Etna as source of the aerosol veil but did not rule out a much more distant origin, including Alaska. More recently, a tropical source had been proposed (16). However, now that Okmok volcano has been singled out with a high degree of confidence, the age of its last caldera-forming eruption (known as Okmok II), previously constrained by radiocarbon estimates, snaps into a precise focus.

McConnell et al. invite a fresh look at the history of the ancient Mediterranean world and make an important contribution to the growing field of environmental history.

The caldera itself is around 10 km across and dominates the northeast end of Umnak Island, in the center of the Aleutians at a latitude of 53°N (Fig. 1). The pumice and ash deposits have been studied on the volcano and on a neighboring island, yielding a picture of what the eruption was like (20). It began with a Plinian-style sustained explosion, but by far the most voluminous phase followed, after some hiatus, with caldera formation as the summit of the volcano subsided and generation of pyroclastic currents that descended the flanks of the volcano to the sea. The deposits are up to 50- to 100-m thick on Umnak Island. In total, some 30 km^3 of magma were expelled, comparable to the magnitude of the 1815 eruption of Tambora. The ice core signal suggests an eruption early in the year (1), whereas the first deposits on Umnak Island appear to have fallen on mostly snow-free ground (20), suggestive of a summer/fall discharge. However, the interlude between the two phases of the eruption could be several months, and it is the second, much larger episode for which the pumice deposits on the island and the glassy ash grains in the Greenland ice cores show a geochemical match.

While it used to be considered that eruptions outside of the tropics have more limited impacts on large-scale climate, recent computational modeling has revised this view (21). With the 43 BCE eruption source now pinpointed, and sulfur isotopic evidence pointing to stratospheric transport of aerosol (1), the sulfur mass loading of the stratosphere due to Okmok II can be better constrained, improving the parameterization of climate simulations. This increases the robustness of model outputs and makes it more meaningful to evaluate them in the light of available written sources and tree ring-based climate records. In so doing, McConnell et al. (1) invite a fresh look at the history of the ancient Mediterranean world and make an important contribution to the growing field of environmental history. Indeed, one measure of the impact of the study may be the extent to which it influences those historians hitherto less inclined to recognize a role for nature in their theories and narratives.

This work, too, reminds us that very large eruptions can have substantial repercussions for complex societies on the other side of the world. At a time where civil preparedness for low-probability/high-consequence global risks is thrown into the spotlight, it is worth remembering there are other kinds of threat that, too, might one day wreak worldwide havoc. Interdisciplinary research such as the study of McConnell et al. (1) is not only fascinating for its insights into human history, it carries a message for our future.

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1 J. R. McConnell *et al.*, Extreme climate after massive eruption of Alaska's Okmok volcano in 43 BCE and effects on the late Roman Republic and Ptolemaic Kingdom **117**, 15443–15449 (2020).

2 M. P. McCormick, L. W. Thomason, C. R. Trepte, Atmospheric effects of the Mt Pinatubo eruption. *Nature* **373**, 399–404 (1995).

3 P. Minnis *et al.*, Radiative climate forcing by the Mount Pinatubo eruption. *Science* **259**, 1411–1415 (1993).

4 J. Hansen, A. Lacis, R. Ruedy, M. Sato, Potential climate impact of Mount Pinatubo eruption. *Geophys. Res. Lett.* **19**, 215–218 (1992).

5 H. H. Lamb, Volcanic dust in the atmosphere; with a chronology and assessment of its meteorological significance. *Philos. Trans. R. Soc. Lond. A* **266**, 425–533 (1970).

6 H. H. Lamb, *Climate, History and the Modern World* (Routledge, 1982).
7 S. H. Schneider, C. Mass, Volcanic dust, sunspots, and temperature trends. *Science* **190**, 741–746 (1975).
8 J. D. Post, *The Last Great Subsistence Crisis in the Western World* (Johns Hopkins University Press, Baltimore, MD, 1977).
9 C. U. Hammer, H. B. Clausen, W. Dansgaard, Greenland ice sheet evidence of post-glacial volcanism and its climatic impact. *Nature* **288**, 230–235 (1980).
10 P. R. Kyle, P. A. Jezek, Compositions of three tephra layers from the Byrd Station ice core, Antarctica. *J. Volcanol. Geotherm. Res.* **4**, 225–232 (1978).
11 V. C. LaMarche, K. K. Hirschboeck, Frost rings in trees as records of major volcanic eruptions. *Nature* **307**, 121–126 (1984).
12 M. G. Baillie, M. A. Munro, Irish tree rings, Santorini and volcanic dust veils. *Nature* **332**, 344–346 (1988).
13 U. Büntgen *et al.*, Cooling and societal change during the Late Antique Little Ice Age from 536 to around 660 AD. *Nat. Geosci.* **9**, 231–236 (2016).
14 C. Oppenheimer *et al.*, The Eldgjá eruption: Timing, long-range impacts and influence on the Christianisation of Iceland. *Clim. Change* **147**, 369–381 (2018).
15 S. Guillet, C. Corona, F. Ludlow, C. Oppenheimer, M. Stoffel, Climatic and societal impacts of a "forgotten" cluster of volcanic eruptions in 1108–1110 CE. *Sci. Rep.* **10**, 6715 (2020).
16 M. Sigl *et al.*, Timing and climate forcing of volcanic eruptions for the past 2,500 years. *Nature* **523**, 543–549 (2015).
17 M. Stoffel *et al.*, Estimates of volcanic-induced cooling in the Northern Hemisphere over the past 1,500 years. *Nat. Geosci.* **8**, 784–788 (2015).
18 A. Burke *et al.*, Stratospheric eruptions from tropical and extra-tropical volcanoes constrained using high-resolution sulfur isotopes in ice cores. *Earth Planet. Sci. Lett.* **521**, 113–119 (2019).
19 R. B. Stothers, M. R. Rampino, Volcanic eruptions in the Mediterranean before AD 630 from written and archaeological sources. *J. Geophys. Res. Solid Earth* **88** (B8), 6357–6371 (1983).
20 A. Burgisser, Physical volcanology of the 2,050 BP caldera-forming eruption of Okmok volcano, Alaska. *Bull. Volcanol.* **67**, 497–525 (2005).
21 M. Toohey *et al.*, Disproportionately strong climate forcing from extratropical explosive volcanic eruptions. *Nat. Geosci.* **12**, 100–107 (2019).