LETTER

REPLY TO STRUNZ AND BRAECKEL:

Agricultural failures logically link historical events to extreme climate following the 43 BCE Okmok eruption

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We report (1) ice core evidence that unambiguously identifies massive sulfur fallout over much of the Arctic, attributed using tephra geochemistry to eruption of Alaska's Okmok volcano, with climate model simulations indicating 2 y of extreme temperatures and precipitation throughout the Northern Hemisphere starting in early 43 BCE. This climate event occurred in the waning years of the Roman Republic and Ptolemaic Kingdom during a period of well-known social, political, and economic stress including food shortages, epidemic disease, and unusually inclement weather reported in ancient sources (Fig. 1). We contend that such a climate anomaly—corroborated by paleoclimate proxies—undoubtedly contributed to historical events primarily through disruptions in food production in the Mediterranean region. Without offering any specific criticisms or substantive alternatives, Strunz and Braeckel (2) disagree with our contention.

First, they assert that unusual natural phenomena in ancient sources such as comets or darkening of the sun need not be based on actual events. While we note it has become fashionable to dismiss such events as tropes, we agree that separating facts from fabrications reported in the ancient sources is difficult (1). This does not preclude drawing some reliable conclusions, however, and it is plausible that signs and portents reported by ancient sources, such as the atmospheric phenomena surrounding the death of Caesar, are based on actual events. Strunz's and Braeckel's critique only has merit if it offers an alternative hypothesis as to why so many authors report severe atmospheric, climatic, and societal phenomena consistent with the aftermath of documented eruptions in 44 and 43 BCE of Etna and Okmok, respectively, while such a density of reports is conspicuously absent for other years covered by and between the same authors.

Second, Strunz and Braeckel (2) assert that "a detailed analysis of integrated socioenvironmental mechanisms would be indispensable to overcome 'black-box determinism,'" concluding that "a superficial correlation between climatic and social events cannot substantiate the purported effects." While delineating integrated socioenvironmental mechanisms clearly is desirable, quantifying such mechanisms and feedbacks is difficult over such a distance of time and based on such thin ancient sources, leading us to caution against trying to establish direct causal linkages between the climate effects of the 43 BCE Okmok eruption and historical events (1). Rather than black-box determinism, however, we suggest an obvious yet fundamental and far-reaching mechanism linking the historical events reported in the ancient sources to the aftermath of the Okmok eruption: extreme climate and disruptions to food production in vulnerable, largely agrarian societies. Drawing such linkages is possible only because of the accurately dated, high-depth-resolution ice-core measurements and attribution to Okmok we report that tightly constrain physically based climate model simulations. It is only logical to conclude that such an extreme climate event—including the second- and eighth-coldest years of the past 2,500 y at the start of the fourth-coldest decade—had a significant effect on food production and society during this already tumultuous, critical juncture of antiquity (Fig. 1), just as it would even on today's highly mechanized agricultural system.

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The authors declare no competing interest.

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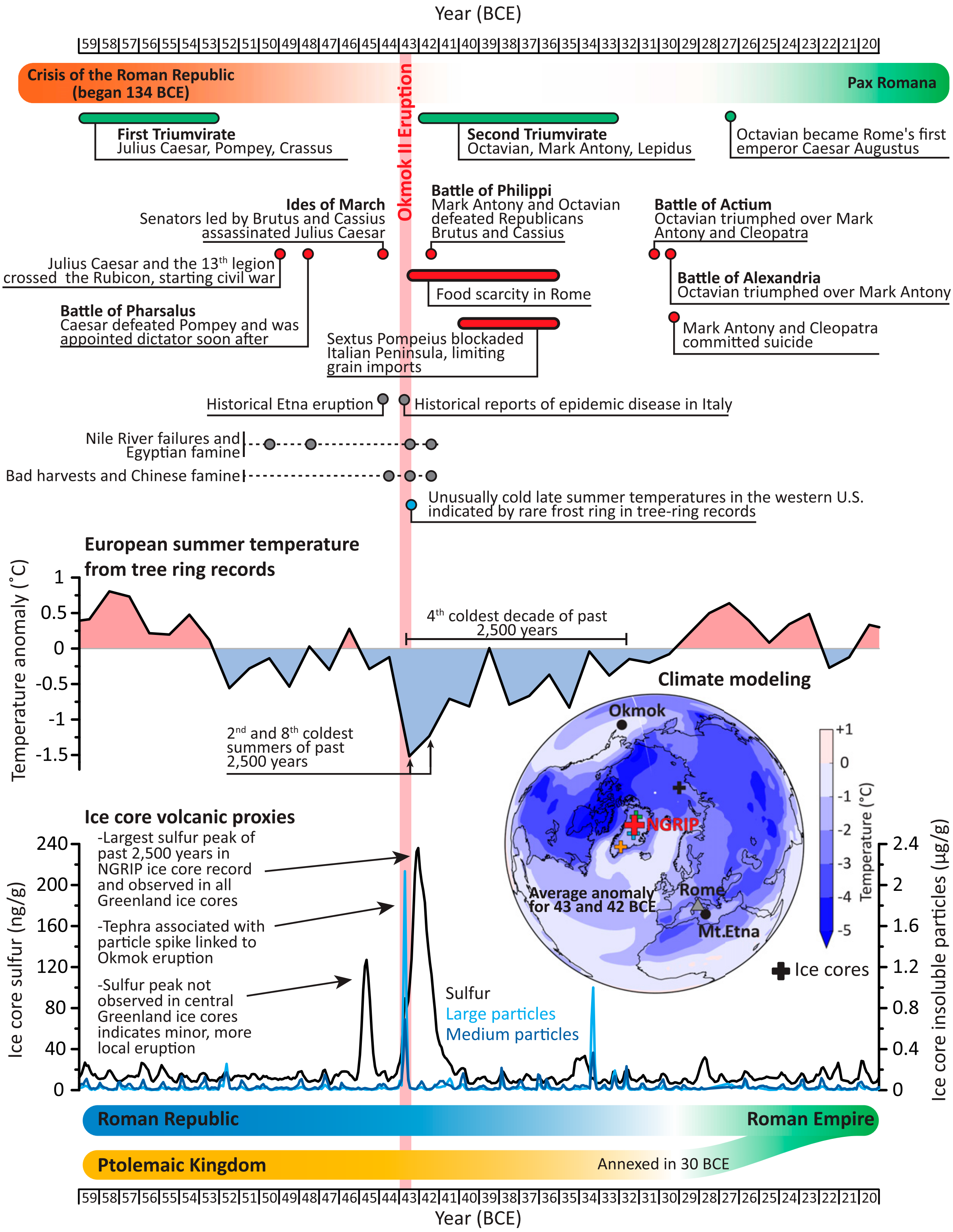

Fig. 1. **Timeline summarizing the timing, duration, and climate effects of the unknown 45 BCE and Okmok 43 BCE eruptions relative to historical and other events during the waning days of the Roman Republic and Ptolemaic Kingdom (after ref. 1). European summer temperatures are taken from ref. 3.**

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. *Proc. Natl. Acad. Sci. U.S.A.* **117**, 15443–15449 (2020).

2 S. Strunz, O. Braeckel, Did volcano eruptions alter the trajectories of the Roman Republic and the Ptolemaic Kingdom? Moving beyond black-box determinism. *Proc. Natl. Acad. Sci. U.S.A.* **117**, 32207–32208 (2020).

3 J. Luterbacher *et al.*, European summer temperatures since Roman times. *Environ. Res. Lett.* **11**, 24001 (2016).