American Mineralogist, Volume 103, pages 952–965, 2018

Ascent rates of rhyolitic magma at the onset of three caldera-forming eruptions

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Abstract

Important clues to the initiation and early behavior of large (super-) eruptions lie in the records of degassing during magma ascent. Here we investigate the timescales of magma ascent for three rhyolitic supereruptions that show field evidence for contrasting behavior at eruption onset: (1) 650 km^3, 0.767 Ma Bishop Tuff, Long Valley; (2) 530 km^3, 25.4 ka Oruanui eruption, Taupo; and (3) 2500 km^3, 2.08 Ma Huckleberry Ridge Tuff, Yellowstone. During magma ascent, decompression causes volatile exsolution from the host melt into bubbles, leading to H_2O and CO_2 gradients in quartz-hosted re-entrants (REs; unsealed inclusions). These gradients are modeled to estimate ascent rates. We present best-fit modeled ascent rates for H_2O and CO_2 profiles for REs in early-erupted fall deposits from Bishop ($n = 13$), Oruanui ($n = 9$), and Huckleberry Ridge ($n = 9$). Using a Matlab script that includes an error minimization function, Bishop REs yield ascent rates of 0.6–13 m/s, overlapping with and extending beyond those of the Huckleberry Ridge (0.3–4.0 m/s). Re-entrants in Oruanui quartz crystals from the first two eruptive phases (of 10) yield the slowest ascent rates determined in this study (0.06–0.48 m/s), whereas those from phase three, which has clear field evidence for a marked increase in eruption intensity, are uniformly higher (1.4–2.6 m/s).

For all three eruptions, the interiors of most REs appear to have re-equilibrated to lower H_2O and CO_2 concentrations when compared to co-erupted, enclosed melt inclusions in quartz. Such reequilibration implies the presence of an initial period of slower ascent, likely resulting from movement of magma from storage into a developing conduit system, prior to the faster (<1–2.5 h) final ascent of magma to the surface. This slower initial movement represents hours to several days of reequilibration, invalidating any assumption of constant decompression conditions from the storage region. However, the number of REs with deeper starting depths increases with stratigraphic height in all three deposits (particularly the Bishop Tuff), suggesting progressive elimination of the deep, sluggish ascent stage over time, which we interpret to be the result of maturing of the conduit system(s). Our results agree well with ascent rates estimated using theoretical approximations and numerical modeling for plinian rhyolitic eruptions (0.7–30 m/s), but overlap more with the slower estimates.

Keywords: Ascent rate, supereruption, diffusion modelling, conduit processes, re-entrants