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 km3, 0.767 Ma Bishop Tuff, Long Valley; (2) 530 km3, 25.4 ka Oruanui eruption, Taupo; and (3) 2500 km3, 2.08 Ma Huckleberry Ridge Tuff, Yellowstone. During magma ascent, decompression causes volatile exsolution from the host melt into bubbles, leading to H2O and CO2 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 H2O and CO2 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 H2O and CO2 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

INTRODUCTION

Magma ascent rates

The rate at which magma ascends has a strong influence on the manner in which it (eventually) erupts. Slower ascent allows degassing of volatiles from the magma, favoring a more effusive eruption, whereas fast decompression fosters volatile retention and consequently results in more explosive behavior (Eichelberger et al. 1986; Mangan and Sisson 2000; Cashman 2004; Castro and Gardner 2008). Determining the rates at which magma ascends, and how those rates evolve over the course of an eruption, is thus important for understanding eruptive activity and improving monitoring and response for specific volcanoes (Dingwell 1996). Furthermore, the ability to determine ascent rates through the use of erupted materials permits reconstruction of the progression of activity from individual eruptions, including historic events.

Ascent rates have been estimated using experimentally determined rates of breakdown rim formation on hydrous phases, the growth of microlites in matrix melt, and bubble number densities (see review in Rutherford 2008). However, many of these methods are best applied to slower magma ascent rates, hotter systems with lower silica contents, or are heavily influenced by processes in specific regions of the conduit system (e.g., bubbles nucleating around the fragmentation front; Toramaru 2006; Rotella et al. 2014). For large explosive rhyolitic eruptions, ascent timescales are often so short that they remain difficult to constrain with petrological tools. As a result, many studies have used analytical and numerical conduit models to constrain values (5–30 m/s: see reviews by Rutherford 2008; Gonnermann and Manga 2013), or used estimates based on the diffusion rate of H2O into bubbles (0.7–5 m/s; summarized in Rutherford 2008). Thus, our ability to determine magma ascent rates for explosive rhyolitic eruptions requires the application of a speedometer that can record short timescales and be quenched rapidly after fragmentation.