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Quantifying magma ascent rates for explosive and effusive eruptions

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Magma ascent rate can control the explosivity and hazard potential of a given eruption but is notoriously difficult to directly determine from erupted samples or geophysical datasets. Here we investigate the timescales of magma ascent and associated magma ascent rates of the three most recent eruptions of Kelud volcano (Indonesia), which alternate between explosive (1990), effusive (2007), and explosive (2014). Despite the variety of eruptive styles, previous work shows that the magmas that led to these eruptions were originally stored at very similar conditions of depth, temperature, and volatile contents in the melt, although the explosive events contained an exsolved volatile phase (Utami et al., 2021 and 2022). We constrained magma ascent times by investigating the compositions and textures of apatite crystals and combined these data with the Aptimer diffusion model (Li et al. 2020). We found that apatite crystals from the explosive eruptions in 1990 and 2014 are unzoned in volatile elements, whereas those from the 2007 dome are reversely zoned in chlorine and/or fluorine. Diffusion modelling of these elements in zoned apatite of the 2007 dome give magma ascent times of up to 250 days, which overlap with the period of seismic unrest. In contrast, the inferred maximum magma ascent, and degassing times from apatite from the 1990 and 2014 are much shorter, on the order of < 2 days. Using the magma storage depth derived from the calculated pre-eruptive pressure, we determine that these timescales correspond to ascent rates of about 50 to 0.3 x 10-3 m s-1 for the 2007 dome event, and >0.1 m s-1 for the 1990 and 2014 explosive eruptions. These magma ascent rates correspond well with independent estimates from magma discharge rates for the three eruptions (Maeno et al. 2019), and thus validate the apatite zoning models to derive reliable magma ascent times. Our study also highlights the important role of magma ascent on eruptive styles, which for the case of the Kelud eruptions we have studied includes the role of an exsolved volatile phase in the magma ascent and explosivity.