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Time-series experiments of pyroxene crystal nucleation and growth in basaltic magmas and implications for magma rheology

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Basaltic volcanism is strongly influenced by magmatic viscosity, which, in turn, is controlled by magma composition, crystallisation, oxygen fugacity and vesiculation. We developed an environmental cell to replicate the pressure and temperature during magma ascent from crustal storage to the surface, while capturing crystallisation using in-situ 4D X-ray computed microtomography. Crystallisation experiments were performed at Diamond Light Source, using monochromatic 53 keV X-rays, a pixel size of 3.2 µm, a sample to detector distance of 2000 mm, 1440 projections per 180 deg, an acquisition time of 0.04 s, and a rotation velocity of 3.125 deg.s-1. The redox conditions were controlled using an oxidised nickel disk for each experiment. Our starting materials were samples made of crystal-free glass cylinders (Ø 3 mm) from the 2001 Etna eruption with 0.9 and 0.8 wt. % water content. In the experiments, samples and crucibles were sealed initially by applying ~10 N loads. All samples were then heated up above glass transition (between 800 °C and 900 °C) in order to allow sample homogenisation while preventing volatiles exsolution. We then pressurised each sample by applying uniaxial loads (between 80 and 380 N), using high-degree alumina pistons, in order to generate enough internal pressure to maintain bubble-free samples when the desired high temperature was reached. Once at the initial high temperature, we began experiments via dropping the temperature to different target isothermal (from 1210 to 1130 °C or 1180 to 1110 °C) and isobaric conditions (8 and 10 MPa, respectively). For the whole duration of the experiments, we were able to observe directly and record pyroxene crystal nucleation and growth. Specifically, we were able to observe pyroxene nucleation on bubbles at small undercooling (ΔT) and epitaxial growth of pyroxene at large ΔT. An increase of ΔT (up to 50 °C) can be associated with a decompression of a magma chamber or a decompression during magma ascent in the conduit. As ΔT = 30 - 50 °C can be reached in most of the basaltic volcanic systems on Earth, our results provide a feasible explanation of which mechanisms control nucleation and growth of pyroxene crystals in hydrous basaltic magmas. In addition, epitaxial

growth promotes a faster increase of the crystal volume. As a larger crystal content translates into a higher viscosity, our results have important implications for magma rheology, and are extremely important to improve our understanding of magma ascent dynamics during volcanic eruptions, and our capacity to predict eruptions and mitigate volcanic hazards.