Crystallisation in basaltic magmas revealed via in situ 4D synchrotron X-ray microtomography and implications for lava flows

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Magma crystallisation is a fundamental process driving eruptions and controlling the style of volcanic activity. Crystal nucleation delay, heterogeneous and homogeneous nucleation and crystal growth are all time-dependent processes, however, there is a paucity of real-time experimental data on crystal nucleation and growth kinetics, particularly at the beginning of crystallisation when conditions are far from equilibrium. In this study, we reveal the first in situ 3D time-dependent observations of crystal nucleation and growth kinetics in a natural magma, reproducing the crystallisation occurring in real-time during a lava flow, by combining a bespoke high-temperature environmental cell with fast synchrotron X-ray microtomography. We find that both crystal nucleation and growth occur in pulses, with the first crystallisation wave producing a relatively low volume fraction of crystals and hence negligible influence on magma viscosity. This result explains why some lava flows cover kilometres in a few hours from eruption inception, highlighting the hazard posed by fast-moving lava flows. We use our observations to quantify disequilibrium crystallisation in basaltic magmas using an empirical model. Our results demonstrate the potential of in situ 3D time-dependent experiments and have fundamental implications for the rheological evolution of basaltic lava flows, aiding flow modelling, eruption forecasting and hazard management.