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In situ 4D dendritic crystallization in basaltic magmas reveals how magma mobility occurs within the Earth's crust

FABIO ARZILLI[1], MARGHERITA POLACCI[2], GIUSEPPE LA SPINA[3], NOLWENN LE GALL[4], EDWARD W LLEWELLIN[5], RICHARD A BROOKER[6], RAFAEL TORRES-OROZCO[7], DANILO DI GENOVA[8], DAVID NEAVE[2], MARGARET HARTLEY[2], HEIDY M MADER[6], DANIELE GIORDANO[9], ROBERT ATWOOD[10], PETER D LEE[4], FLORIAN HEIDELBACH[8] AND MIKE R BURTON[2]

[1]University of Camerino
[2]University of Manchester
[3]Istituto Nazionale di Geofisica e Vulcanologia-Osservatorio Etneo
[4]University College London
[5]Durham University
[6]University of Bristol
[7]Universidad Veracruzana
[8]University of Bayreuth
[9]University of Torino
[10]Diamond Light Source

Presenting Author: arzilli.fabio@gmail.com

The mobility of basaltic magma within the Earth's crust is controlled by magma viscosity. Crystallization and crystal morphology affect the viscosity, mobility and ultimately eruptibility of magma, by locking it at depth or enabling its ascent towards the surface. However, relationships between crystallinity, rheology and eruptibility remain uncertain because of the challenges associated with documenting magma crystallization in real time. Here we show, for the first time, the results of in situ 3D time-dependent, high temperature experiments performed under water-saturated conditions to investigate crystallization kinetics in a basaltic magma at crustal pressure. In situ four-dimension (4D) (3D plus time) crystallization experiments were performed using synchrotron X-ray microtomography. This new 4D approach provides unique quantitative information on the growth kinetics and textural evolution of pyroxene crystallization in basaltic magmas, quantifying dendritic growth on initially euhedral cores and revealing surprisingly rapid increases in crystal fraction and aspect ratio at undercoolings ≥30 °C. Such crystallization favours a rheological transition from Newtonian to non-Newtonian behaviour within minutes. We applied a numerical model to quantify the effect of dendritic crystallization on basaltic dike propagation towards the surface. Modelling results show that dendritic crystallization can strongly affect magma rheology during magma ascent with important implications for the mobility of basaltic magmas within the crust.