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Cyclic activity at silicic volcanoes: A response to dynamic permeability variations

Anthony Lamur (1), Yan Lavallée (1), Jackie Kendrick (1), Gudjon Eggertsson (1), James Ashworth (2), and Richard Wall (1)

(1) Department of Environmental sciences, University of Liverpool, Liverpool, United Kingdom (anlamur@liv.ac.uk), (2) Department of Earth and Environmental sciences, Ludwig Maximillian University, Munich, Germany

Silicic volcanoes exhibit cyclic eruptive activity characterised by effusive (dome growth) to quiescent periods punctuated by short explosive episodes. The latter, characterised by fast emissions of gas and ash into the atmosphere, results from stress release through fracturing and causes significant hazards to the surrounding environment. Understanding the formation, development and closure of fractures as well as their impact on the volcanic system is hence vital for better constraining current models.

Here, we present the results of two sets of experiments designed to understand first, the development of permeability through fracturing and second, the timescale over which these fractures can persist in magmas.

To characterise the influence of a macro-fracture, the permeability of intact volcanic rocks with a wide porosity range (1-41%) was measured at varying effective pressures (-0.001-30 MPa). We then fractured each sample using the Brazilian disc method to induce a tensile macro-fracture, before measuring the permeability under the same conditions. While our results for intact samples are consistent with previous studies, the results for fractured samples display a distinct permeability-porosity relationship. We show that low porosity samples (<18%) suffer a net increase in permeability of up to 4 orders of magnitude upon fracturing, compared to high porosity samples (>18%) that show a less than 1 order of magnitude increase. This suggests that a macro-fracture has the ability to efficiently localise the flow in low porosity rocks by becoming the prevailing structure in a previously micro-fracture-dominated porous network, whereas at higher porosities fluid flow remains controlled by pore connectivity, irrespective of the presence of a fracture.

To assess the longevity of fractures in magmas we developed a novel experimental set-up, in which two glass rods were placed in contact for different timescales at high temperatures before being pulled apart to test the tensile strength recovery of the fracture. We show that fracture healing starts within timescales 50-100 times longer than the structural relaxation time of the melt and that that full healing can be achieved within only a few hours of contact (timescale decreasing with decreasing viscosities) at magmatic temperatures. These results are important for understanding the permeability decrease associated with annealing.

We postulate that rapid permeability evolution due to fracturing or fracture healing may be the cause of observed cyclicity at silicic volcanoes, whereby "instantaneous" increases in permeability occur through the development of macro-fractures drives explosions. We propose that the timescale for this cyclicity is governed by the competition between stress build up through gas accumulation under a relatively impervious plug until failure and fracture healing through annealing or, as shown in other studies, mineral precipitation and sintering of particulate material in fractures.