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# Permeability evolution governed by shear: An example during spine extrusion at Unzen volcano, Japan

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A volcano's eruptive style is strongly controlled by the permeability of the magma and the surrounding edifice rock – explosive activity is more likely if exsolved gases cannot escape the system. In this study, we investigate how shear strain causes variations in permeability within a volcanic conduit, and discuss how spatio-temporal variation in shear regimes may develop.

The eruption of Unzen volcano, Japan, which occurred between 1990 – 1995, culminated in the extrusion of a ~60 metre-high dacitic spine. The spine, left exposed at the lava dome surface, displays the petrographic architecture of the magma in the shallow conduit. Observations and measurements made in the field are combined with laboratory experiments to understand the distribution of permeability in the shallow conduit. Examination of the lava dome led to the selection of two sites for detailed investigation. First, we examined a section of extruded spine ~6 metres in width, which displays a transition from apparently unsheared rock in the conduit core to rocks exhibiting increasing shear towards the conduit margin, bounded by a fault gouge zone. Laboratory characterisation (mineralogy, porosity, permeability, X-ray tomography) was undertaken on these samples. In contrast, a second section of spine (extruded later during the eruption) exhibited a large tensile fracture, and this area was investigated using non-destructive in-situ permeability measurements.

Our lab measurements show that in the first outcrop, permeability decreases across the shear zone from core to gouge by approximately one order of magnitude perpendicular to shear; a similar decrease is observed parallel to shear, but is less severe. The lowest permeability is observed in the most highly sheared block; here, permeability is ~2.5 x10-14 m2 in the plane of shear and 9 x10-15 m2 perpendicular to shear. Our measurements clearly demonstrate the influence of shear on conduit permeability, with significant anisotropy in the shear zone. The sheared rocks are strongly micro-fractured, resulting in a porosity decrease of up to 4% and permeability decrease of over one order of magnitude with increasing effective pressure (effective pressure = confining pressure – pore pressure) between 5 – 100 MPa, representative of increasing lithostatic pressure from ~200 m to ~4 km depth in the crust. In contrast, our field study of the second spine section, which features a 2 cm wide by 3 metre-long tensile fracture flanked by a 40-cm wide shear damage zone, reveals that dilational shear can result in an increase in permeability of approximately three orders of magnitude.

The contrasting shear zone characteristics can be attributed to different shear regimes, which likely occur at different depths in the conduit. At greater depth in the system, where lithostatic pressures largely exceed pore pressure, compactional shear appears to dominate, reducing the permeable porous network as magma strains along the conduit margin, whereas at shallower levels, where the effective pressure is low, dilational shear becomes dominant, resulting in the creation of permeable pathways. We conclude that contrasting shearing regimes may simultaneously affect magma ascent dynamics in volcanic conduits, causing a range of dynamic permeability variations (positive and negative), which dictate eruptive behaviour.