Fracture-driven magma degassing pathways in intruding rhyolitic magma

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Abstract

Degassing efficiency during the emplacement of silicic magma can determine the eruptive potential. Effusive lava domes are coupled with localized degassing through transient fractures near the walls of the conduit (Holland et al. 2011), whereas explosive eruptions are a result of bulk magma fragmentation. Complex interplay between viscous and brittle processes is likely occurring in magmas close to the viscous-brittle transition even in intrusive settings, but evidence of such relationships can be easily overprinted or erased either via viscous healing or by post-emplacement fluid alteration. Here we present excellently preserved mechanical deformation features grading from viscous into brittle in the Sandfell laccolith, Eastern Iceland. Building on work by Mattsson et al (2018), we mapped the area and categorized each outcrop on a deformation scale of 1-5, 1 being purely viscous flow banding and 5 being breccia. The intermediate categories are as follows: 2) 'vesicle trains,' where the higher porosity flow bands have undergone continuous shear, stretching and aligning the vesicles parallel to the shear direction. 3) 'Fracture bands' (small/simple), clearly brittle tensile fractures confined to a planar band, interpreted as the initial flow band plane. The outcrop fell under this category if fracture bands contained only one fracture set and/or were <5 cm in thickness. 4) Fracture bands (large/complex), similar to category 3 except more than one fracture set is present and/or fracture band is >5 cm thick. We measured anisotropy of magnetic susceptibility (AMS) of coherent Sandfell rhyolite to determine magnetic fabric, and coupled these data with structural measurements of magma flow and fracture bands along with the categories of deformation. Porosity/permeability measurements were taken on coherent and flow-banded samples, and micro-CT scans were made of fracture band blocks to quantify fracture connectivity. Mapping results show clusters of dominantly-brittle and dominantly-viscous deformation features throughout the laccolith. Permeability of coherent rhyolite was below the detection limit, while along a flow band permeability was 2.05×10^{-14} m^2. Micro-CT results show strong preference of permeable flow along fracture lengths, with minor connectivity between main fractures. This exemplifies the increase of permeability with continued deformation from viscous to brittle. We suggest that during early laccolith growth stages, degassing occurred within flow bands. Continued inflation-induced shearing stretched and joined vesicles within the flow bands together, increasing permeability. Magma pore pressure increased from volatile exsolution and coupled with the accumulation of inflation stresses in the magma. Eventually, the tensile strength of the magma was overcome by these stresses, and tensile fractures propagated outward from the edges of the flow band. These fracture bands provided highways for fluids to move through, eventually escaping the laccolith entirely or remaining in the fractured rhyolite. Continued inflation deformed areas of the magma further after it had crossed the brittle transition, brecciating the magma. Based on our interpretations, the abundance of these features throughout the rhyolite (~80% of the exposed volume) would have effectively degassed the magma body, and as a result it remained below the pressure threshold required to trigger an eruption. The documentation of fracture bands in other intrusions and lavas with different compositions and crystallinities leads us to propose that this process takes place to some degree in all silicic magmas undergoing shear.

References

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