Geophysical Research Abstracts
Vol. 21, EGU2019-4832-1, 2019
EGU General Assembly 2019

Re-activation of magma pathways: Insights from multiple-dykes on La Palma, Canary Islands

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Dykes are the most common means of magma transport in basaltic volcanoes, so knowledge of dyke propagation paths is critical for volcanic hazard analyses. Some dykes contain internal chill margins and/or compositional variation that suggest they formed from two or more temporally separate dyking events. These multiple-dykes have been studied from a geochemical perspective to explore fractionation in magma chambers, but literature on the mechanics of their formation is lacking. It is commonly assumed that multiple-dykes form either because (1) the initial dyke did not have time to solidify completely before the subsequent injection, or (2) the solidified dyke (or its margin) is weaker than the host rock it intrudes. In this contribution we present an analysis of exceptionally well-exposed multiple-dykes on the island of La Palma (Canary Islands, Spain) that appear not to have formed by either of these mechanisms.

Dykes in the study area are basaltic and variably vesiculated. They are crosscut either by 5-15 cm spaced cooling joints or 1-10 cm spaced and remarkably persistent margin-parallel joints (MPJs). Internal contacts within the dykes show distinct glassy chill margins up to $\sim$1 cm thick, suggesting that they comprise multiple intrusions and that the exterior (older) dyke had cooled prior to subsequent intrusions. Dyke interactions were observed along cliff faces, where younger intrusions intersect and are reoriented along older ones by as much as 60°; the older dykes clearly provide preferential propagation pathways. This observation is counterintuitive, as dykes at this location crosscut comparatively weak and compliant phreatomagmatic tuff, scoria and matrix-rich volcanic breccia.

As such, we propose that the multiple-dykes formed due to the mechanical contrast between solidified older dykes and the host-rock. Linear-elastic models suggest that the stiffness contrast will result in significantly larger stress within the dykes than the more-compliant host rocks under volcanic and gravitational loading, and that this stress will be rotated towards parallelism with the dyke. As a result, a multiple-dyke is formed as subsequent intrusions tend to be deflected along the dyke contact (if the dyke has a weak margin) or within the dyke itself due to the stress rotation. Geomechanical tests also show that the dykes have anisotropic elastic properties, tensile strength and fracture toughness, probably due to pervasive flow fabrics defined by aligned plagioclase lathes. This anisotropy will exaggerate the stress rotation and encourage formation of MPJs during volcano inflation/deflation cycles, which in turn will further enhance the anisotropy and multiple-dyke formation.

At a large scale, the geomechanical discontinuities that solidified dykes create give volcanic edifices a structural memory of past stress-states. Deflection of active dykes along these discontinuities will cause intrusions to become misoriented with respect to current stresses and hence potentially unexpected propagation paths. Re-activation of older dykes also has implications for the organisation of the magma plumbing system, encouraging re-use of older vents and directing dykes along volcanic rift-zones or towards shallow magma reservoirs.