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Flow channelling and the emplacement of intrusions and lava flows

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It is well known that a magma-driven fracture (a dyke, an inclined sheet, or a sill) subject to a constant magma overpressure opens into (gets an aperture variation of) an ellipse. Here overpressure is defined as the difference between the total magma pressure inside the fracture and the stress acting perpendicular to the fracture walls. Most dykes, sheets and sills are extension fractures, in which case the stress acting perpendicular to them is the minimum compressive (maximum tensile) principal stress, sigma 3. While many magma-driven fractures have been modelled as formed under constant overpressure, it is known that in heterogeneous and anisotropic crustal segments, such as in composite volcanoes and rift zones, the magma overpressure is unlikely to be constant. This follows because the mechanical properties, in particular the Young's moduli, of the rock layers and units through which the magma-driven fracture propagates are likely to vary abruptly from one layer to the next one. Thus, even if the remote tectonic loading is constant, the local stresses in the host rock, including sigma 3, may change irregularly between layers. Since the magma overpressure depends on sigma 3 in each rock layer dissected by the magma-driven fracture, it follows that the overpressure varies between layers and units.

Here we present new analytical solutions for the effects of overpressure variation, given by Fourier cosine series, in a magma-driven fracture on its opening (aperture) variation and the surrounding local displacement and stress fields. The method is very flexible and allows us to model abrupt overpressure variations in vertical and lateral sections. For vertical sections in a crustal segments composed of rock layers and contacts with abruptly varying Young's moduli, the results indicate an aperture variation that is subsequently reflected in thickness variations of dykes, as are commonly measured in the field. For lateral sections, the analytical solutions indicate very clearly how strongly the aperture of a dyke and, at the surface, of a volcanic fissure depends on the overpressure variation. Because of the cubic law, stating that the volumetric rate of flow of magma (and other fluids) is a function of the cube (the third power) of the fracture aperture, any significant overpressure-generated variation in fracture aperture may lead to flow channelling, in which case much of the fluid transport becomes confined to those segments of the fracture that have unusually large openings.

We propose that these results may help explain the formation of exceptionally wide segments along dykes, segments that subsequently may develop into circular conduits and, on solidification, plugs. Flow channelling in feeder-dykes to lava flows is likely to be one reason for the formation of crater cones and to have large effects on the mechanism of lava-flow emplacement. Similarly, the rate of formation and the geometry of shallow magma chambers and other magma bodies supplied with magma from dykes are likely to be significantly affected by aperture variations and flow channelling in the dykes.