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Crustal deformation associated with the intrusion of igneous bodies: Insights from analogue modelling techniques

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Ground deformation in volcanic regions can be the surface manifestation of magma movement at depth. Increased availability of geodetic measurements in volcanic regions today offer the potential for geoscientists to better mitigate hazards based on more detailed records of changes in surface topography recorded over short and long time periods. However, distinguishing the signals of magma intrusion can be challenging and additional ground-based data is often needed. Improving our understanding of the relationship between the surface deformation and the dynamics of the evolving underlying volcanic plumbing system will provide greater insights on the depth of the magma and the intrusion geometry, with the potential to constrain when and where an eruption may happen.

This study simulates the formation of ground and subsurface deformation patterns induced by the propagation of magma-filled fractures in the Earth's crust using scaled laboratory experiments. The models use dyed water as a magma analogue and solidified gelatine as an elastic crustal analogue. The gelatine is prepared in a square-based experimental tank measuring 40 x 40 x 30 cm^3. Propagation of dykes in the Earth's crust is modelled by injecting fluid through the base of the tank into a single homogeneous layer of solidified gelatine. Propagation of sills is modelled by injecting the fluid through the base of the tank into two superposed layers of solidified gelatine with contrasting stiffness. The experiments are monitored using digital cameras to record changes in the intrusion geometry over time, and progressive deformation of the surface of the crustal analogue is recorded using an overhead laser scanner. Polarised light allows subsurface stress patterns to be observed as the intrusions grow. The evolving strain in the crustal analogue is quantified using digital image correlation (DIC), where passive-tracer particles suspended in the gelatine solid are fluoresced in a vertical laser sheet.

In single-layered experiments, a vertically propagating dyke is formed that is penny-shaped. The experimental results show that the propagation of dykes causes two topographic highs to form at the surface flanking a region of topographic low directly above the dyke tip prior to an eruption. This deformation pattern is also evident in the sub-surface during early stages of dyke growth where the dyke tip is consistently flanked by 'bow-shaped' stress fields, which correlates well to the evolving strain where strain vectors are highly concentrated near the tip of the dyke. In multi-layered experiments, the dyke transitions into a horizontal sill that forms between the two superposed layers, exploiting the weak interface between them, and producing a distinctive surface and sub-surface deformation signal. These results agree well with theoretical models of dyke propagation in an elastic material and offer an exciting opportunity to ground-truth inversion modelling techniques in nature and improve the interpretation of ground deformation in volcanic regions.