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Surface stresses and displacements induced by dikes and inclined sheets

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Sheet intrusions supply magma to almost all eruptions. Mechanically, the erupting sheets are primarily extension fractures and of two main geometric types: dikes and inclined (cone) sheets. Regional dikes are mostly subvertical, many metres, occasionally tens of metres, thick, with strike dimensions (strike length) from kilometres to tens of kilometres (or more). By contrast, inclined sheets dip on average 30-40°, are mostly less than one metre thick, and with strike dimension of hundreds of metres or, at most, a few kilometres. The density/frequency is also generally much greater in sheet swarms than in regional dike swarms.

Forecasting the geometry and likely propagation path (including a possible eruption) of a sheet intrusion during volcanic unrest is of fundamental importance. The inferred geometry of the sheet is also an indication of the volume of magma that leaves the chamber during the unrest period. Sheet paths and geometries (including depth and opening/aperture) are commonly determined from geodetic surface data, in particular InSAR and GPS data. Standard interpretation methods of the data use mostly dislocation models that assume the volcano and the hosting crustal segment to be an elastic half space of uniform mechanical properties. By contrast, field observations of volcanoes (active and extinct) show that they are composed of a variety of layers whose mechanical properties vary widely. In particular, Young's modulus of layers and contacts in a typical active volcanic zone may vary by 2-3 orders of a magnitude.

Here we provide numerical results on a dike/inclined sheet arrested at 0.5 km depth below the surface of an active volcano/volcanic zone, with several layers of varying stiffness (Young's modulus) between the tip of the dike/inclined sheet and the surface. In particular we vary the stiffness of one layer from 10 GPa to 0.01 GPa. The results show as the layer becomes more compliant (0.1-0.01 GPa) stresses and displacements (lateral and vertical) at the surface become suppressed.

The results also show that the surface stresses and displacements induced by inclined sheets depend much on their dip and are generally widely different from those induced by vertical dikes. Also, the width of any dike-induced graben or zone of tension fractures is, according to the present results, roughly twice the depth to the tip of the arrested dike. In particular, the numerical results show that the surface-uplift peaks occur at locations which differ widely from those of the tensile/shear stress peaks and do not, in contrast with common interpretations, coincide with the location of the boundary faults of a dike-induce graben.

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