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Magma chambers, dyke injections, and surface deformation in composite volcanoes

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Composite volcanoes and rift zones are composed of numerous alternating material units or layers such as lavas, sediments, and pyroclastics. Commonly, these layers have widely different mechanical properties. Composite volcanoes are also referred to as stratovolcanoes and (in Iceland) central volcanoes. Many lava flows and welded pyroclastic flows are stiff (with a high Young's modulus), whereas non-welded pyroclastic units, sediments, and soil layers are soft (with a low Young's modulus). In basaltic edifices, by contrast, most of the layers are of similar (basaltic) lava flows, so that the mechanical contrast between layers is comparatively small.

Composite volcanoes and rift zones have commonly been modelled as homogeneous and istotropic rock bodies. Then the stress trajectories of the maximum principal compressive stress along which ideal dykes and inclined sheets should propagate show no abrupt attitude changes, suggesting that all buoyant dykes should reach the surface. While some dykes reach the surface, feeder dykes form a small minority (perhaps only 3-10%) of the dykes in any swarm. All other dykes in a swarm become arrested and never reach the surface. Some dykes become arrested in thick, essentially homogeneous layers, but many more at contacts between layers. And those dykes that propagate through contacts are commonly offset.

Numerical models of magma chambers and dykes indicate that offset and, in particular, arrested dykes can be explained by rotation of the principal stresses at and near contacts between layers of contrasting mechanical properties. A vertically propagating dyke meeting a mechanical layer where the direction of the maximum principal compressive stress becomes horizontal has two main options: the dyke can change into sill, perhaps continuing its vertical propagation at one end of the sill, or the dyke can stop its propagation altogether.

The numerical models results also indicate that near-surface effects of propagating or arrested dykes depends strongly on mechanical layering. In particular, the stresses around the dyke tip and at the surface, and the associated surface deformation, are largely controlled by the mechanical layering. Thus, when a dyke is assumed to be emplaced in a homogeneous and isotropic crustal segment, the calculated surface stresses and deformation may be very different from those obtained for the same dyke in a layered crustal segment. It follows that inversion of surface deformation data using standard homogeneous, isotropic half-space models to infer dyke geometries may yield results that have little similarly with the real dyke being modelled

Our main conclusions are as follows: (1) During unrest periods, composite volcanoes develop local stresses that may be very different from those in an otherwise similar but homogeneous and isotropic body. (2) Most dykes injected from a chamber in a volcano become arrested at depths in a volcano, commonly at contacts between layers. (3) Dyke-induced stresses depend much on the mechanical properties of the layers between the dike tip and the surface. In particular, soft layers and weak contacts may suppress the dyke-induced stresses and the associated surface deformation. (4) Analytical surface-deformation models where the volcano is assumed to behave as a homogeneous, isotropic half space are likely to yield results that have little similarity with the actual structure being modelled.

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