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Modelling dyke propagation paths in anisotropic successions

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Almost all eruptions are supplied with magma through dykes or inclined sheets (cone sheets). The dykes/sheets, in turn, are injected from a source which is normally either a shallow magma chamber or a deep-seated reservoir. During a volcanic unrest period with dyke injection, one main aim is to forecast the likely propagation path of the dyke and, in particular, the probability of the dyke reaching the surface to erupt.

The propagation path of a dyke injected from a chamber/reservoir during unrest is partly determined from seismic data and partly from geodetic surface data, in particular InSAR and GPS data, using mostly dislocation models that assume the volcanic zone to be elastic half spaces of uniform mechanical properties. By contrast, field observations of volcanoes (active and extinct) show that they are composed of layers whose mechanical properties vary widely. In particular, Young's modulus or stiffness of layers and contacts in a typical active volcanic zone may vary by 2-3 orders of a magnitude. How mechanical layering affects dyke-propagation paths is best determined by detailed field studies of actual dykes in well-exposed sections composed of widely different rock layers.

Such sections, with many dykes and a great variety in the mechanical properties of the layers and contacts, are provided by the caldera walls of Santorini, a stratovolcano located in the Aegean Sea, Greece. The volcano is a part of the active Hellenic South Aegean Volcanic arc, formed by the subduction and rapid rollback of the African plate beneath the Aegean microplate. This study focuses on quantifying dyke propagation paths, combining field data from Santorini with numerical models. To do this we have mapped a dyke swarm exposed in the northern caldera wall. We measured the attitude and thickness of 91 dykes as well as features such as dyke segmentation, arrested dike tips, associated faults and other discontinuities. In this study we seek to understand the role of mechanical anisotropy in influencing dyke propagation paths, including dyke arrest.

The finite-element software COMSOL Multiphysics is used to model dyke-propagation paths as seen in the field. In the model runs we use different mechanical properties of the layers, vary the magmatic overpressure (driving pressure) as well as the external, tectonic loading. The calculated crustal stresses, in particular the trajectories (orientations) of the maximum compressive principal stress, are then used to forecast the likely dyke-propagation paths. The numerical results are then compared with the observed dyke paths.

We also study the effects of normal faults, of which there are several in the sections, on dyke paths. Some dykes follow steep normal faults along parts of the dyke paths, but then leave the fault at shallower crustal depths to resume their normal path. Other dykes are seen to be arrested at discontinuities and contacts between mechanically dissimilar layers. Layering, contacts, and local stresses apparently largely control dyke paths.