Geophysical Research Abstracts
Vol. 14, EGU2012-9404, 2012
EGU General Assembly 2012

Interpreting sub-surface deformation sources at volcanoes: Insights from DEM models

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Continuum-based modeling is routinely used to constrain the shape, size and orientation of sub-surface deformation sources responsible for geodetically-observed surface displacements. However, this sometimes leads to the inference of deformation sources with finite geometries of uncertain geological meaning. For example, deformation sources in the literature include shallowly-inclined (4-25°) prolate ellipsoids (i.e. 'cigars) or a single gently tilted plane centered beneath the volcano. Directly relating such sources to the shape and orientation of subterranean magma bodies, whilst always tempting, is not readily reconcilable with field data typical of sub-volcanic igneous intrusions.

One possibility is that such inclined source geometries may represent not only a deflating magma body, but also associated discontinuous (i.e. fracture-related) deformation in the surrounding host rock. To test this hypothesis, we extracted surface displacement data from Distinct Element Method (DEM) models of magma body deflation that simulate a transition from continuous to discontinuous deformation and the localization of fractures. We then performed continuum-based modeling of the DEM surface data to retrieve the apparent sub-surface deformation source at different stages of the collapse evolution. Our results show that discontinuous deformation at depth induces asymmetries in the model's free surface displacement profile even if no discontinuities reach the surface. This is because the accumulation of discontinuous deformation tends to be path-dependent and ultimately asymmetric. The deformation-induced asymmetry of the surface displacement profile can, in principle, give rise to inclined or prolate deformation source geometries, even if the original magma body itself was not inclined.