Geophysical Research Abstracts
Vol. 20, EGU2018-5342, 2018
EGU General Assembly 2018

Distinct Element Method (DEM) numerical models of multi-cyclic caldera deformation

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Restless calderas constitute a major hazard to humanity. An acute problem for accurate assessment of hazard is the persistent uncertainty and debate about how caldera-related deformation is triggered, evolves, and is structurally accommodated. Long-term (>10^4 yr) caldera deformation may include multiple cycles of large scale (10^2 – 10^3 m) intrusion-induced uplift and eruption-related subsidence. Deformation cycles can also manifest as numerous short term (months to years) ‘unrest episodes’ of meter-scale uplift and subsidence. Both long- and short-term deformations are punctuated by fault formation and/or reactivation and by eruption.

To gain further insights into the initiation, development, and final geometry of caldera structures, researchers have turned to physical and numerical models, particularly new numerical modeling techniques such as the Distinct Element Method (DEM). The principle advantage of using the DEM over more commonly used continuum models (e.g. Finite Elements) to model large strain volcanic deformation is that it can not only precisely calculate displacements, stresses, and strains based on realistic rock properties, but it can also directly model the initiation, growth, rupture, and reactivation of complex discontinuities like faults.

We generated 2D DEM models of restless calderas, starting with pre-collapse inflation (tumescence), followed by collapse and later by post-collapse inflation (resurgence). Deformation during initial tumescence is characterized by inward-dipping reverse faults, while collapse (both symmetric and asymmetric) is accommodated by outward-dipping reverse faults, with some smaller scale inward-dipping normal faults. This matches well with geophysical data from calderas such as Rabaul, Sierra Negra, and Axial, as well as with existing small-scale physical models. We also show that faults formed during previous stages of the caldera cycle are reactivated during subsequent stages, with fault reactivation progressively dominating over new fault generation. Additionally, we investigate the effect of varying reservoir roof geometry. Our models help to shed light on the mechanics at work underneath active calderas and to improve volcanic hazard assessment.