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Bonded 2D-DEM Models of Pit Craters and Collapse Calderas

E.P. Holohan, M.P.J. Schöpfer, and J.J. Walsh

Fault Analysis Group, UCD School of Geological Sciences, Dublin 4, Ireland (Eoghan.Holohan@ucd.ie, +353 1 716 2609)

Subsidence of the roof of a magma reservoir commonly produces volcanic depressions, which, depending on scale, are termed pit craters or collapse calderas. To identify what geometric and mechanical factors influence the structural evolution of this subsidence, we used Distinct Element Method (DEM) numerical models. The models comprise an assemblage of gravitationally-loaded circular particles that interact at their contacts according to elastic-frictional laws. Cohesion is provided by inter-particle bonds that break once their shear or tensile strength is exceeded. Varying particle and bond micro-properties yields assemblage macro-properties characteristic of natural rock masses (e.g. elasticity, failure, and strain softening), with fracture localization simulated by bond breakage. The magma reservoir is represented as a region of non-bonded, low-fiction particles. Withdrawal of magma is simulated by incrementally reducing the area of the reservoir particles. The resultant gravity-driven failure and subsidence of the overlying reservoir roof is explicitly replicated.

We investigated the effect on subsidence of several initial mechanical and geometric properties. Of these, the strength (cohesion) and thickness/diameter ratio (T/D) of the roof exerted strongest influences, whilst the roof's Young's Modulus and the reservoir's ceiling curvature imparted secondary influences. These properties interacted to produce four 'end-member' subsidence styles, although elements of several styles tended to occur in any one model realization: (1) Predominantly central sagging at low T/D and low strength; (2) hitherto unrecognized 'central snapping' at low T/D and high strength; (3) predominantly single central block subsidence at low to intermediate strength and at intermediate T/D ratios; (4) multiple central block subsidence at high strength and high T/D ratios. The critical T/D ratio, at which subsidence changes from single central block to multiple central block, was strongly dependent on material strength. Our model results provide a more quantitative understanding of the genesis of subsidence styles observed or inferred in the field: e.g. at Nindiri crater, Nicaragua; Dolomieu caldera, Reunion; and Miyakejima caldera, Japan.