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The effect of ring fault attitude on caldera unrest

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Collapse calderas are a surface deformation resulting from failure of a magma chamber roof, and in the case of piston-like subsidence, result in slip along the bounding ring faults. Understanding collapse-caldera dynamics is vital because of the potential for large destructive eruptions. Ring faults bounding collapse calderas have been observed in geophysical and analogue studies. The role of ring-fault attitude, however, on the development of collapse calderas is not well constrained. Steeply inward-dipping normal ring faults are those commonly found bounding calderas, although outward-dipping reverse ring faults do also occur and are favoured in some models of caldera formation. Here we present the results of many new finite element numerical models which investigate how the stress conditions for ring-fault formation depend on the dip of the resulting ring faults. In these models, an oblate ellipsoidal (sill-like) magma chamber, 8 x 2 km, is located in a homogenous crustal layer at 3 km depth below the surface. The dip of inward and outward dipping faults is altered between models to investigate the effects of different dips on the stress conditions needed for ring-fault formation or reactivation. The stress conditions most likely to initiate slip on a caldera fault are those whereby (1) the maximum tensile stress peaks at the surface, (2) the maximum shear stress peaks at the chamber margin (above the lateral ends of the sill-like chamber), and (3) the maximum tensile stress at the surface peaks above the lateral ends of the associated chamber. The boundary conditions most common for ring fault formation and caldera slip are minor doming and external extension. It is easier (requires less energy) to generate ring faults in a basaltic edifice, where individual layers have similar mechanical properties and therefore promote stress field homogenisation, than in stratovolcanoes composed of layers with widely different mechanical properties. The present results indicate that vertical to steeply inward-dipping ring faults do not significantly alter the near-surface stress field. By contrast, outward-dipping reverse faults have large effects on the near-surface stresses, increasing the maximum surface tensile stress by up to several mega-pascals under certain conditions. The formation of shallow-dipping ring faults is generally easier than the formation of (the commonly observed) steeply to vertical dipping faults. These results may help to explain the apparent rarity of caldera-forming unrest periods, as most natural examples exhibit steeply dipping ring faults.