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Caldera collapses in composite volcanoes and basaltic edifices

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In composite volcanoes, collapse-caldera formation, and slip on existing ring-faults, occur rarely, if at all. When caldera slip occurs, however, it is commonly associated with violent, explosive eruptions which can destroy large and densely populated areas. By contrast, ring-fault formation or slip is comparatively common in many basaltic edifices (such as in Galapagos and Hawaii), but these slips often occur without any eruptions or, at most, small, effusive eruptions. Any viable model of ring-fault formation must explain this difference between composite volcanoes and basaltic edifices as regards ring-fault formation.

Collapse calderas are usually defined as circular or moderately elliptical volcanic depressions with a diameter exceeding about 1 mile (1.6 km). Here the lower limit of the diameter of a collapse caldera is taken as 2 km. This is in accordance with current estimates of calderas sizes on Earth as being from about 1-2 km to about 75 km in maximum diameter. The lower limit of 2 km is also chosen so as to distinguish between pit craters, some of which exceed 1 km in diameter, and calderas. Normally, the diameter of a caldera is many times greater than those of any associated vents. Typical collapse calderas are many kilometres in diameter and with vertical displacement (subsidence) from several hundred metres to several kilometres. Some calderas are multiple, that is, consist of two or more adjacent ring faults; others are composed of one or more small ring faults inside a large ring fault. Most ring faults (and ring dykes) are vertical or dip steeply inward.

If a ring fault is to form, the maximum shear stress and near-surface tensile stress must peak above the lateral ends of the associated shallow chamber. Most magma-chamber geometries and loading conditions, however, do not generate stress fields that are likely to initiate a ring faults or slip on an existing ring fault. This is because the stresses do not peak above the lateral ends of the chamber, but at its top and in the central part rather than the marginal parts of the free surface above the chamber.

Traditional models of ring-fault formation assume that there is an underpressure (magmatic pressure less than lithostatic) in the chamber. In these models, the ring fault would be an outward-dipping reverse fault. How the underpressure is developed, and why magma would still continue to flow out of the underpressured chamber, remains to be explained. Our numerical studies indicate that sill-like shallow magma chambers, particularly if located in volcanic fields subject to small doming from a deeper reservoir, may generate stress fields suitable for ring-fault formation. For a homogeneous crustal segment, a sill-like chamber subject to doming is likely to trigger a ring fault, or slip on an existing one, since both the tensile and shear stresses peak at suitable locations.

For a layered crustal segment (a composite volcano) the probability of ring-fault formation, or slip on an existing one, depends much on loading conditions and stress-field homogenisation. Since the stress-field is easier to homogenise in volcanoes composed of mechanically similar layers, it follows that caldera collapse is more common in basaltic edifices than in stratovolcanoes. And since the magma in a basaltic edifice is normally gas poor, only small eruptions, or no eruptions at all, are normally associated with the ring-fault slip. Generally, for a reasonable stress-field homogenisation, a sill-like chamber subject to horizontal tension and/or doming (from a deeper reservoir) may trigger ring-fault formation.

The main conclusions may be summarised as follows: (1) For ring faults to form or slip, the shear and tensile stresses must peak above the lateral ends of the associated shallow magma chamber. A shallow chamber most likely to generate such stresses is sill-like (oblate spheroidal). (2) In composite volcanoes, local stresses develop in layers with different mechanical properties. It follows that the dip of a ring fault may change from one layer to another; from being outward dipping to being inward dipping. (3) The layers that constitute basaltic edifices have more similar mechanical properties than those that constitute composite volcanoes. It is therefore comparatively easy to homogenise the stress field in basaltic edifices. Consequently, ring-fault formation and slip are more common in basaltic edifices than in composite volcanoes. (4) Large-scale stress-field homogenisation at a suitable location is rare in composite volcanoes, and so is the formation of, and slip on existing, ring faults.

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