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Numerical studies of the initiation of caldera faults

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Caldera faults are primarily dip-slip faults. Their initiation and development depends on the local stresses in the hosting crustal segment. The local stresses are controlled by the loading conditions as well as by the mechanical properties of its rock units and structures that constitute the volcano. Many volcanoes never develop a caldera; for most that do, caldera formation is a rare event. Also, most unrest periods in existing calderas do not result in caldera-fault slip. Previous results indicate that prolate magma chambers are unlikely to provide local stresses suitable for caldera-fault formation. By contrast, the most suitable magma-chamber shape is sill-like (oblate ellipsoidal). However, in the present study, spherical (circular) chambers are also considered. Most calderas are hosted by crustal segments or volcanoes composed of layers with widely different mechanical properties and loading conditions. For these reasons, the initiation of caldera faults is best studied through numerical models.

Here I present numerical models of caldera-fault formation in volcanoes with shallow spherical or sill-like magma chambers. All the models are two-dimensional, but the results where crustal segments are modelled as homogeneous and isotropic compare well with known three-dimensional analytical solutions. In all the anisotropic models, the crustal segment (including the volcano) above the shallow chamber is composed of 30 comparatively thin layers with stiffnesses (Young's moduli) alternating between 1 GPa to 100 GPa. The chamber itself is located in a single, thick layer. The crustal segment hosting the chamber is either 20 km or 40 km wide but has a constant thickness of 20 km. The loading conditions considered are crustal segments subject to: (a) underpressure (lack of magmatic support) of 5 MPa; (b) tensile stress of 5 MPa; (c) excess magmatic pressure of 10 MPa at the bottom of the crustal segment (doming of the volcanic field containing the chamber); and (d) combination of tension and doming. In all models, the magma-chamber top is at 3 km depth; the diameter of the sill-like

chamber is 8 km (its thickness is 2 km), that of the spherical chamber is 4 km.

The main results are as follows: (1) Underpressure and excess pressure in a chamber normally results in dyke injection rather than caldera formation. (2) For doming or tension, a spherical magma chamber normally favours dyke injection rather than caldera-fault initiation. However, when the spherical chamber is located in a very soft (10 GPa) layer, the local stress field may be suitable for caldera-fault formation. (3) For a sill-like chamber in a 20-km wide volcanic field, a caldera fault may initiate either during horizontal tension, or a combination of tension and doming. (4) For a sill-like chamber in a 40-km wide volcanic field, doming alone is sufficient to initiate a caldera fault. The results indicate that the local stresses in composite volcanoes most likely to initiate caldera faults are associated wtih sill-like chambers subject to tension, doming, or both.

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