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The Role of Magma Chamber-Fault Interaction in Caldera Forming Eruptions

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We examine the role of the position and orientation of a regional fault in the roof of a magma chamber on stress distribution, mechanical failure, and dyking using 2D finite element numerical simulations. The study pertains to the magma chamber behavior in the relatively short time intervals of several hundreds to thousand of years. The magma chamber is represented as an elliptical inclusion (eccentricity, a/b=0.12) at a relative depth, H/a, of 0.9. The fault has a 45o dip and is represented by a frictionless fracture. We use several system configurations with different fault position in the chamber roof. The temperature field in the host rock is calculated assuming a quasisteady-state thermal regime that develops through periodic episodes of magma supply. The rheology of the surrounding rocks is treated using viscoelasticity with temperature activated strain-rate dependent viscosity. Strain weakening of the rocks in the ductile zone is described within the frame of the Dynamic Power Law model (Simakin and Ghassemi, 2005). The magma pressure is coupled with the deformation of the rock mass hosting the chamber, including the fault. The variation of magma pressure in response to magma supply and chamber deformation is calculated in the elastic and viscoelastic regimes. The latter corresponds to slow filling, while the former represents a filling time much less than the viscous relaxation time scale. The resulting "equation of state" for the magma chamber couples the magma pressure with the chamber volume in the elastic regime, and with the filling rate for the viscoelastic regime. It appears that bulk chamber modulus for sill like magma chamber close to the surface (H/a<1) is approximately order of magnitude less than generally accepted estimate 2E/3(1+nu). For Young modulus of the surrounding rocks of 30 GPa it is in the range 1.3-1.6 GPa depending on the fault position. Analysis of stresses is used to predict dyke propagation conditions, and the mechanical failure of the chamber roof for different fault positions and magma overpressures. Results show that an outward dipping fault located on the periphery of the chamber roof hinders the propagation of dykes to the surface, causing magma to accumulate under the footwall of the fault. At high to moderate overpressures (30 to 40 MPa), the fault causes localized shear failure and chamber roof collapse that might lead to the first stage of caldera-forming eruption. Our results are in agreement with recent field observation of the influence of faulted roof on the style of eruption from the shallow basaltic magma chamber at Galapagos Islands (Amelung et al. 2000).

References

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