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Stress changes variations around a pressured magma chamber: constraints on magma intrusion and fault slip

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Pressure variations in a magma chamber may cause ground deformation and redistribution of the stress in the surrounding rocks. At Etna volcano eruptive sequences and local seismicity have revealed a significant time correspondence between volcanic unrest and rupture along fault structures. Ground deformation and stress change are often interpreted in terms of overpressure in a magma chamber without taking into account the total pressure on its walls. When studying magma reservoir failure and conditions for nearby fault ruptures, an analysis of stability is required and total pressure, rather than overpressure, has to be estimated. We performed a stress-strain analysis at Etna volcano using the Finite Element Method to investigate the perturbations to the local stress regime produced by pressure sources embedded in a inelastic domain. The main focus is to understand magma reservoir failure and characterize the conditions under which rupture on the pre-existing faults can occur. An initial state of stress is computed under the load of internal gravity body force. A gravitationally loaded model, that fails by slip on pre-existing fractures obeying a Coulomb friction law or as intact rock according to Drucker-Prager failure criterion, is considered. The investigation of elasto-plastic rheology proves useful, since elastic models are not able to explain the observed deformation without requiring unrealistically high overpressures beyond the crustal strength. Several simulations using different pressure sources, medium parameters and fault geometries were performed to demonstrate how different initial stress conditions can affect the magma chamber stability and slip pattern on the pre-existing fault structures. The magma pressure that the chamber wall can sustain without failing depends mainly on the initial stress state, which is affected by volcano topography only at shallow depth. As the magmatic pressure builds up, the simulations indicate that host rocks fail first at the crest of the magma chamber promoting earthquakes and upward magma propagation. Stress changes and slip distributions on the nearby pre-existing faults are also investigated to clarify the relationship between magmatic inflation and fault slip promoted by the induced stress changes. The proposed models place an upper limit on the pressure that a magma chamber can sustain before failing and provide a quantitative estimate of the interaction between volcano activity and tectonic processes.