Numerical modeling of deformation and stress fields around a magma chamber: constraints on failure conditions and rheology

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We present a stress-strain analysis using the Finite Element Method to investigate failure conditions of pressured magma chambers embedded in an inelastic domain. The pressure build-up induces variations in the stress field until failure conditions are reached. Therefore, the definition of the failure conditions could have a significant impact on the volcano hazard assessment. Using a numerical approach, we analyze the stresses in a gravitationally loaded model assuming a brittle failure criterion, to determine the favorable conditions for magma chamber failure in different source geometries, reference stress states, rock rheologies and topographic profiles. The numerical results allow us to pinpoint the conditions promoting seismicity near the magma chamber. The methodology places a limit on the pressure that a magma chamber can sustain before failing and provides a quantitative estimate of the maximum uplift expected at the ground surface. Thermally-activated ductile regimes, which may develop in the region surrounding a heated magma chamber, are also investigated. The stress relaxation in a ductile shell may prevent the wall rupture, favoring the growth of large overpressured chambers, which could lead to considerable deformation at the ground surface without significant seismicity. The numerical results suggest that a shallow spherical source, compressive regime, gentle edifice topography, and growth of a ductile shell are important factors for the initial formation and the mechanical stability of magma storage systems. These findings could help in gaining insights on the internal state of the volcano and, hence, in advancing the assessment of the likelihood of volcano unrest.