Elastic-brittle models and hydromechanical considerations for the geometry of failure and pressure conditions around a spherical magma chamber

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Change in pressure within a circular magma chamber is an approximation commonly used to fit geodetical observations and guess chamber depth and radius. However, models applying assume that the internal overpressure applied normal to the chamber wall is bounded by the tensile strength of rocks. While Grosfils recently showed that the gravity component should be incoroporated in the wall-parallel stress component, thus increasing the theoretical pressure limit for tensile failure orders of magnitude greater than the tensile strength (Grosfils, 2007), here we show that failure should instead initiate in shearing mode when accounting for a Mohr-Coulomb yield criteria. Using two-dimensional elasto-plastic finite-difference modelling, failure develops in three stages: (1) tensile faulting near the ground surface, (2) shear failure around the chamber wall, and (3) faults connection from the chamber wall to the ground surface, as fault patterns expand and verticalise. While predictions of surface deformation and stress based on elasticity remain valid for the first two stages, they break down after faults connection between the chamber and the ground surface. Modeled failure locations depend on the mesh geometry, and is associated to numerical mesh-locking issues. We illustrate three different mesh geometries, that constrain the validity of the models. The effect of fluid pressure is also studied, as we conducted hydromechanical models that indicate that the initial rock porosity near the chamber wall is a key parameter that strongly influences the change in fluid pressure, volumetric strain and effective normal stress, and, consequently, the initiation and propagation of shear failure. We show that a rock with a low porosity is more prone to fail, and changes in fluid pressure can lead to additional deformations that can be misinterpreted as only volcanic in origin. The modeled failure geometries show imbricated ring faults, which drawn in a diagram provide insights on how failure evolves in time and space around an inflating intrusive body. The northern granite of Arran island is proposed as a natural example of this process.