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Conditions for shear and tensile failure around an inflating circular magmatic chamber: internal overpressure and shear band geometries obtained from analytical and numerical elasto-plastic models

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Surface displacements calculated from a pressure change in a circular magmatic body are commonly used to determine chamber depth and radius in the assumed elastic crust, based on geodetical constraints. However, many models also assume that the overpressure acting out of the chamber's walls is bounded by the tensile strength of rocks. While it has recently been shown that this pressure limit is much greater when the wall-parallel stress component of gravity is accounted for, here we show from analytical and numerical solutions that failure around the chamber wall should occur by shearing rather than by tensile opening, simply because the Mohr-Coulomb yield stress is lower than the tensile yield stress. Two-dimensional elasto-plastic models of a magmatic chamber with progressively increasing internal overpressure, show that failure develops in three stages : (1) tensile failure near the ground surface, (2) shear failure around the chamber wall, (3) and fault connection from the chamber wall to the ground surface as the fault pattern expands outwards excentrically. While predictions of surface deformation and stress based on the theory of elasticity remain valid for the first two stages, they break down as the plastification domain connects the chamber and the ground surface. Detail shear band geometries are obtained thanks to exceptionnally high numerical mesh resolution, and compare well with excentric slip-lines geometries calculated in tunnelling engineering. The intersecting connection point of stage 3 is suggested to trigger the formation of a secondary magmatic chamber, if the initial chamber is deep enough. Additional models are displayed which account for the traditional effect of pore-fluid pressure (ratio l) on the Mohr-Coulomb effective normal stress. Then, a lithostatic state of pore-fluid pressure in the bedrock (l=1) cancels the effect of gravity, allowing for mode 1 tensile failure to occur at the chambers' wall, associated to internal overpressures now close to tensile strength. We conclude that the field observation of mode I tensile faults around circular magmatic chambers can be explained by the presence of high pore-fluid pressures in the surrounding bedrock, that reduce the effect of gravity and thus also the internal overpressure required to trigger failure. A companion presentation demonstrates additional effects when hydromechanical coupling is accounted for.