Thermal-mechanical models of magma chamber pressurization: Implications for chamber growth and caldera formation

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Rapid magma chamber overpressurization due to the influx of new material or the exsolution of volatiles is often cited as a triggering mechanism for the eruption of a shallow magma chamber. Specifically, the increase in chamber overpressure may drive the tensile stress along the chamber boundary above the tensile strength of the surrounding wall rock and trigger a dike or sill intrusion and/or eruption. A major limitation to previous numerical and analytical models of magma chamber rupture is that overpressure is assumed constant and applied as a fixed boundary condition. This fixed boundary condition does not allow magma chamber expansion to dissipate overpressure. Understanding how overpressures build is critical for determining eruption triggers. In this study, we utilize thermomechanical models to investigate how magma chambers overpressurize as the result of either the influx of new melt or volatile exsolution. By incorporating an adaptive reservoir boundary condition we are able to track how overpressure dissipates as the magma chamber expands to accommodate internal volume changes. We find that the size of the reservoir greatly impacts the resultant magma chamber overpressure. In particular, overpressure estimates for small to moderate sized reservoirs (1-10 km^3) are up to 70% lower than previous predictions. Furthermore, our models indicate that systems >100 km^3 do not generate large overpressures, because magma volume changes are accommodated by deformation of the viscoelastic host rock. We apply our models to Santorini Volcano in Greece where recent seismic activity and ground deformation observations suggest the potential for a large caldera forming eruption. A viscoelastic model with a fixed overpressure boundary condition predicts a much lower magma flux than calculated using a Mogi source. This suggests that the increase in volume flux is much more modest than has been indicated in previous investigations. Conversely, the incorporation of an adaptive boundary condition reproduces Mogi estimations of a high magma flux and suggests that the magma reservoir present at Santorini may be quite large. Model results further indicate that, if the magma chamber is >100 km^3, overpressures generated due to the high magma flux may be below the tensile strength of the host rock, thus requiring an additional triggering mechanism for eruption.