EGU21-11191
https://doi.org/10.5194/egusphere-egu21-11191
EGU General Assembly 2021
© Author(s) 2022. This work is distributed under
the Creative Commons Attribution 4.0 License.

Thermomechanical Controls on the Timing of Magma Reservoir Failure in a Viscoelastic Crust

Matthew Head[1], James Hickey[1], Joe Thompson[1], Joachim Gottsmann[2], and Nicolas Fournier[3]
[1]Camborne School of Mines, University of Exeter, Penryn, UK (m.head2@exeter.ac.uk)
[2]School of Earth Sciences, University of Bristol, Bristol, UK
[3]GNS Science, Wairakei Research Centre, Taupō, New Zealand

As volcanic systems undergo unrest, understanding the conditions required for reservoir failure, the associated timescales, and the links to geophysical observations are critical when evaluating the potential for eruption. The characteristics and dynamics of a pressurised magmatic system can be inferred from episodes of surface deformation, but this process is heavily reliant on the assumed crustal rheology. In volcanic regions, shallow or long-lived magmatic systems can significantly perturb the regional geothermal gradient, altering the rheology of the surrounding crustal rock. Viscoelasticity incorporates a time-dependent viscous deformation response, accounting for the increased ductility and thermomechanical heterogeneity induced by the modelled reservoir.

Here, we investigate the influence of an imposed thermal regime on the critical reservoir overpressure (OPc) required to facilitate failure in elastic and viscoelastic models, alongside the predicted critical surface uplift (Uc). By evaluating tensile and Mohr-Coulomb failure criteria on the reservoir walls, we can determine the mechanical stability of the magma reservoir and identify the conditions that are susceptible to failure. We explore a range of reservoir temperatures (representing felsic, intermediate, and mafic magma compositions) and background geothermal gradients, to simulate varied volcanic regions, and use the Standard Linear Solid viscoelastic rheology together with a temperature-dependent viscosity structure, calculated from the thermal constraints. The models incorporate mechanical heterogeneity in the form of a temperature-dependent Young's modulus, accounting for the thermal weakening of the surrounding crustal rock. We use an overpressure rate of 10 MPa yr^{-1}, in excess of lithostatic pressure, that produces an average elastic volumetric strain rate of ~3-7x10^{-12} s^{-1}, depending on the imposed thermal regime.

We show that reservoir failure is systematically inhibited by incorporating viscoelasticity, with OPc for Mohr-Coulomb failure increasing by up to 65% with respect to the corresponding elastic model. The greatest increases in OPc, and Uc, are observed when pairing cool reservoir temperatures (i.e., felsic composition) with low background geothermal gradients. In contrast, stress partitioning due to the viscoelastic crustal rheology promotes failure at the ground surface, decreasing the required OPc for tensile failure by up to 32%. The greatest reductions in OPc are

produced in models that couple a hot reservoir temperature (i.e., mafic composition) with low background geothermal gradients. By resisting mechanical failure on the reservoir wall, temperature-dependent viscoelasticity impacts the conditions required for dyke nucleation and propagation. Further to this, a viscoelastic crustal rheology dramatically reduces the timescales for throughgoing failure; complete brittle failure connecting the reservoir to the ground surface. This occurs much earlier than suggested by elastic models, which could have implications for interpreting the conditions, and onset, of a potential eruption.