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Finite-element modelling of visco-elasto-plastic two-phase flow

Tobias Keller (1), Dave May (1), and Boris Kaus (2)

(1) ETH Zürich, Geophysics, Zürich, Switzerland (keller@erdw.ethz.ch), (2) J. Gutenberg-Universität Mainz, Geosciences, Mainz, Germany

Many unresolved questions in geodynamics revolve around the physical behavior of the two-phase system of a silicate melt percolating through and interacting with a tectonically deforming host rock. Well accepted equations exist to describe the physics of such systems and several previous studies have successfully implemented various forms of these equations in numerical models. To date, most such models of magma dynamics have focused on mantle flow problems and therefore employed viscous creep rheologies suitable to describe the deformation properties of mantle rock under high temperatures and pressures. However, the use of such rheologies is not appropriate to model melt extraction above the lithosphere-asthenosphere boundary, where the mode of deformation of the host rock transitions from ductile viscous to brittle elasto-plastic. Here, we introduce a novel approach to numerical model magma dynamics, focusing on the conceptual study of melt extraction from an asthenospheric source of partial melt through the overlying lithosphere and crust. To this end, we introduce an adapted set of two-phase flow equations, coupled to a visco-elasto-plastic rheology for both shear and compaction deformation of the host rock in interaction with the melt phase. We describe an implementation of such a physical model into a finite-element code and evaluate the functionality and potential of this methodology using a series of simple model setups, which demonstrate the modes of melt extraction occurring around the rheological transition from ductile to brittle host rocks. The models suggest that three principal regimes of melt extraction may emerge: viscous diapirism, visco-plastic decompaction channels and elasto-plastic diking. Thus, our model of magma dynamics interacting with active tectonics of the lithosphere and crust provides a unique framework to further investigate magmato-tectonic processes such as the formation and geometry of magma chambers and conduits, as well as the emplacement of plutonic rock complexes.