Numerical modeling of two-phase flow: Interaction of partial melting with active tectonics

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We investigate the behaviour of a two-phase system that involves partial melt production and percolation through a viscoelastoplastic continental lithosphere and crust under ongoing tectonic deformation. Using two-dimensional numerical simulations we examine the coupled magmatic and tectonic processes leading to intrusive rock formation in a continental setting. We do this by tracking melt from its formation in the upper mantle, during its ascent through the lithosphere, until it is emplaced and crystallized as an intrusive body in the crust.

The numerical modeling approach is based on the assumption that the melt fraction is equal to the porosity of the rock and that porosity change reflects, apart from melting and crystallization, the compaction or dilation of the matrix framework due to both viscous and elastic processes. Both modes of compaction are connected to the local effective pressure, which is obtained as the difference between the bulk pressure over both phases and the local fluid pressure. The magmatic model is chosen to represent a typical melt evolution starting with an arc-type basaltic melt that will fractionate into mafic cumulates and more highly evolved melt, which will again crystallize as a felsic plutonite rock. Compositional contamination by melting of crustal rocks during the magma's ascent is taken into account.

The model setup involves a continental crust of 50 km thickness and 100 km of the underlying mantle. At the lithosphere-asthenosphere transition, we introduce a source region for partial melt by applying an initial temperature slightly above a wet mantle solidus. The melt production and propagation depends on the evolution of temperature and dynamic pressure in the lithosphere and crust as the region is being deformed tectonically. Here, we focus on extensional tectonics as they provide the best conditions for the extraction of mantle melt. Compressional and transpressional tectonics will be the subject of further investigations.

First results indicate that melt propagation is strongly related to the regional stress field, and that brittle fault zones form important conduits for the propagation of partial melt, especially through the more competent parts of lithosphere and lower crust. Where the partial melt reaches either mechanical barriers or neutral bouancy with respect to the host rock, regions of magma accumulation may quickly evolve into magma chambers with melt content exceeding 80%. There, the melt may either reside until it crystallizes or fractionate until the more evolved rest of the melt has obtained new bouancy to force its way further through the crust.

A possible application of such models is to deepen the understanding of the processes involved in, and the geometry and field relations expected from, the emplacement of hydrated slab melts into the overriding continental plate in an ocean-continent subduction setting.