12th International Workshop on Modeling of Mantle Convection
and Lithospheric Dynamics

August 20th to 25th 2011, Döllnsee Germany

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

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We investigate the behaviour of a two-phase system that involves production and percolation of partial melt through a visco-elasto-plastic 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.

The numerical modeling approach is based on the assumption that the melt fraction is equal to the porosity of the rock and that porosity changes reflects, apart from melting and crystallization, the compaction or dilation of the matrix framework due to visco-elasto-plastic processes. All modes of compaction are connected to the local effective pressure, which can be understood as the volumetric stress acting on the solid rock matrix. 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 rheology of the solid phase largely determines the mode and efficiency of melt transport. Therefore it is of considerable importance to formulate a realistic visco-elasto-plastic rheology. In the case of two-phase flow modeling, we additionally formulate a volumetric viscosity to consitute compaction/decompaction deformation along with a standard deviatoric rheology for shear deformation.

First results indicate that melt propagation is strongly related to the regional stress field, and that plastic failure zones (decompaction tubes, dikes and faults) form important conduits for the propagation of partial melt, especially through the more competent parts of lithosphere and 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 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.