Coupling geodynamic with thermodynamic modelling for reconstructions of magmatic systems

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Coupling geodynamic with petrological models is fundamental for understanding magmatic systems from the melting source in the mantle to the point of magma crystallisation in the upper crust. Most geodynamic codes use very simplified petrological models consisting of a single, fixed, chemistry.

Here, we develop a method to better track the petrological evolution of the source rock and corresponding volcanic and plutonic rocks by combining a geodynamic code with a thermodynamic model for magma generation and evolution. For the geodynamic modelling a finite element code (MVEP2) solves the conservation of mass, momentum and energy equations. The thermodynamic modelling of phase equilibria in magmatic systems is performed with pMELTS for mantle-like bulk compositions. The thermodynamic dependent properties calculated by pMELTS are density, melt fraction and the composition of the liquid and solid phase in the chemical system: SiO_2-TiO_2-$Al2O_3$-$Fe2O_3$-$Cr2O_3$-FeO-MgO-CaO-$Na2O$-$K2O$-$P2O5$-H_2O. In order to take into account the chemical depletion of the source rock with increasing melt extraction events, calculation of phase diagrams is performed in two steps:

1) With an initial rock composition density, melt fraction as well as liquid and solid composition are computed over the full upper mantle P-T range.

2) Once the residual rock composition (equivalent to the solid composition after melt extraction) is significantly different from the initial rock composition and the melt fraction is lower than a critical value, the residual composition is used for next calculations with pMELTS.

The implementation of several melt extraction events take the change in chemistry into account until the solidus is shifted to such high temperatures that the rock cannot be molten anymore under upper mantle conditions. An advantage of this approach is that we can track the change of melt chemistry with time, which can be compared with natural constraints.

In the thermo-mechanical code the thermodynamic dependent properties from pre-computed phase diagrams are carried by each particle using marker-in-cell method . Thus the physical and chemical properties can change locally as a function of previous melt extraction events, pressure and temperature conditions. After each melt extraction event, the residual rock composition is compared with the bulk composition of previous computed phase diagrams, so that the used phase diagram is replaced by the phase diagram with the closest bulk chemistry.

In the thermo-mechanical code, the melt is extracted directly to the surface as volcanites and within the crust as plutonites. The density of the crust and new generated crust is calculated with the thermodynamic modelling tool Perple_X.

We have investigated the influence of several input parameters on the magma composition to compare it with real rock samples from Eifel (West-Germany). In order to take the very inhomogeneous chemistry of European mantle into account, we include not only primitive mantle but also metasomatised mantle fragments in the melting source of a plume (Eifel plume).