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Compositional evolution in magmatic systems investigated by coupled petrological-geodynamical models

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The chemical and mineralogical evolution of crustal magmatic systems are incompletely understood, as most studies are limited either by their temporal or spatial resolution. Exposed plutonic bodies lack information about the chemical, thermal and mechanical processes in the past, which strongly influence the evolution of each individual magmatic system. We focus in our study on the compositional evolution of plutonic systems affected by thermal and mechanical processes. For this, we coupled a 2D visco-elasto-plastic finite element code (MVEP2), with a thermodynamic modelling approach (Perple_X). Density, melt fraction, chemical liquid and solid as well as mineralogical compositions are computed for different starting rock compositions over a given P-T range. The evolving chemistry is tracked on markers via 10 main oxides (SiO_2-TiO_2-Al2O_3-Cr2O_3-MgO-FeO-CaO-Na2O-K2O-H_2O), of which there are initially ca. 2 million. As soon as the local chemistry changes due to melt extraction, new phase diagrams are computed based on the residual solid chemistries for the deflated magma chamber or on the liquid chemistry for newly generated magma filled fractures. Thousands of phase diagrams are computed to track the chemical evolution of each individual marker affected by melt extraction.

For studying crustal scale magmatic systems, we injected mafic sills periodically into the crust. The initial sill injections are focused in either one or two crustal main zones, which may interact with each other. How the composition in magmatic systems changes is controlled by mechanical processes as fractures transport magma through the crust and successively deplete the source region. The formation of magma filled fractures is tracked with a semi-analytical dike/sill initiation algorithm that forms new magma filled fractures as a function of the local stress field above the partially molten region. Dike generation is thus affected by the background strain rate, amount and depth of melt accumulations as well as parameters that control the plastic and viscous behaviour of the crust (e.g. cohesion, viscous creep flow law etc.).

Results show that the lifetime of magma chambers is influenced not only by the thermal structure but also by the formation of magma filled fractures that extract magma and thus deplete the source region. The local stress field affects the crack propagation direction and thus even controls how the surrounded crust is heated up. To which extend melting of crustal host rocks takes place, depends on the number, size and arrangement of magma filled fractures. Magma mixing affects mechanical processes (fracturing) as well as by changing the thermal and compositional structure and thus the amount of melt in the partially molten region.