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Insight into subduction and exhumation processes from thermodynamic and rheologic forward modelling - A case study from the Sesia Zone (Western Alps)

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Thermodynamic and thermo-mechanical calculations are increasingly used to gain insight into processes in subduction zones. We use thermodynamic forward modelling that considers fractional crystallisation and water fractionation in order to understand the physico-chemical properties of subducted slabs of continental crust and thus to constrain the mechanisms that enable their subduction and exhumation.

In order to relate model results to Nature, we compare thermodynamically modelled chemical mineral zonation patterns with those in garnet, amphiboles and mica from structurally well-defined locations in the Sesia Zone (Western Alps). We combine the physico-chemical parameters derived from the thermodynamic models with rheological calculations based on the extrapolation of laboratory-derived flow laws for different deformation mechanisms to study the weakening effects of fluid and grain size reduction during the exhumation of subducted continental crust.

Our results show that the chemical and physical evolution of the subducted slab is intimately tied to its initial volatile content and to the devolatilisation scenario of the buried rocks. Especially water-undersaturation has tremendous effects on the physical properties of the downgoing slab. Initially water-undersaturated, metagranitoid rocks become up to 10% denser than their water-saturated equivalents, facilitating the subduction of continental crust. The depths of devolatilisation- and density-changing-reactions coincide in "cold" subduction zones. This strongly decreases the bulk strength of the downgoing slab.

Rheologic calculations incorporating the thermodynamically determined rock densities along different possible P-T paths of exhumation show that volume and density changes associated with the retrograde phase transitions, the size of the subducted rock body, and the shear strength of the rock surrounding this body determine whether or not buoyancy-driven exhumation occurs. The nature of the reactions is obviously determined by initial rock composition and the shape of the P-T path. Buoyant rise of subducted continental rocks like those in the Sesia Zone was only possible if the surrounding mantle rock underwent hydrolytic weakening and/or a switch from intracrystalline plasticity to grainsize dependent, viscous granular flow.