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Quantifying fluid-rock interaction by combined thermodynamic and trace element modeling

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The Western Alpine Sesia-Lanzo Zone (SLZ) is a sliver of eclogite-facies continental crust that got exhumed from mantle depth in the hanging wall of a subducted oceanic slab. It was subjected to the influx of fluids originating from devolatilisation reactions in the subducted slab beneath it. Prior to the retrograde fluid influx the SLZ rocks were affected by multiple dehydration reactions due to pre-Alpine amphibolite and granulite-facies metamorphism as well as by the Alpine high-pressure (HP) overprint. As a result of these overprints the relatively dry SLZ rocks are excellent tracers of any fluid infiltration at high pressure during exhumation.

Our samples preserve relict eclogite-facies mineral assemblages that show fluid-induced compositional re-equilibration along grain boundaries, brittle fractures and other fluid pathways. Multiple fluid influx stages are indicated by retrogression of primary omphacite forming phengite, albite and epidote as well as by a characteristic partial compositional replacement and/or overgrowth zoning in phengite and sodic amphibole producing step-like compositional zoning patterns with respect to major and trace elements. Step-like major element zoning in phengite and sodic amphibole is characterised mainly by a drastic Fe-Mg exchange with significantly lower XMg values in the overprinted areas that are well-visible in back scattered electron images. The concentrations of fluid mobile trace elements, such as Li, Be, B, Sr and Pb are different in the cores of phengite and amphibole from different samples and are much lower and tend towards a common value in the affected areas of both minerals.

Thermodynamic forward modelling indicates a minimum reactive fluid influx of 0.1 to 0.5 wt% in weakly-retrogressed samples and 1 to 3 wt% in strongly-retrogressed mylonitic samples. Phase relations and reaction textures indicate a mobility of K, Ca, Fe and Mg, whereas Al is relatively immobile in these medium temperature/high pressure fluids.

Combining thermodynamic models with mass-balanced trace element distribution models, incorporating the effect of fluid influx and fluid liberation, enables quantification of fluid amounts, fluid trace element compositions as well as the distinction between reaction- and fluid-controlled trace element distributions. Our results show that retrograde epidote growth in the SLZ rocks largely controls the budget of Sr and Pb concentrations in the fluid and the wall rock phases. This implies that these two elements are only weak tracers for fluid influx in such a system. In contrast, concentrations of Li, Be and B in phengite and sodic amphibole are largely controlled by the amount and composition of the infiltrating fluid thus being excellent tracers of the fluid-rock interaction. Best fit models show that concentrations in the infiltrating fluid were ca 1, 200, and 400 μg/g for Be, B and Li respectively and that the fluid/rock ratio during infiltration was about 0.01. Fluid-rock interaction and mineral reactions in the wall rock can lead to significant enrichment of Li up to concentrations of 650 μg/g, but has little effect on the concentrations of Be and B, in the fluid. These results suggest a significant fluid-triggered mobilisation of B and Li at blueschist-facies conditions.