

Deciphering the detailed pressure-, temperature and chemical evolution of metamorphic rocks using thermodynamic and trace-element modeling in garnet

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Major element zonations in metamorphic minerals, such as garnet, often preserve detailed information about the temporal physico-chemical evolution of the host rock. Thus, the reaction history of a sample as well as constraints on reaction rates can be deduced from complex growth zonations in garnet and their subsequent diffusional modification. Extraction of this information is often performed using thermodynamic equilibrium models, which is in many cases problematic because the chemical composition of the reacting rock volume continuously changes and amounts. Furthermore, compositions of stable phases are P-T path-dependent parameters. Thermodynamic forward models that utilise Gibbs energy minimisation and consider element fractionation along distinct P-T trajectories yield detailed information about the shape of the P-T path, mineral reactions and changing phase relations during subduction. Apart from major elements, metamorphic minerals often preserve complex trace element zonations that preserve information about mineral reactions and associated kinetic processes, such as transport- or interface-controlled element incorporation in metamorphic phases.

In this work we combine thermodynamic forward models that bear detailed information on mode and major element composition of stable phases with a mass balance distribution of rare earth elements (REE) among the calculated stable assemblage during high pressure metamorphism. The aim is to interpret a combination of modelled major- and trace element zonation patterns in complexly zoned UHP garnets from the Western Gneiss Region (Norway), in order to study mineral reactions, trace element distribution and thermodynamic equilibrium among fluid and solid phases during prograde metamorphism. All investigated garnets show multiple growth zones and preserve complex growth zonation patterns with respect to both, major and rare earth elements. Despite differences in the major element zonation, the REE patterns are almost identical in all garnets and can be divided into four zones with characteristic REE patterns.

Our thermodynamic models can reproduce the complex major element zonations and growth zones in the natural garnets and predict garnet growth during four different reactions: (1) chlorite breakdown, (2) epidote breakdown, (3) amphibole breakdown and (4) garnet growth from cpx at UHP conditions. Mass-balanced REE distribution among the stable phases yielded characteristic REE zonations in garnet closely resembling those observed in the natural samples that reflect mineral breakdown reactions and indicate REE incorporation in near-thermodynamic equilibrium along a steep P-T trajectory.

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