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Thermodynamic forward models to calculate P-T phase diagrams that reflect fractional equilibrium crystallisation of garnet in path-dependent reacting bulk rock chemistries

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Predictions on phase assemblages and phase compositions in metamorphic rock based on thermodynamic equilibrium calculations, such as pseudosections, are prone to misinterpretations due to sluggish reaction kinetics. It is evident that commonly applied thermodynamic calculations require equilibrated chemical potentials within all minerals and throughout the entire considered rock volume. Compositionally zoned metamorphic minerals, often present in metamorphic rocks, indicate element fractionation into the early crystallised cores due to fractional crystallisation and thus reflect small scale chemical disequilibrium domains during the metamorphic evolution of the rock. Garnet, one of the most important minerals in metamorphic petrology, is a classic example of a mineral that often preserves such compositional growth zonations. These compositional variations are blossom and curse, as on the one hand they complicate the extraction of thermodynamic parameters due to their disequilibrium characteristics, on the one hand they record geodynamic processes that can be interpreted if disequilibrium effects are considered in thermodynamic models.

Several works have shown that garnet growth is discontinuous along certain prograde pressure-temperature paths and that bulk rock depletion due to element fractionation can lead to garnet growth interruptions during prograde metamorphism, which in turn leads to characteristic, often step-like compositional zoning and typical concentric inclusion patterns. Understanding of these characteristic patterns will enable more precise quantification of geodynamically relevant factors, such as garnet growth rates and detailed reaction paths.

Here we present thermodynamic forward models that concentrate on the metamorphic evolution of garnet in commonly observed metamorphic settings under the consideration of element fractionation from the effective, i.e. reacting bulk rock composition (EBC) due to fractional garnet crystallisation. We model garnet growth along a series of P-T paths, representative for barrovian and subduction zone metamorphism in basaltic and felsic rock compositions in order to detect path-dependent P-T regions of limited or ceased garnet growth.

With our approach it is possible to detect fields that are characterised by thermodynamic garnet destabilisation due to changing EBC as a result of fractional garnet crystallisation along typical P-T paths. The mapped areas of limited garnet growth occur in metapelitic as well as metabasaltic rocks and develop along barrovian but also high-pressure P-T paths. Such general thermodynamic forward models allow a better general interpretation of often observed garnet growth zonations resulting from fractional crystallisation and sluggish diffusional re-equilibration.