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The use of trace element zoning patterns in garnet to infer reaction paths of metamorphic rocks

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Garnet is one of the most versatile minerals in metamorphic petrology. It is stable over a large pressure and temperature range and thus occurs in many metamorphic environments. Garnet has a wide range of chemical compositions and its major and trace element composition well reflects the pressure (P), temperature (T) and chemical conditions (X) as well as the element transport kinetic properties of the host rock during growth. Hence, compositional growth zonations in garnet contain information about most geochemical, mineralogical and petrological properties of metamorphic rocks. However, detailed interpretation of complex zoning patterns in metamorphic garnet was hindered mainly by the lack of knowledge about the various contributions of kinetic and equilibrium effects to the trace element incorporation into garnet.

In this contribution we combine thermodynamic equilibrium calculations together with mass balanced trace element distribution among coexisting phases with diffusion models that simulate kinetically controlled element transport in a reacting host rock. Comparison of the model results with natural garnets enables detailed interpretation of commonly observed major and trace element patterns in high-pressure (HP) and ultra-high pressure (UHP) garnets in terms of reaction paths and physico-chemical properties of the host rock.

The comparison of our numerical models with a series of well-investigated (U)HP samples shows that the kinetic influence on rare earth element incorporation into garnet is limited in most rocks at the early stages of garnet growth and increases with increasing grade of rock transformation. We show that REE zoning patterns can be used to distinguish between cold (lawsonite-stable) and warm (epidote-stable) prograde reaction paths. REE liberation along a warm P-T trajectory occurs in three breakdown reactions involving chlorite, epidote and amphibole. All three reactions result in characteristic heavy (HREE) and medium (MREE) REE growth patterns in garnet reflecting the contrasting partition of REE among garnet and the reacting mineral matrix. In contrast, REE liberation along a cold trajectory is predominantly controlled by the breakdown of amphibole, which produces a pronounced incorporation of both HREE and MREE in the rims of the growing garnet. Chromium concentration variations in garnet are also an excellent source of information about the reaction path. The Cr distribution in garnet cores from different UHP samples clearly reflects the prograde transformation of magmatic clinopyroxene into garnet+omphacite. The formation of garnet from omphacite at UHP conditions is indicated by concentric Cr (and REE) enrichments in the outermost rims of the garnet porphyroblasts.

We would like to emphasise that detailed investigation and interpretation of trace element patterns in metamorphic garnet gives important insight into the reaction path of the host rock, which in turn has crucial implications for the interpretation of geochronological data from metamorphic garnets.