

Cation diffusion zoning in garnet yields peak temperature and cooling rate

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The retrograde re-equilibration of mineral compositions by volume diffusion poses a potential problem for conventional thermometry, but, on the other hand, opens possibilities for kinetics-based approaches to constrain peak temperature. Divalent cations in garnet are evidently suitable for this purpose, yet their use in geospeedometry is relatively underexploited. We

developed a new model to treat cation diffusion profiles in garnet. To allow active use of this model, we constrained important model parameters empirically. This was done through an EPMA major-element study on large garnet grains (1-6 mm) from a slowly cooled granulite from the Pikwitonei Granulite Domain, Manitoba, Canada.

Diffusion zoning was observed for all major divalent cations in garnet. Length scales differ among diffusing species, increasing from ca. 0.5 mm for Ca to well over 1.5 mm for Fe(II) and Mg. The results are used in conjunction with the well-known geological boundary conditions and cooling history of the sample 1) to test estimates of divalent-cation diffusion parameters in natural samples and 2) to develop a tool that constrains peak temperature for garnet-bearing rocks using diffusion zoning in garnet.

The approach was tested externally by applying it to various metamorphic terranes worldwide to estimate peak temperatures of metamorphism. The results overlap within uncertainties with published peak temperature estimates, but are up to four times more precise. The combination of diffusion models for Mg and Ca eliminates one variable from the calculations and thus yields constraints on peak temperature and average cooling rate from the major element analysis of garnet crystals alone.

High-grade metamorphic rocks, which are pushed far from their composition at peak conditions, are characterized by well developed diffusion zoning and hence provide more precise estimates of peak temperatures using this method. This unusual and counterintuitive aspect indicates the fundamental difference to conventional thermometry. Unlike that approach, 'diffusion thermometry' employs the tendency of natural systems towards equilibrium rather than requiring this state to be reached. This simple and effective way to estimate peak temperatures is particularly advantageous in cases where insufficient equilibration, significant retrograde re-equilibration, or the absence of critical assemblages complicate the use of conventional thermometers.