New insights into the origin and fate of REE zoning in garnet from in-situ trace-element mapping

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Garnet is without a doubt the most useful and versatile mineral in the study of lithosphere dynamics, as it provides a direct record of pressure, temperature, time, deformation, and fluid flow in metamorphosed rocks. The concentration and zoning of rare earth elements (REE) in garnet are central to extracting such information; REE in garnet enable garnet chronology (Sm-Nd, Lu-Hf), and impart a "garnet-stable" signature on cogenetic phases, which allows petrochronology and general petrogenetic tracing of garnet stability in minerals and melts. There is nevertheless significant uncertainty in the actual meaning of REE compositions and zoning in terms of the mechanisms by which garnet grows and incorporates REE, and the possible role of REE diffusive re-equilibration.

To provide new insight into the REE systematics of garnet, we applied quantitative trace-element mapping of garnet grains from metamorphic rocks that record peak temperatures above 750°C and cooling rates as low as 1.5 °C Myr^{-1}. The mapping was done using an ArF excimer laser ablation (LA) system equipped with a fast-evacuation ablation cell coupled to a high-resolution double-focussing single-collector inductively coupled plasma mass spectrometry (ICPMS) instrument at the Vegacenter, Swedish Museum of Natural History. The results were compared with numerical simulations of REE diffusion in garnet using experimental diffusivity constraints.

Garnet in all samples preserves Rayleigh-type or oscillatory growth zoning with sharply defined interfacial angles that match the garnet habit. Oscillatory zoning, in particular its uniform restriction to peripheral parts of metamorphic garnet, can be explained through the kinetics of garnet nucleation and growth and thus neither require nor indicate external forcing, such as tectonic processes or alternating between open- and closed-system behaviour. Re-equilibration of REE compositions appears restricted to domains with nebulous and patchy zoning, which likely form by interface-coupled dissolution and re-precipitation reactions mediated by fluids or melts. In all cases, the observed growth zoning is inconsistent with the fast diffusivity predicted by experiments. These observations demonstrate the reliability of REE signatures in magmatic tracing and petrochronology, and establish Lu-Hf chronology as an accurate and precise means of dating garnet.