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Stress-induced redistribution of yttrium and heavy rare-earth elements (HREE) in garnet during high-grade polymetamorphism

T.S. Røhr,* H. Austrheim, and M. Erambert

Physics of Geological Processes (PGP) and Department of Geosciences, University of Oslo, PO Box 1047 Blindern, 0316 Oslo, Norway

Abstract

Almandine garnet ($Alm_{62.6}Pyr_{11.4}Sps_{8.4}And_{6.5}Grs_{4.0}$) exceptionally rich in Y_2O_3 (1.8–2.3 wt%), Sc_2O_3 (0.11–0.23 wt%), $HREE_2O_3$ (1.9–2.3 wt%), and Na_2O (~0.3 wt%) occurs in Precambrian quartzofeldspatic granulites (T ~ 860 °C) on Hisarøya, Western Gneiss Region, Norway. The granulites were partially reequilibrated to eclogite-facies (P = 14.9 ± 1.3 kbar, T = 649 ± 67 °C) and amphibolite-facies assemblages during the Caledonian Orogeny. The granulite-facies garnet is reequilibrated in an outer zone, typically ~4 µm thick, where both Y_2O_3 and $HREE_2O_3$ concentrations decrease to 1.2 wt%, and overgrown by Caledonian garnet with Y_2O_3 and $HREE_2O_3$ both below 0.1 wt%. The granulite-facies cores are also reequilibrated to lower Y_2O_3 and $HREE_2O_3$ (both ~1.8 wt%) along deformation structures including microfaults with horsetails, en-echelon bands, and splaying features around the tip of fractures. Locally, these reequilibrated zones, typically 10–20 µm across, have shoulders with higher Y and HREE (~2.9 wt%) than in the original garnet, suggesting closed-system behavior for these elements. In addition, the garnet locally displays a complex mesh-like pattern with high and low HREE and Y bands, possibly related to strain. Two charge-balancing mechanisms account for Y and HREE incorporation: (1) the yttrium aluminum garnet ($Y_2Al_2O_6$, YAG) substitution involving incorporation of Al into the tetrahedral site is dominant in the granulite-facies garnet, and (2) coupled substitution with Na into the dodecahedral site is increasingly important during high-P reequilibration. The internal closed-system reequilibration of the granulite-facies garnet may be related to stress concentrations build up in garnet during the eclogite-facies event. Local stress concentrations during propagation of fractures may be the driving force behind the redistribution of elements seen within cores of granulite-facies garnet.

Keywords: Garnet, almandine, HREE, heavy rare earth elements, yttrium, sodium, Lu, Yb, Er, Tm, Dy, YAG, WGC, granulite, eclogite, deformation, fracturing, fracture propagation, diffusion