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Enhanced mass transfer through short-circuit diffusion: Growth of garnet reaction rims at eclogite facies conditions

Lukas M. Keller,[1,*] Rainer Abart,[1] Richard Wirth,[2] Daniel W. Schmid[3] and Karsten Kunze[4]

[1]Institute for Geological Sciences, Free University Berlin, Malteserstrasse 74-100, 12249 Berlin, Germany
[2]GeoForschungsZentrum Potsdam, Department 4, Telegrafenberg, 14482 Potsdam, Germany
[3]Physics of geological processes, University of Oslo, 1048 Blindern, 0316 Oslo, Norway
[4]Institute for Geology, Swiss Federal Institute of Technology, Sonneggstrasse 5, 8092 Zürich, Switzerland

Abstract

In the Monte Rosa area, Northern Italy, the assemblage garnet + phengite + quartz was formed in polymetamorphic metapelites from pre-existing biotite and plagioclase during an eclogite-facies Alpine metamorphic overprint. While phengite nucleated within plagioclase, garnet formed 10 to 20 μm wide continuous rims along the original biotite-plagioclase interphase boundaries. Garnet formation involved diffusion of Ca-, Fe-, and Mg-bearing species across the growing rims. The garnet rims show an overall asymmetric compositional zoning and distinct nanometer scale chemical patterns across grain boundaries within the garnet polycrystal. The compositional patterns resulted from the interplay of diffusion along grain and interphase boundaries and volume diffusion. Individual garnet crystals are separated by low-angle grain boundaries, which are predominantly oriented perpendicular to the reaction rim giving rise to an overall palisade microstructure. Grain boundaries contain arrays of closely spaced channels about 2 nm wide, which are filled with an amorphous phase. These channels represent direct links between the garnet-biotite and garnet-plagioclase reaction fronts and provide pathways for fast diffusion. From numerical simulation of the observed chemical patterns, diffusion of Ca and Fe is inferred to have been 5–6 orders of magnitude faster within grain boundaries than through the interior of garnet grains. Although the amorphous grain boundary phase only takes up a small fraction (2–5 per mil) of the total volume of the garnet polycrystal, short-circuit diffusion along grain boundaries contributed substantially to material transfer across the growing garnet rim. Despite the presence of fast pathways, bulk diffusion was too slow to allow for chemical equilibration of the phases involved in garnet rim formation, even on a micrometer scale. Relying on published garnet volume diffusion data, D_{gb} (where gb = grain boundary), is estimated to be on the order of $10^{-(19-20)}$ m^2/s at the estimated reaction conditions of 650 °C and 12.5 kbar, where D_{gb}^{Ca} is slower than D_{gb}^{Fe} by a factor of ten.

Keywords: Garnet, high-pressure metamorphism, grain boundary, diffusion, TEM