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SPECIAL COLLECTION: MECHANISMS, RATES, AND TIMESCALES OF GEOCHEMICAL TRANSPORT PROCESSES IN THE CRUST AND MANTLE

Timescales of exhumation and cooling inferred by kinetic modeling: An example using a lamellar garnet pyroxenite from the Variscan Granulitgebirge, Germany†

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Abstract

We present a numerical modeling approach to infer timescales of the exhumation and cooling history recorded in the chemical composition of minerals in a garnet pyroxenite from the Granulitgebirge, Saxony/Germany. The studied sample contains remarkable exsolution textures from former megacrysts that produced up to millimeter-wide, alternating lamellae of garnet (Grt) and clinopyroxene (Cpx). Compositional profiles of major and minor elements measured with the electron microprobe perpendicular to the Grt-Cpx interfaces reveal systematic zoning patterns for Fe, Mg, Al, Si, Cr, Ti in clinopyroxene and Ca, Fe, Mg, Mn in garnet, respectively. In addition to simple thermal modeling that is used to constrain the conditions of emplacement of the Granulitgebirge Massif at shallow crustal levels, we combine thermodynamic data with a numerical finite difference scheme that simulates growth and simultaneous diffusive exchange between garnet and clinopyroxene along a virtual cooling path. The latter model assumes local equilibrium at the interface. Diffusive fluxes are constrained by mass balance. It is shown that zoning patterns such as Fe-Mg exchange between garnet and clinopyroxene can be used to extract cooling rates and thus timescales of exhumation, while the profiles for the minor elements are provisionally related to the growth history of the lamellae. Furthermore, zoning profiles in the lamellae can only be reproduced with ultrahigh cooling rates similar to contact metamorphic conditions. This in turn, suggests that the massif was emplaced at temperatures above 900 °C in agreement with the observed spatial extent of a contact aureole within low-grade metasedimentary rocks surrounding the granulite massif as predicted by thermal modeling. Exhumation of the massif without cooling below 900 °C requires an exhumation rate of several centimeters per year. Thus, we propose an almost isothermal exhumation period of ~1 Ma followed by isobaric cooling from 900 to 600 °C within less than 10 ka.

Keywords: Diffusion, timescales, garnet, clinopyroxene, kinetics, reaction rate, contact metamorphism