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Using element zoning in minerals to add a time constraint to the P-T evolution of crustal geodynamic processes: A study of a lamellar garnet pyroxenite from the Variscan Granulitgebirge, E Germany

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The Granulite Massif is a dome structure in the central part of the Mid-European Variscan Belt. The exhumed massif consists of high pressure granulite facies rocks and fragments of altered oceanic crust and mantle. Estimated metamorphic peak conditions of 2.3 GPa and 1000°C and geochronology data suggest exhumation rates of >9-18 mm/yr (Rötzler & Romer, 2001). Determination of peak conditions rely on the assumption that equilibrium between minerals was attained and, more importantly, completely preserved during the entire exhumation process. Similarly, determination of exhumation rates is based on the temperature dependent closure of the diffusion of certain isotopes or fission tracks in minerals. This method only represents an average between two or more single temperatures. In this study, we take advantage of the fact that the chemical composition of a solid-solution phase is a function of intensive variables, such as temperature and/or pressure. The dynamic nature of geological processes such as exhumation leads to the adjustment of the mineral composition. The change of chemical composition, however, requires mass transport of major and trace elements, which is often kinetically controlled and leads to incomplete equilibration as preserved in element zoning patterns. Unraveling such zoning patterns combined with geothermobarometry is thus the key tool to decipher the origin and evolution of a mineral along a P-T-t-path.

We present data of a garnet pyroxenite from the Granulitgebirge, Germany. The rock contains remarkable exsolution textures from former megacrysts (Massonne & Bautsch, 2002) that produced up to mm-wide, alternating lamellae of garnet (grt) and clinopyroxene (cpx). Compositional profiles of major and trace elements measured with the electron microprobe perpendicular to the grt-cpx interfaces reveal systematic zoning patterns for Fe, Mg, Al, Si, Cr, Ti in cpx and Ca, Fe, Mg, Mn in grt.

In addition to simple thermal modelling 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 grt and cpx 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 grt and cpx can be used to extract cooling rates and thus timescales of exhumation, while other profiles, such as Ca, Al, and Si can be rather 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. In turn, this suggests that the massif was emplaced at temperatures above 900°C in agreement with the observed spatial extent of the low-grade metasediments surrounding the Granulitgebirge Massif as predicted by thermal modeling. Exhumation of the massif without cooling below 900°C requires an exhumation rate comparable to the speed of active plate movements (several cm/yr). Thus, we propose an almost isothermal exhumation period of $\sim$2 Ma followed by rapid, isobaric cooling from 1000 to 600°C within less than 10 ka.