Constraints on Sm-Nd diffusion rates from laser ablation ICP-MS analyses and conventional dating of prograde garnets

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Metamorphic garnets are important phases for obtaining both P-T and age information on metamorphic processes. Establishing the rates of cation diffusivity and closure temperatures of the relevant isotopic systems in garnet are therefore crucial for any P-T-t interpretations in metamorphic terranes. While the generally slow diffusion rates of major and trace cations in garnets do not allow a precise experimental determination of their respective diffusion data, calculation of diffusion parameters from the composition of natural garnets is often hampered by the lack of information on their prograde evolution and independent P-T-t constraints.

Here we report results of a major element, *REE* and Sm-Nd isotopic study of prograde garnets from the HP-HT felsic granulites from the Variscan Bohemian Massif. The garnets (Alm 0.53, Prp 0.27, Grs 0.19, Sps 0.01, up to 2 mm in diameter) are zoned in Mg, Fe, Ca and Mn with Fe/(Fe+Mg) decreasing from core to rim. The outer rim (*c*. 200 microns) shows retrograde zoning with increasing Fe/(Fe+Mg), decreasing Ca and a large increase of Mn content (Fig. 1). As garnet is the only Mn-bearing phase in the rock, the Mn increase in the rim can only be attributed to garnet resorption during the retrograde decompression path. Composition maps suggest that the zoning in the rim is not related to proximity of any other phase (e.g. biotite or plagioclase) in the matrix. Laser probe ICP-MS analyses from the identical grain show zoning in *REE* on a comparable scale to that of the major elements, with Sm and Nd concentrations of 10 and 6 ppm in the core and 5 and 1 ppm in the rim, respectively. The Sm/Nd ratio of 1.5 is constant across the grain, suggesting an infinite *REE* reservoir (i.e. efficient *REE* mobility) during garnet growth. However, it increases to 5.5 in the outer 200 microns of the profile. This is also likely to have resulted from the preferential uptake of Sm to Nd during garnet resorption.

Modelling the garnet core and plagioclase compositions using THERMOCALC suggests that they equilibrated at *c*. 20 kbar and 1000°C but approx. 20% of the original garnet volume has been resorbed during decompression and exhumation to upper crustal levels. However, such P-T conditions contrast with biotite inclusions which are present as a prograde phase in the garnet. Simple diffusion modelling using the available diffusion parameters for major cations suggests that in order to preserve the residual growth zoning, the studied garnet must have spent only a short time («1 Ma) at the peak conditions. In such a short time span the heat could not have been conducted to the crust but it was rather heated through convection of mantle melts. A minimum final equlibration temperature of the garnet rim and matrix biotite of 750°C is calculated from the Fe-Mg exchange. A whole-rock–garnet Sm-Nd isochron yields an age of 351 $\pm$ 4 Ma. Because of the presence of the high Sm/Nd rim in the garnets, this data can only represent a minimum age for prograde garnet growth. The end of prograde evolution is further constrained by a series of U-Pb zircon and monazite data as well as Sm-Nd dating of other garnets and accessory phases. These mark the drop in temperature below *c*. 700°C following isobaric decompression and mostly yield ages in the range of 345–338 Ma. In addition, hornblende, muscovite and biotite Ar-Ar ages, which cluster within the range of 330–295 Ma, indicate a cooling rate of *c*. 9–10°C/Ma between 340 and 295 Ma.

The studied compositional profiles show that both prograde and retrograde zoning of major cations and *REE* in the garnet have been preserved on the same (1 mm) scale. In addition, it can be inferred from the geochronological data that the garnet must have stayed above *c*. 700°C for a minimum of 10 Ma without resetting its Sm-Nd isotopic system.

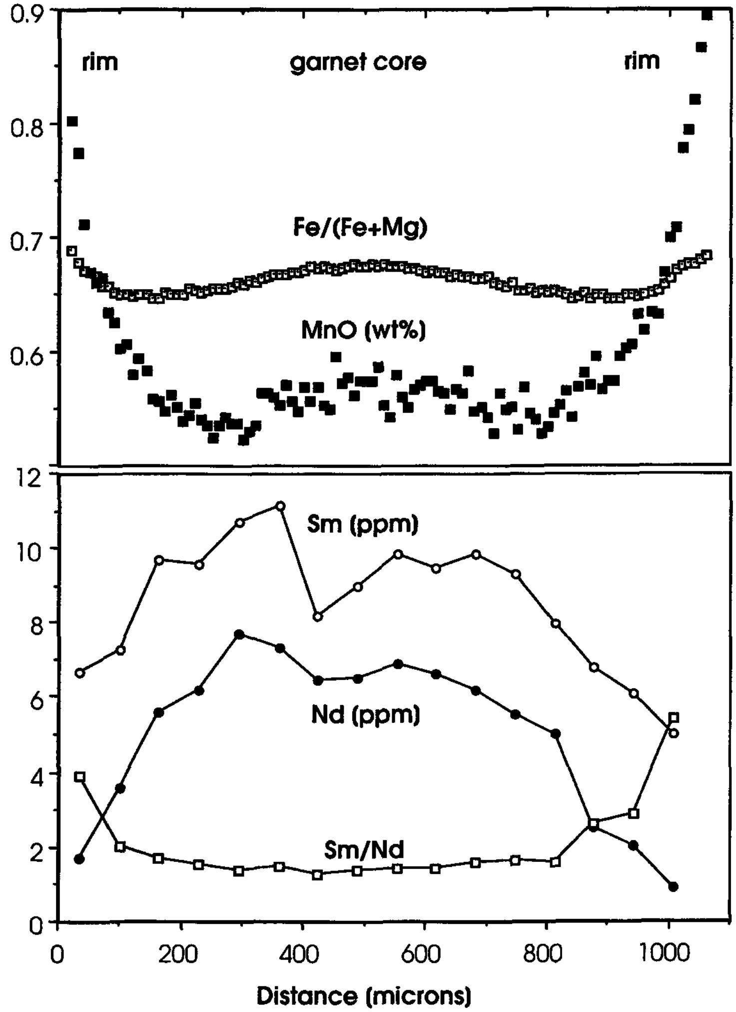

FIG. 1. Prograde and retrograde zoning of major cations and *REE* in garnet.

Accordingly, the major cations and the rare earth elements in garnets (of comparable composition) should also have similar diffusion parameters and the Sm-Nd ages of garnets which preserve their major-element growth zoning should correspond to the time of garnet growth.