Experimental *REE* partitioning between amphibole, clinopyroxene, garnet and basaltic to tonalitic melts: applications to the tonalite genesis

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Tonalites and trondhjemites from Archean greenstone belts and present-day active continental margins have steep negative slopes with N-MORB normalized (La/Yb) ratios between 20 and 60 (Rudnick & Taylor, 1986; Wedepohl *et al.*, 1991). It is widely accepted today that tonalitic melts from these tectonic settings are formed by partial melting of basic lower crust (Arth & Hanson, 1972, Martin, 1987, Wedepohl *et al.*, 1991). There is no consensus, however, whether garnet or amphibole in the crystalline residue of tonalitic melts accounts for their steep *REE*-patterns. Distinguishing between these alternatives requires, in particular, reliable sets of garnet/liquid and amph/liquid partition coefficients relevant for P, T, X conditions of tonalite genesis. In this paper we present new experimentally determined partition coefficients of rare earth elements for garnets, amphiboles and clinopyroxenes in equilibrium with a tonalitic melt and discuss their implications for tonalite genesis.

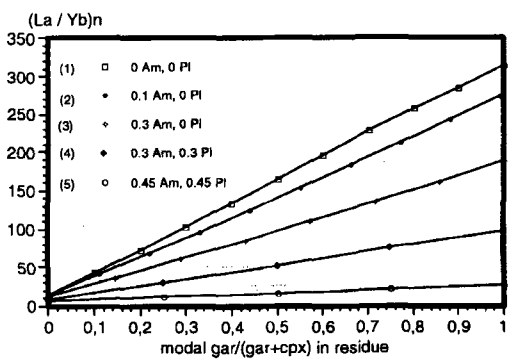

FIG. 1. Calculated $(La/Yb)_n$ ratios as function of the modal gar/(gar + cpx) fraction and different plagioclase and amphibole contents in residues for granulite xenolith S36 at melting degrees of 15%. The shaded area indicates La/Yb ratios of natural tonalites and trondhjemites.

Experiments with a basic granulite from Eifel (Germany) plus 1 wt% H_2O and a tonalite from Tonale (western Alps, Italy) plus 7 wt.% H_2O were carried out at 10 to 15 kbar and 800 to 1150°C using doped and undoped samples. Run products from experiments with doped materials were analyzed by EMS (Cameca Camebax), those from samples with lower doping levels and natural trace element abundances were analyzed by Cameca 3f ion probe. To avoid mutual analytical interferences only two trace element oxides (0.5 wt. %) were added to different splits of the sample in each experiment. The partition coefficients measured with the electron microprobe were determined by a method similar to that of McKay (1986).

At 1100°C and 12.5 kb as well as at 1100°C and 15 kb, runs producing clinopyroxenes and garnets, respectively, were reversed for all elements. For these two series the partition coefficients agree very well within analytical errors.

In order to check the validity of Henry's Law in our experiments, two sets of runs were carried out. For clinopyroxenes experiments were performed at the same run conditions (1100°C, 12.5 kb) at different doping levels of either Yb or Ce, and for garnets (1100°C, 15 kb) at natural concentrations and 0.5 wt.% doping level. Within analytical error, the values obtained at different doping levels and with different analytical techniques (SIMS and EMP) agree very well, indicating Henry's Law behaviour for the rare earth elements within the investigated concentration range.

Partition coefficients of amph./liquid, cpx/liquid, and garnet/liquid, where liquid is a tonalitic melt, obtained in this study are used below to calculate hypothetical *REE*-patterns of tonalitic melts obtained for 15% partial melt from basic granulite xenoliths believed to represent lower crust beneath the Eifel/Germany (Loock *et al.*, 1990). Assuming that the trace element

abundances of the granulites are equal to those of the tonalite source rock and that the tonalitic melts are generated by a process close to batch melting, normalized La/Yb ratios shown as a function of the modal cpx/gar ratio of crystalline residues in Fig.1 are obtained. The various curves in Fig.1 reflect the modal proportions of the other mineral phases which may be present in the residue of a tonalitic melt. They define a range from bi-mineralic eclogite (garnet-cpx, upper curve) to garnet amphibolite (lower curve). The shaded field shows the $(La/Yb)_N$-ratio of tonalites from Archean terraines and active continental margins.

According to Fig.1 the modal proportion of garnet in the residue of natural tonalite melts has to be restricted to a narrow range in order to account for their $(La/Yb)_N$-ratios. In bi-mineralic cpx-gar-assemblages (curve 1) values in excess of 60 are obtained as the modal proportion of garnet exceedes 15 wt.%. For eclogites (25 to 60 wt.% garnet), hypothetical $(La/Yb)_N$-ratios range from 85 to almost 200. At the same time $(Yb)_N$ drops to values of less than 0.08 which is significantly below the MORB-normalized Yb abundances (<0.1) of any natural tonalite. On the other hand, in amphibolites (curves 4 & 5) at least 5 to 6 wt.% garnet is required to reach a minimum value of 20 for $(La/Yb)_N$.

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