Distribution of incompatible trace elements between the constituents of mantle spinel peridotites: Inversion of ICP-MS data

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Minerals of the Earth's upper mantle have crystal structures notoriously unfavourable to large ion lithophile elements (LILE, such as K, Rb, Cs, Ba, Th, U), and to some extent to the high field strength elements (HFSE, such as Nb and Ta). Several authors have suggested that, in the convective mantle and the lower lithosphere, these 'highly incompatible elements' are dominantly concentrated in small fractions of partial melt. These melts would be volatile-rich and rather similar in composition to kimberlites and/or carbonatitic magmas (McKenzie, 1989). Alternatively, at shallow depth (lithosphere), the small volume melts could be silica-rich (Schiano and Clocchiatti, 1994; Kelemen *et al.*, 1995).

In the lithospheric mantle, LILE and HFSE may also be concentrated in accessory minerals such as amphibole, phlogopite, apatite and titanates, in fluid-derived inclusions trapped in minerals, or along grain boundaries (e.g. Zindler and Jagoutz, 1988). Among the predominant rock-forming minerals, only clinopyroxene is considered to play a significant role as a host for incompatible elements. However, very few high-quality are available to constrain these assumptions. Minerals such as orthopyroxene, olivine and spinel have rarely been analysed, and the importance of fluid/melt inclusions and grain boundaries as reservoirs of trace elements remains controversial. For this reason, some important issues such as the behaviour and distribution of the HFSE in the upper mantle are still a matter of debate.

The aim of this paper is to provide quantitative estimates of the distribution of lithophile trace elements between the various constituents of spinel peridotites from the East African Rift. Predominant and accessory minerals were separated in 12 mantle xenoliths from Mega (Sidamo region, South-Eastern Ethiopia). The samples range in composition from fertile, cpx-rich lherzolites to refractory harzburgites and show variable degree of recrystallization coupled with trace-element variations (Bedini *et al.*, 1997). The less recrystallized samples (deformed xenoliths) consist of apatite-bearing porphyroclastic peridotites with low cpx/opx ratios. They are strongly enriched in LILE, with negative anomalies of the HFSE. The most recrystallized samples (granular xenoliths) consist of apatite-free peridotites with coarse-grained, granular textures. These samples are depleted or only slightly enriched in LILE and display no significant HFSE anomaly. Except for minor apatite in some of them, the Sidamo xenoliths are devoid of modal metasomatism. Their trace element concentration encompasses almost the whole range reported in the literature for basalt-borne xenoliths. Mineral separates (ol, opx, cpx, spinel and apatite) and their leachates were analysed by ICP-MS, for rare earth elements (*REE*) and several incompatible trace elements (Rb, Sr, Ba, Zr, Hf, Nb, Ta, Th, U, and Ti). Spinel surfaces were investigated by SEM and EPMA to determine the composition of the attached micro-phases.

In spite of their highly variable trace-element signature, the different rock types show rather similar trace-element distribution between peridotite constituents. Clinopyroxene display systematic, though variable, depletion of HFSE relative to *REE*, both in HFSE-depleted and undepleted peridotites. Our results indicate that this mineral is not the predominant host for the most incompatible elements. Olivine and orthopyroxene have enhanced HFSE abundances relative to *REE*, which, nevertheless, do not balance clinopyroxene depletion.

Mass-balance inversion shows that the trace element composition of whole rocks is controlled by five distinct components (Fig. 1):

(1) the silicate minerals which account for the total *HREE* and Hf abundance, and 50-90% of *LREE*, Sr,

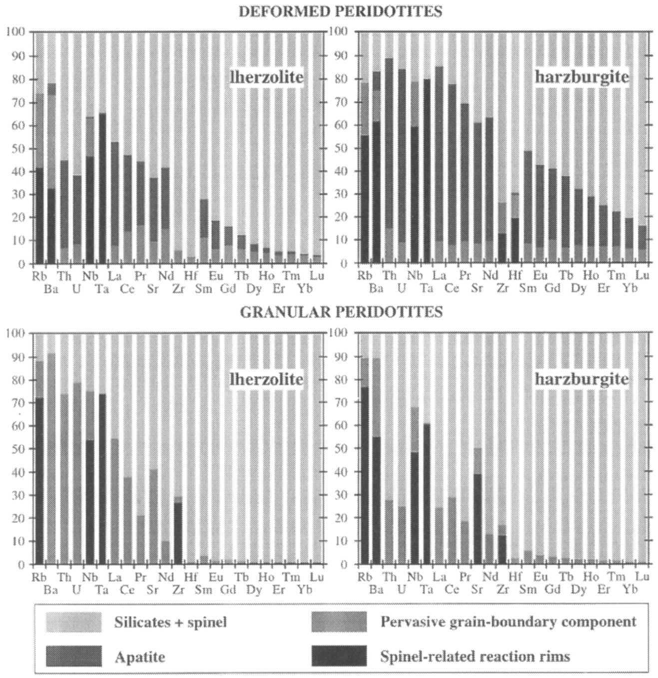

FIG. 1. Contribution (in %) of, respectively, (1) silicate minerals and spinel (with their fluid-derived inclusions), (2) apatite, (3) a pervasive grain-boundary component and (4) microphases attached to spinel surfaces, to the whole-rock composition of Sidamo xenoliths, as calculated with the inverse method of Tarantola and Valette (1982). The results are shown for four samples representative of the main textural and petrographic facies.

and Zr, in the apatite-free peridotites;

(2) the mineral-hosted fluid inclusions which play a significant role for Rb (20–25%), and to a lesser degree for Ba, Th, and U;

(3) a pervasive grain-boundary component, probably of carbonatite composition, which contributes 20–40% of the whole-rock budget for Ba, Th, U, and Sr, and 10–25% for Nb and *LREE*, in the apatite-free samples;

(4) thin reaction layers (< 10 μm thick) coating the surfaces of spinel grains and mainly composed of Ti-oxides and phlogopite. They are the predominant repository of Nb-Ta (50–90%) and Rb-Ba (50–80%) in all studied xenoliths;

(5) apatite which largely predominates the budget of Th, U, Sr, and *LREE* (40–85%) in the samples containing this mineral.

Compared to the other peridotite constituents, fluid inclusions in minerals give a negligible contribution to the trace element budget of the whole-rocks. However, they strongly affect inter-mineral trace element ratios. Inter-mineral element partitioning is dominantly controlled by fluid-derived inclusions for *LREE* and highly incompatible elements such as Rb, Ba, Th, U, Nb and Ta. For the most incompatible elements such Rb, inter-mineral partitioning is close to one in several samples, suggesting that the rock-forming minerals contain similar amounts of homogeneous inclusions.

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