

Geochemical Processes in Peridotite Xenoliths from the Premier Diamond Mine, South Africa: Evidence for the Depletion and Refertilisation of Subcratonic Lithosphere

K.S. Viljoen¹, I.T.M. Dobbe², A.J. Smit³

¹ Mineralogy Division, Mintek, Private Bag X3015, Randburg, 2125, South Africa

² FEI Electron Optics B.V., PO Box 80066, 5600 KA Eindhoven, The Netherlands

³ Group Exploration, De Beers Consolidated Mines, PO Box 82232, Southdale, 2135, South Africa

The Premier kimberlite is located in the Central Terrain of the Archaean Kaapvaal Craton (de Wit et al., 1992), with a preferred emplacement age of 1180 Ma (Allsopp et al., 1989; Richardson et al., 1993). Underground mining operations reveal that the kimberlite, which is cut by a 1100 Ma gabbroic sill, penetrates a norite phase of the Bushveld Complex. The Bushveld Complex is among the largest layered intrusions known, comprising a sequence of basic rocks 7-9 km thick, with an areal extent of 66 000 km² (the Rustenburg Layered Suite) and subsequent granites. The Premier diamond mine is renowned as the source of many of the world's largest gem diamonds, e.g. the Cullinan and Centenary diamonds. The locality has been the subject of xenolith studies (e.g. Danchin, 1979; Boyd and Mertzman 1987; Boyd, 1989; Boyd et al., 1993) as well as minerals occurring as inclusions in diamond (Gurney et al., 1985).

Mantle-derived xenoliths present include harzburgites and lherzolites (Danchin, 1979). Premier garnet lherzolites can be clearly subdivided into coarse and deformed varieties on the basis of differences in mineral composition and texture. Deformed lherzolites may originate from greater depths than those with coarse textures which are in turn more depleted in Fe, Al, Ca and Ti relative to the deformed rocks. Constituent minerals of the deformed xenoliths are extremely titaniferous and clinopyroxenes contain significant potassium. Premier Mine garnet harzburgites are also progressively deformed and less depleted with respect to Fe/Mg with increasing depth of origin (Danchin, 1979).

A prominent upper mantle seismic velocity anomaly within the Kaapvaal craton is associated with the Bushveld layered intrusion (Shirey et al., 2002). In this region, lower than average seismic P-wave velocity appear to extend into the mantle beneath the layered intrusion itself, and also well to the west. Diamond populations from kimberlites located within this region of mantle lithosphere with slower P-wave velocity (including the Premier diamond mine) are characterised by a greater proportion of eclogitic versus

peridotitic inclusions, a greater incidence of younger Sm-Nd ages of silicate inclusions, a greater proportion of diamonds with lighter C isotopic composition, and a lower percentage of low-nitrogen diamonds (Shirey et al., 2002).

The present contribution serves to document evidence found for lithospheric depletion and enrichment in the mantle below the Premier diamond mine through the analysis of mineral and bulk rock compositional trends in garnet-bearing peridotite xenoliths. Trace element contents of garnets in the xenolith suite have been analysed, utilising laser ablation inductively coupled plasma mass spectrometry. The xenolith suite comprises of lherzolites and harzburgites (including subcalcic varieties) which have been previously studied for their major element mineral chemistry and xenolith bulk composition (Fig.1, Danchin, 1979).

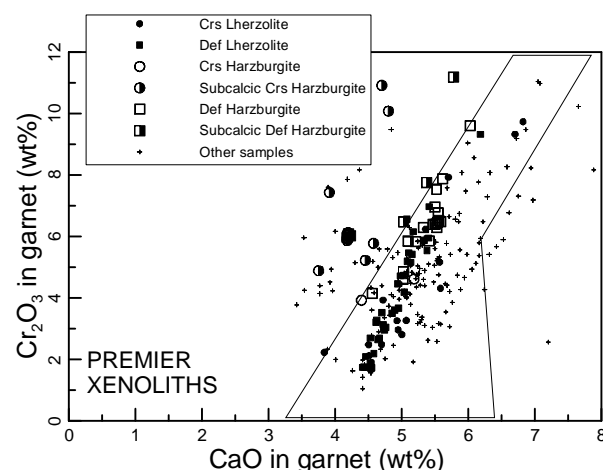


Fig. 1 CaO-Cr₂O₃ chemistry of garnets occurring in xenoliths from the Premier kimberlite, and which were analysed in the present study. The lherzolite region (outlined area) is after Sobolev et al (1973). Data for 'Other Samples' refer to a worldwide database.

Elevated Y and Zr contents of the garnets from coarse and deformed lherzolites, as well as deformed calcic

harzburgites are indicative of extensive high-temperature melt-related metasomatism (Fig. 2). In contrast, coarse and deformed subcalcic harzburgites typically have lower Y and Zr in garnet, or show evidence of lower-temperature, fluid dominated metasomatism (elevated Zr only; Fig. 2). Garnet rare earth element patterns range from sinuous in e.g. the subcalcic harzburgite xenoliths to normal in e.g. the deformed lherzolites (Fig. 3). Individual garnets from some of the xenoliths show compositional heterogeneity corresponding to core-rim zonation patterns described previously for garnets in peridotite xenoliths from kimberlites (Fig. 4). The change in the shape of the rare earth element patterns from sinuous to humped to normal correlates with increasing Y content in the garnets.

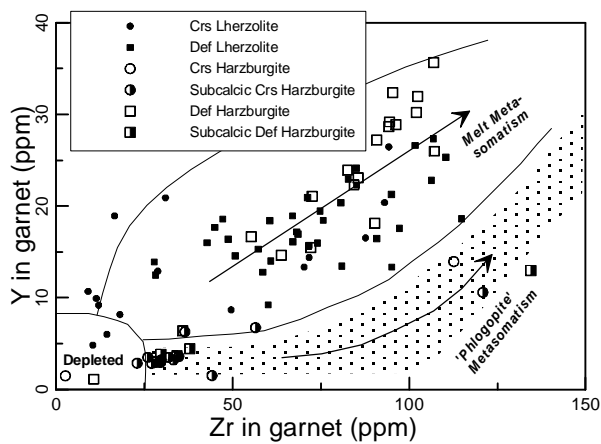


Fig. 2 Zr and Y abundances of garnets occurring in xenoliths from the Premier mine. Fields and metasomatic trends after Griffin et al (1999).

Similar levels of depletion as measured by bulk xenolith Al_2O_3 content are not only evident in subcalcic and calcic harzburgite xenolith varieties, but also in a number of the lherzolites irrespective of texture (i.e. coarse vs deformed; Fig. 5) suggesting that all probably derive from the same (or similar) depleted protolith(s) but with varying levels of metasomatic overprint.

The observed trace element contents and rare earth element patterns in garnets from many of the xenoliths record evidence for substantial overprinting of the original highly depleted substrate, through melt-related metasomatism. Rare earth element patterns changed during metasomatism from sinuous to humped and finally to that typical of magmatic garnets, or garnets showing a low degree of depletion (Burgess and Hart, 2004; Stachel et al., 1997). This is consistent with the conclusion reached by Griffin et al (2003), based on compositional trends observed in peridotitic garnet xenocrysts from Premier. It is therefore considered likely that subcratonic lithosphere below Premier originally consisted solely of highly depleted harzburgite residues.

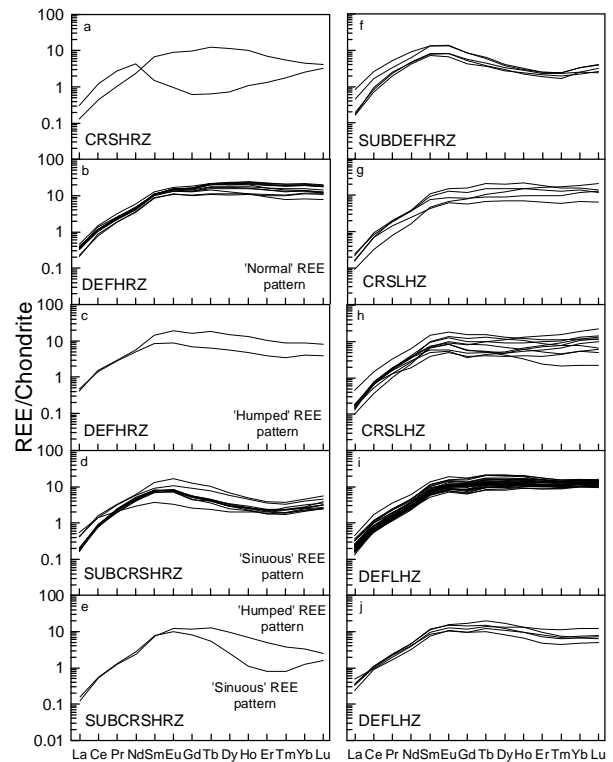


Fig. 3 Chondrite-normalised rare earth element patterns of garnets occurring in peridotite xenoliths from the Premier mine.

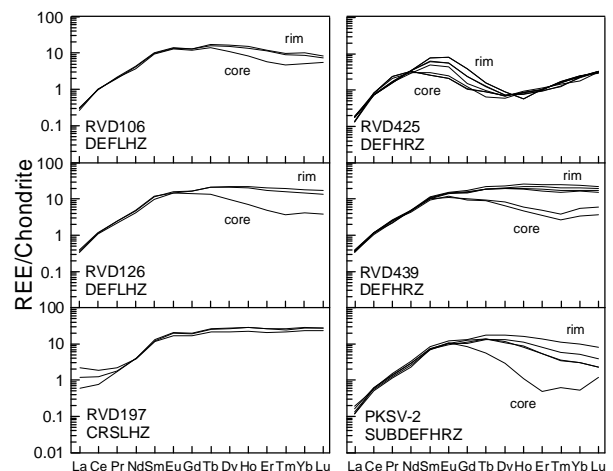


Fig. 4 Rare earth element heterogeneity in individual garnets occurring in peridotite xenoliths from the Premier mine.

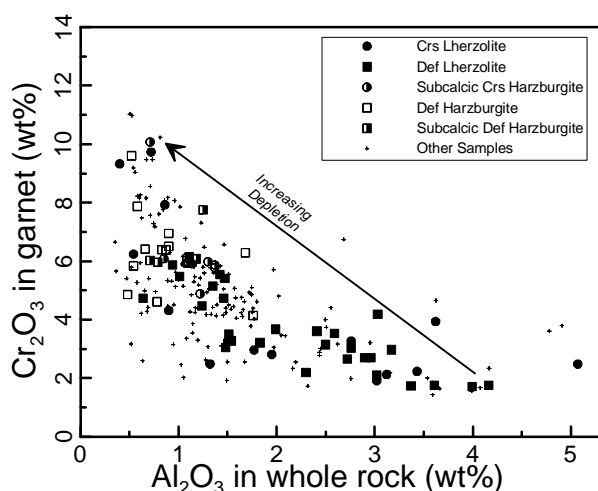


Fig. 5 Cr_2O_3 content for garnets occurring in xenoliths from the Premier mine, plotted against the Al_2O_3 content of the xenolith. Data for 'Other Samples' refer to a worldwide database.

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