

The scale and scope of Cretaceous refertilisation of the Kaapvaal lithospheric mantle, Kaapvaal Craton, South Africa

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Introduction

There are more than 1000 known kimberlite occurrences scattered throughout southern Africa. These kimberlites can be divided into Group I and Group II, on the basis of their Pb, Sr, and Nd isotopic ratios (Smith, 1983). The vast majority of these kimberlites were emplaced during the Jurassic and Cretaceous Periods. Within this subset, there is a firm relationship between group and age of intrusion: Group II kimberlites were emplaced between ~150 and 115 Ma and Group I kimberlites were emplaced between ~105 and 70 Ma (Smith et al., 1985, 1994). Many of these kimberlites carry peridotitic garnet xenocrysts. Major- and trace-element analysis of these xenocrysts yields a wealth of geochemical information about the underlying sub-continental lithospheric mantle (SCLM), including paleogeotherms and several geochemical indicators of depletion or metasomatism. The wide distribution of kimberlites hosting garnet xenocrysts allows the mapping of geochemical parameters over a broader area than usually possible. In addition, the difference in age between Group II and Group I kimberlites allows the comparison of the same volume of SCLM during different intervals of the Jurassic-Cretaceous intrusive episode in areas where these kimberlites overlap spatially.

Methods

We have obtained major- and trace-element analyses of 14,480 peridotitic garnets hosted in 34 Group II kimberlites and 29 Group I kimberlites (Fig.1). The kimberlites occur in environments both on and off craton. For each suite of garnet xenocrysts from a particular kimberlite, we constructed a paleogeotherm based on the Ni-in-garnet thermometer and Cr solubility barometer (Ryan et al., 1996). At the depth where garnets very low in Y become scarce, we introduce a point of inflection and run the deeper part of the geotherm parallel to the diamond-graphite stability line (O'Reilly and Griffin, 2006), similar to geotherms derived from xenolith suites in southern Africa (Finnerty and Boyd, 1987). Once the geotherm is established, all garnets are forced onto the geotherm based on their Ni temperature.

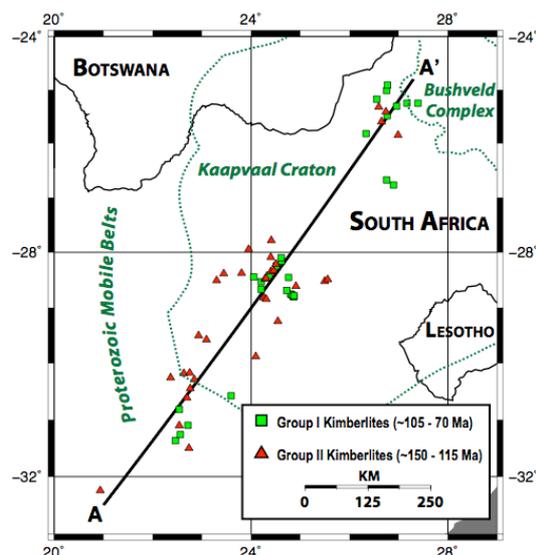


Figure 1. Location map for kimberlites and traverse line. Major tectonic units are outlined in dark green.

Assuming the kimberlites sample the mantle vertically, we have created a cross-section spanning the craton and its southwest margin (A-A'; Fig. 1). Each garnet data point is projected onto the cross-section at its interpreted depth. All kimberlites used are within 100 km surface distance of the cross-section. Then, using the spline method of Smith and Wessel (1990), we contour the Ti contents, the Zr contents, the Zr-Y ratio, and X_{Mg} of olivine co-existing with the garnets along the cross-section using a framework similar to that of Kobussen et al. (2008). We chose to use these four geochemical parameters because they are sensitive indicators of depletion and different styles of metasomatism in cratonic peridotites.

Results

For each geochemical parameter imaged, we have created two plots. The upper panels for each figure are constructed using garnets hosted in Group II kimberlites and thus sample the mantle between 150-115 Ma. The lower panels in each figure are constructed using garnets hosted in Group I kimberlites, which sample the same mantle region later (<105 Ma) during the same intrusive episode. Individual garnets are shown on each plot as open black symbols where they project onto the cross-section, enabling the visual recognition of where plot

resolution is poor. All sections have 2x vertical exaggeration.

The Ti content in garnet ranges from nearly zero to >6000 ppm (1% wt. TiO₂). Typical values for Ti in garnet in cratonic peridotites range from 1250 to 2500 ppm. Values less than 1250 ppm are considered extremely depleted and values higher than 2500 ppm indicate metasomatism. Figure 2 compares the Ti value in garnets from Group II and Group I kimberlites.

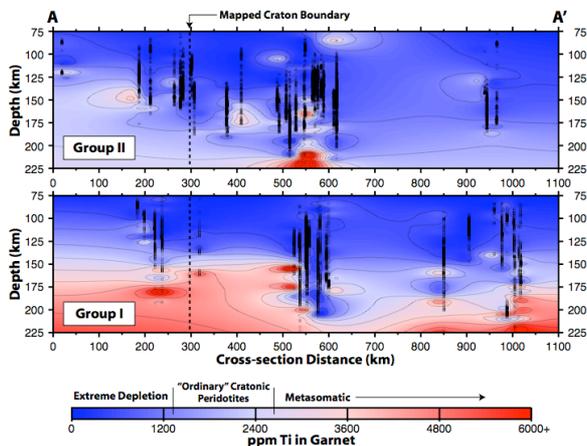


Figure 2. Contoured Ti contents in garnet hosted in Group II (top panel) and Group I kimberlites (bottom panel) along cross-section A-A' from Figure 1.

In the shallower parts of both sections the garnets have Ti contents typical of cratonic peridotites, or much more commonly with extremely depleted signatures. Garnets from the lowermost parts of the lithosphere, in contrast, show signatures typical of strongly melt metasomatised peridotites and such garnets are more common in Group I kimberlites.

The southwest part of the section (0 to 500 km) displays a huge enrichment in Ti between the emplacements of the Group II and Group I kimberlites. The Ti content of the lithospheric mantle in the Kimberley area (~500 to 600 km) is nearly unchanged during this time. It is unclear how much change there is in the northeast because of sampling patterns, but there appears to be some enrichment in Ti in the later (Group I) time slice.

The Zr contents of garnets show a different pattern of depletion/metasomatism (Fig. 3). Again, the shallower parts of both sections show a depleted signature, but the depth extent of depletion is much less and more irregular than for Ti. Particularly noticeable is the large Zr enrichment in the Kimberley area (~500-600 km along section), which can be related to the “phlogopite style” metasomatism commonly observed in xenoliths from the Kimberley area (e.g. Grégoire et al., 2002).

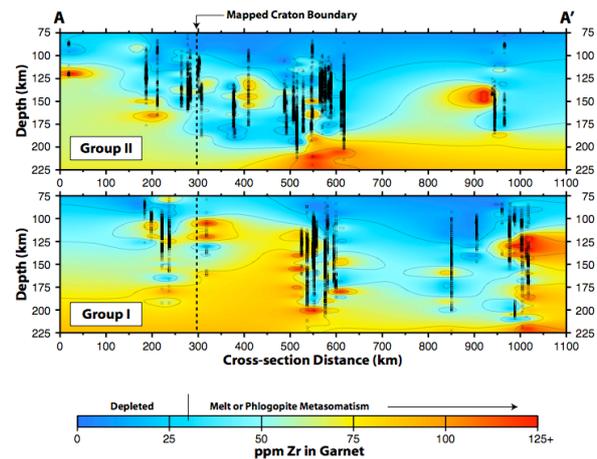


Figure 3. Zr contents of garnet plotted as in Fig. 2.

Another indicator of phlogopite-style metasomatism is the Zr-Y ratio measured in garnets (Griffin et al., 2002; Fig. 4). High ratios suggest either phlogopite metasomatism or enrichment related to extreme melt metasomatism. The overlap of high Zr values (Fig. 3) with high Zr-Y ratios (Fig. 4) in the Kimberley area during Group I time indicates phlogopite metasomatism. The phlogopite signature is not observed in the southwest part of the section where there is strong enrichment in Ti between the intrusion of Group II and Group I kimberlites (Fig. 2).

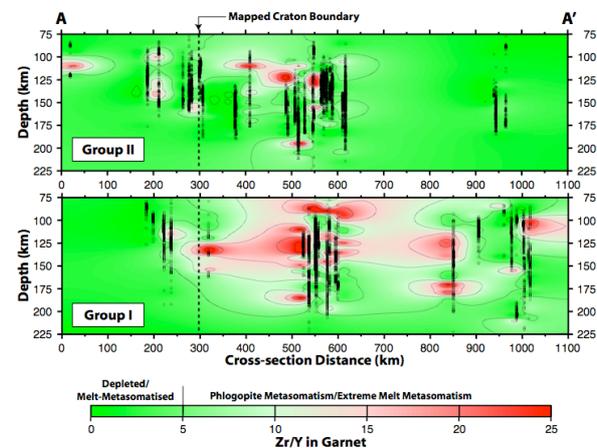


Figure 4. Measured Zr-Y ratio in garnets plotted as in Figure 2.

Finally, the X_{Mg} of olivine coexisting with the garnets was calculated using the method of Gaul et al. (2000; Fig. 5). The pattern of X_{Mg} of olivine more closely resembles the pattern observed for Ti than for Zr, but there are important differences. In the NE part of both Group II and Group I sections there is considerable Fe enrichment compared with the other shallow parts of the sections. This is not accompanied by a rise in Ti.

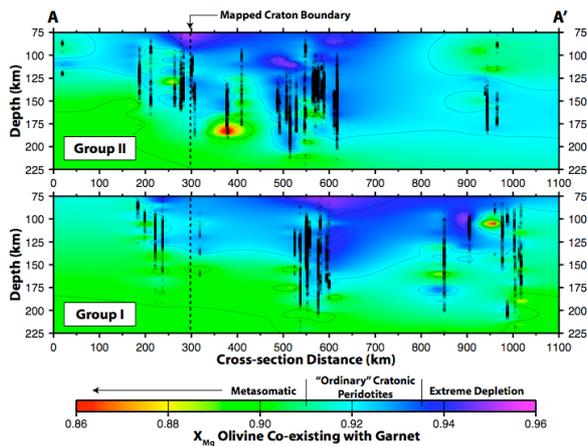


Figure 5. Calculated X_{Mg} for olivine coexisting with garnet, plotted as in Figure 2.

Discussion

Previous work on the Kaapvaal Craton using compilations of data from xenoliths/xenocrysts hosted in Group II and Group I kimberlites have indicated that there was a change in both geotherm and lithosphere chemistry between the eruption of the two groups (Griffin et al., 2003). This conclusion was supported and defined in a spatial context using garnet xenocrysts hosted in kimberlites from the Prieska cluster by Kobussen et al. (2008). In that study, we found a significant change in lithosphere chemistry as defined by Ti in garnet and the calculated X_{Mg} of coexisting olivine in a short and well-defined time window of 9 m.y. between the eruption of the Group II and Group I kimberlites.

Here we confirm this conclusion, but find that the change in lithosphere chemistry appears to be more complex than previously proposed. In the Kimberley area, the changes observed between the eruption of the Group II and Group I kimberlites are dominated by phlogopite-style metasomatism in which garnets are enriched in Zr, but not in Ti and Y.

Melt-related metasomatism is the most likely cause of large-scale modification of the lithosphere in the Prieska area along the SW part of the section (Gurney and Harte, 1980; Kobussen et al., 2008). Bell et al. (2003) suggest that silicate melts might more easily be able to penetrate and metasomatise formerly depleted Proterozoic-age lithosphere due to zones of weakness or melt pathways along tectonic boundaries. This type of infiltration could be assisted by changes in the stress field associated with the opening of the South Atlantic (Bailey, 1992).

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