LITHOSPHERE EVOLUTION BENEATH THE KAAPVAAL CRATON : 200-80 Ma

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The proton microprobe has been used to study the distribution of trace elements in garnet and chromite concentrates from a wide range of kimberlites on the Kaapvaal Craton. These data can be used to reconstruct the local paleogeotherm ("Garnet Geotherm": Ryan et al., 1995; this conference) and to place the information content of each garnet and chromite grain in a depth context. The resulting stratigraphic columns show the distribution of rock types, temperature and metasomatic processes with depth, and demonstrate significant changes in the lithospheric mantle beneath the Kaapvaal Craton over the period 200-80 Ma, during which most of the known kimberlites erupted.

The Garnet Geotherm defined by data from kimberlites (both Group I and Group II) with ages >90 Ma closely follows a 34 mW/m^2 conductive model; this is consistent with the few geothermobarometric data on xenoliths from Group II kimberlites. The base of the depleted lithosphere, as defined by the deepest occurrence of Y-depleted garnets and the deviation of the geotherm from a conductive state, lies at depths of ≈220 km. Assuming that all ultramafic rock types contribute roughly equal proportions of garnets to the concentrate, harzburgitic rocks comprise up to 40% of the mantle at depths between 140-180 km, but are much less abundant both above and below this depth. Melt-related metasomatism (with enrichment in Fe, Ti, Zr, Y and Ga) is relatively minor at depths <180 km, while phlogopite-related metasomatism (with enrichment in Ca and Zr) affects 20-40% of the rocks at depths between 130 and 180 km.

In contrast, the Garnet Geotherm for the kimberlites with ages ≤90 Ma (all of which are Group I) lies close to a 39 mW/m^2 model, in agreement with the abundant geothermobarometric data on mantle xenoliths from these kimberlites. The base of the depleted lithosphere lies at ≈170 km, and the proportion of harzburgite at any depth is significantly less (<25% at any depth) than in the mantle sampled by the older kimberlites. The reduction in harzburgite abundance is attributed at least in part to phlogopite-related metasomatic processes involving the introduction of Ca, which is observed in xenoliths from the Kimberley area (McCammon.et al., this conf.). This style of metasomatism is especially prominent at depths of 120-160 km, where it affects 30-50% of the rock volume. Melt-related metasomatism becomes dominant at depths >170 km, affecting >80% of the garnets with $T_{Ni} \geq 1200°C$.

These data suggest that the process of kimberlite intrusion began with lithospheric melting, presumably initiated by a general heating event, which produced the Group II kimberlites. The existence of Group I kimberlites with ages >100 Ma suggests that an asthenospheric component also was present at this time, and may be responsible for the heat input. Continued eruption of the younger Group I kimberlites was accompanied by extensive heating, thinning and metasomatism of the lithosphere, due to the intrusion of asthenospheric melts at depth. This process has produced major changes in the composition of the lithosphere, including the large-scale conversion of harzburgite to lherzolite, and probably an overall increase in oxidation state.

In the pre-90 Ma period, the diamond stability field in the lithosphere beneath the Kaapvaal Craton extended from ≈125-200 km, the proportion of both harzburgites and depleted lherzolites was relatively large, and the degree of metasomatism was relatively low. In the post-90 Ma lithosphere, the diamond stability field extends only from ≈135-170 km, and the proportion of harzburgite and depleted lherzolite has been strongly reduced by extensive metasomatism. It appears probable that the process of lithosphere heating, thinning and metasomatism documented by the garnet concentrates is related to the generally lower diamond grades of the later kimberlites.

A continuation of this magmatic activity eventually would produce a thinned, oxidised and fertilised lithosphere with a relatively high geotherm, and a low diamond prospectivity. An intermediate stage in this process may be represented by the relatively young kimberlites in Tanzania, which border the East African Rift and were intruded early in the development of the Rift.. In this area, the base of the lithosphere lies near 130 km depth; the mantle below this level has been intensely metasomatised by asthenospheric melts. If this model is correct, then the asthenosphere-derived magmatic activity that produced the Cretaceous kimberlites of the Kaapvaal Craton may be an analogue for the initial stages of continental rifting. This process, which destroys the Archean depleted lherzolite-harzburgite lithosphere and replaces it with more fertile and oxidised lherzolitic material, probably is irreversible. A strong signature of these processes in garnet concentrates may therefore signal an area that has a low diamond prospectivity, and this information can be useful in selecting areas, or time slices within individual regions, that are more prospective.

Reference

Ryan, C.G., Griffin, W.L. and Pearson, N., 1995. Garnet Geotherms: a technique for derivation of P-T data from Cr-pyrope garnets. Jour. Geophys. Res. (submitted).