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Using kimberlite indicator mineral geochemistry to better constrain the thermal and chemical structure of the lithospheric mantle beneath the Kaapvaal craton: correlations with S-to-P receiver functions

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In this study, we present a new analysis of 12,515 pre-analysed garnet xenocrysts recovered from kimberlites from the Barkly West kimberlite cluster. These kimberlites were emplaced in the western Kaapvaal Craton, South Africa in two pulses. These analyses are used to constrain the chemical and thermal structure of the subcontinental lithospheric mantle (SCLM) beneath the Kaapvaal Craton. In South Africa, kimberlites are distinguished based on geochemistry and petrology: (1) the hydrous, K-rich, and generally older Group II (age: ~200-114Ma; aka Kaapvaal lamproites) and (2) the younger, carbonate-rich and magnesian Group I kimberlites (age: ~112-86Ma). Upon ascent, kimberlites entrain mantle xenoliths, xenocrysts (e.g., garnet) and sometimes diamonds. Historically, mantle xenoliths have been employed to investigate the SCLM, but the large abundance of xenocrysts, available from a larger array of kimberlites, allows a more spatially robust characterisation of the SCLM. We investigate peridotitic garnets, i.e., G10 (CaO-poor) and G9 (CaO-rich) garnets, to allow single-mineral thermobarometry. Generally, G10 garnets have low CaO and high Cr2O3 contents and high Mg-numbers relative to G9 garnets. G9 garnets are typically more enriched in incompatible elements (i.e., Zr, Y, Ti) and heavy REE. Profiles of mantle composition obtained from garnets exhumed by both Group I and Group II kimberlites provide evidence for (likely metasomatic) enrichment of the SCLM at depths greater than 90-150 km, with the enrichment revealed by garnets from group I kimberlites being generally greater in magnitude and extending to shallower depths. Distinctions between Group II and Group I derived garnets suggest modification of the SCLM by two distinct metasomatic agents, and that Group I-related metasomatism was much more pervasive. For each kimberlite group, two paleogeotherms were calculated (one each for G10 and G9 garnets) using garnet thermobarometry. For Group II kimberlites, the G10- and G9-based paleogeotherms are very distinct from each other, cooler and warmer paleogeotherms, respectively. However, for Group I kimberlites, the paleogeotherms obtained from G10 & G9 are consistent with each other and are similar to the G9-based paleogeotherm obtained from Group II kimberlite xenocrysts. We infer that the Group II G10-based paleogeotherm, which has the lowest thermal gradient, is consistent with a steady state cratonic geotherm, devoid of transient thermal perturbations. However, geotherms with higher gradients obtained from Group II G9 and all Group I peridotitic garnet xenocrysts are the products of transient thermal disturbances, likely related to the effect of hot infiltrating melts.

Recent seismological studies have discovered sharp velocity changes within the SCLM known as mid-lithospheric discontinuities (MLDs). Globally, negative MLDs observed in cratonic areas have been associated with metasomatism. However, beneath the Kaapvaal Craton we note positive MLDs, which coincide with the observed layer of metasomatism which has resulted in increased clinopyroxene and garnet modal abundance. Is clinopyroxene and garnet generation responsible for positive MLDs beneath the Kaapvaal Craton?