Isotopic analyses of clinopyroxene in mantle xenoliths demonstrate the effects of kimberlite melt metasomatism upon the lithospheric mantle

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As clinopyroxene is the main host of most lithophile elements in the lithospheric mantle, the trace element and radiogenic isotope systematics of this mineral have frequently been used to characterise mantle metasomatic processes. To further our understanding of mantle metasomatism, both solution-mode Sr-Nd-Hf-Pb and in situ trace element and Sr isotopic data have been acquired for clinopyroxene grains from a suite of peridotite (lherzolites and wehrlites), MARID (Mica-Amphibole-Rutile-Ilmenite-Diopside), and PIC (Phlogopite-Ilmenite-Clinopyroxene) rocks from the Kimberley kimberlites (South Africa). The studied mantle samples can be divided into two groups on the basis of their clinopyroxene trace element compositions, and this subdivision is reinforced by their isotopic ratios. Type 1 clinopyroxene, which comprises PIC, wehrlite, and some sheared lherzolite samples, is characterised by low Sr (~100–200 ppm) and LREE concentrations, moderate HFSE contents (e.g., ~40–75 ppm Zr; La/Zr < 0.04), and restricted isotopic compositions (e.g., \( ^{87}\text{Sr}/^{86}\text{Sr} = 0.70369–0.70383 \); \( \varepsilon\text{Nd} = +3.1 \) to +3.6) resembling those of their host kimberlite magmas. Available trace element partition coefficients can be used to show that Type 1 clinopyroxenes are close to equilibrium with kimberlite melt compositions, supporting a genetic link between kimberlites and these metasomatised lithologies. Thermobarometric estimates for Type 1 samples indicate equilibration depths of 135–155 km within the lithosphere, thus showing that kimberlite melt metasomatism is prevalent in the deeper part of the lithosphere beneath Kimberley. In contrast, Type 2 clinopyroxenes occur in MARID rocks and coarse granular lherzolites, which derive from shallower depths (<130 km), and have higher Sr (~350–1000 ppm) and LREE contents, corresponding to higher La/Zr of ~0.05. The isotopic compositions of Type 2 clinopyroxenes are more variable and extend from compositions resembling the “enriched mantle” towards those of Type 1 rocks (e.g., \( \varepsilon\text{Nd} = -12.7 \) to -4.4). To constrain the source of these variations, in situ Sr isotope analyses of clinopyroxene were undertaken, including zoned grains in Type 2 samples. MARID and lherzolite clinopyroxene cores display generally radiogenic but variable \( ^{87}\text{Sr}/^{86}\text{Sr} \) values (0.70526–0.71177), which might be explained by the interaction between peridotite and melts from different enriched sources with the lithospheric mantle. In contrast, the rims of these Type 2 clinopyroxenes trend towards compositions similar to those of the host kimberlite and Type 1 clinopyroxene from PIC and wehrlites. These results are interpreted to
represent clinopyroxene overgrowth during late-stage (shortly before/during entrainment) metasomatism by kimberlite magmas. Our study shows that an early, pervasive, alkaline metasomatic event caused MARID and lherzolite genesis in the lithospheric mantle beneath the Kimberley area, which was followed by kimberlite metasomatism during Cretaceous magmatism. This latter event is the time at which discrete PIC, wehrlite, and sheared lherzolite lithologies were formed, and MARID and granular lherzolites were partly modified.