Hidden reservoirs in the continental lithosphere? Evidence from Hf-Sr-Nd-Pb isotopes in southern African kimberlite megacrysts

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Introduction

Hidden mantle reservoirs with anomalous isotopic compositions have been proposed to explain apparent differences between the isotopic composition of the upper mantle as inferred from oceanic basalts and estimates of bulk silicate earth (BSE) composition based on chondrite meteorites (e.g., $^{142}Nd/^{144}Nd$). In particular, the displacement of the Nd-Hf isotopic oceanic basalt array away from the BSE composition toward slightly more radiogenic $^{176}Hf/^{177}Hf$ values has prompted speculation that a hidden mantle reservoir exists that has relatively unradiogenic ε_{Hf} for a given ε_{Nd} value (Bizzarro et al., 2002). The presence of anomalously unradiogenic ε_{Hf} relative to ε_{Nd} in kimberlites and their megacrysts has been explained as the signature of ancient subducted oceanic crust (MORB and/or OIB) segregated at a deep mantle boundary layer, such as the transition zone or core-mantle boundary, constituting a hidden reservoir in the deep mantle (Nowell et al., 2004). Moreover, the presence of such isotopic signatures, which lie outside the range of modern oceanic basalts, has been used to argue for a deep mantle plume origin for kimberlites (Tappe et al., 2013). More recent refinement of chondrite Nd-Hf isotopic compositions (Bouvier et al., 2008) has removed the necessity for a hidden reservoir to reconcile the composition of oceanic basalts with a chondritic mantle, but the unusual Hf-Nd isotopic compositions of kimberlites and megacrysts still requires explanation.

We present Hf-Sr-Nd-Pb isotopic and trace element evidence from clinopyroxene megacrysts from seven Cretaceous southern African kimberlites that (1) requires the presence of a component having anomalously unradiogenic Hf and "enriched mantle" characteristics (unradiogenic ε_{Nd} and $^{206}Pb/^{204}Pb$, radiogenic $^{87}Sr/^{86}Sr$) within the continental lithospheric mantle and (2) suggests the ubiquitous presence of a strong HIMU mantle source with a chemical signature of carbonatite metasomatism in the deep lithosphere or asthenosphere beneath southern Africa.
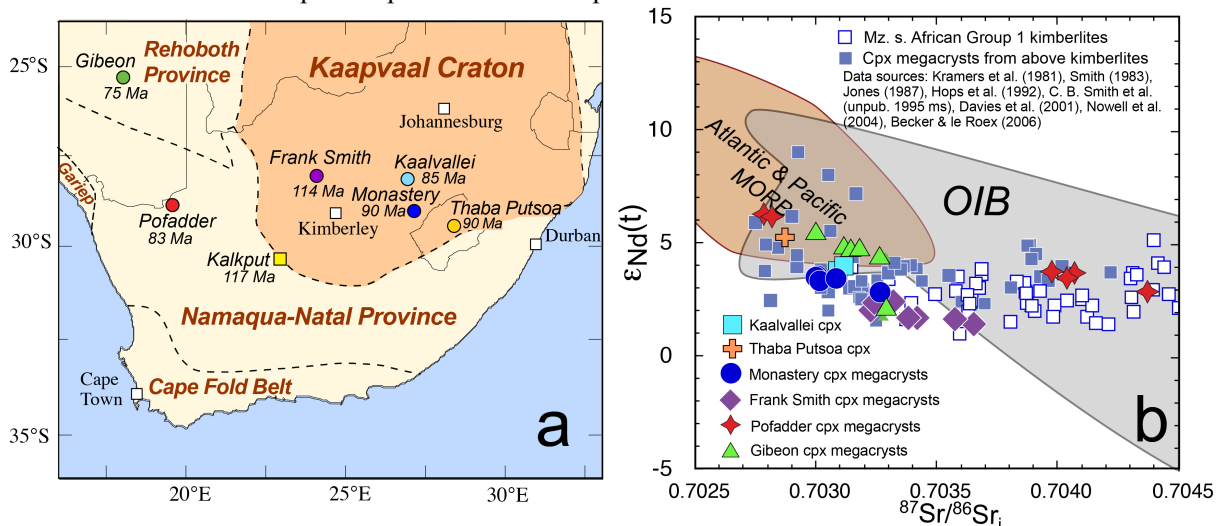

Figure 1. (a) Map of kimberlites from which clinopyroxene megacrysts in this study were analysed. (b) $^{87}Sr/^{87}Sr$ vs. $\varepsilon_{Nd}(t)$ plot for the studied Group 1 kimberlite megacrysts along with literature data.

Approach and Results

Approximately 30 clinopyroxene megacrysts from seven Cretaceous southern African kimberlites/clusters (Fig. 1; six Group 1 and one Group 2) were analysed for trace elements and Hf-Sr-Nd-Pb isotope compositions using ultra-low blank methods, mainly at Arizona State University. For four of these (Monastery, Frank Smith, Gibeon and Pofadder, all Group I), six or more

megacrysts were analysed from each so as to cover a range of compositions (Cr-poor to Cr-rich) and crystallization temperatures (based on Ca# = 100*Ca/(Ca+Mg) in atomic %). For each of these megacryst suites, the sample with the highest crystallization temperature (lowest Ca#) has the lowest $^{87}Sr/^{86}Sr_i$ (0.7027-0.7032), highest $\varepsilon_{Nd}(t)$ (+3.5 to +6.5) and highest $^{206}Pb/^{204}Pb_i$ ratios (19.6-20.7), similar to the 'HIMU' or 'FOZO' source components of ocean island basalts, and has ε_{Nd}-ε_{Hf} values that fall only slightly below the global Nd-Hf oceanic basalt array. As crystallization temperatures decrease, the $^{87}Sr/^{86}Sr$ values of the megacrysts increase and ε_{Nd}, ε_{Hf} and $^{206}Pb/^{204}Pb$ values all decrease. The samples crystallizing at the lowest temperatures typically fall furthest (up to 8.5 eHf units) below the Nd-Hf oceanic basalt array. This pattern is most easily explained by assimilation of a lithospheric component that has anomalously low ε_{Hf} compared to ε_{Nd}, combined with high $^{87}Sr/^{86}Sr$ and low ε_{Nd} and $^{206}Pb/^{204}Pb$ values. The above isotopic variations are also accompanied by increases in Zr and Hf concentrations and decreases in $(Lu/Hf)_N$ ratios.

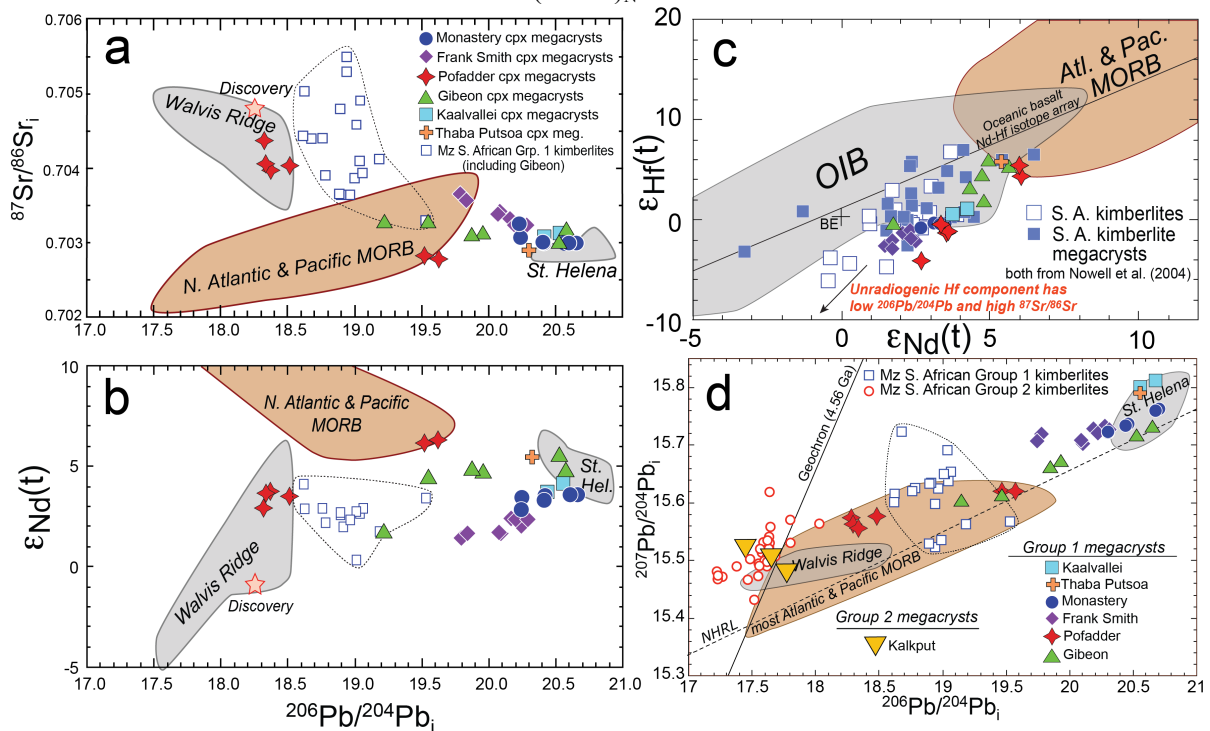**Figure 2**. Isotope ratios plots for clinopyroxene megacrysts: (a) $^{206}Pb/^{204}Pb$ vs $^{87}Sr/^{86}Sr$, (b) $^{206}Pb/^{204}Pb$ vs. $\varepsilon_{Nd}(t)$, (c) $\varepsilon_{Nd}(t)$ vs $\varepsilon_{Hf}(t)$ and (d) $^{206}Pb/^{204}Pb$ vs. $^{207}Pb/^{204}Pb$. Kimberlite data are from Figure 1 plus Fraser and Hawkesworth (1992).

Discussion

We propose that southern African Group 1 and Group 2 kimberlites preferentially assimilate metasomatic vein components in the lithospheric mantle analogous to the phlogopite-ilmenite-clinopyroxene (PIC) and MARID xenolith suites, respectively. Chemical data suggest that PIC and MARID xenoliths have low and moderate Lu/Hf ratios, respectively, relative to Sm/Nd (Gregoire et al., 2002), and over time could evolve appropriately unradiogenic Hf and Nd isotopic compositions lying below and on the Hf-Nd isotopic array, respectively.

The prevalence of the strong HIMU isotopic signature in Cr-poor clinopyroxenes from all Cretaceous Group 1 kimberlite megacryst suites investigated, whether on on-craton or off-craton, is intriguing and suggests that this mantle source composition is not derived from localised, deep-seated mantle plumes. The Group 1 megacryst suite that shows the weakest HIMU signature (Pofadder) is strongly dominated by Cr-rich megacryst compositions, suggesting that its HIMU signature may have been diluted at shallow levels. Further, the fact that the Cr-poor megacrysts tend to show strong negative anomalies in Zr and Hf (and often Ti) appears to support the possibility that this HIMU signature could have developed in the deep lithosphere in-situ by a metasomatic process involving recycled carbonatitic material, in a scenario similar to that envisioned by Weiss et al. (2016).
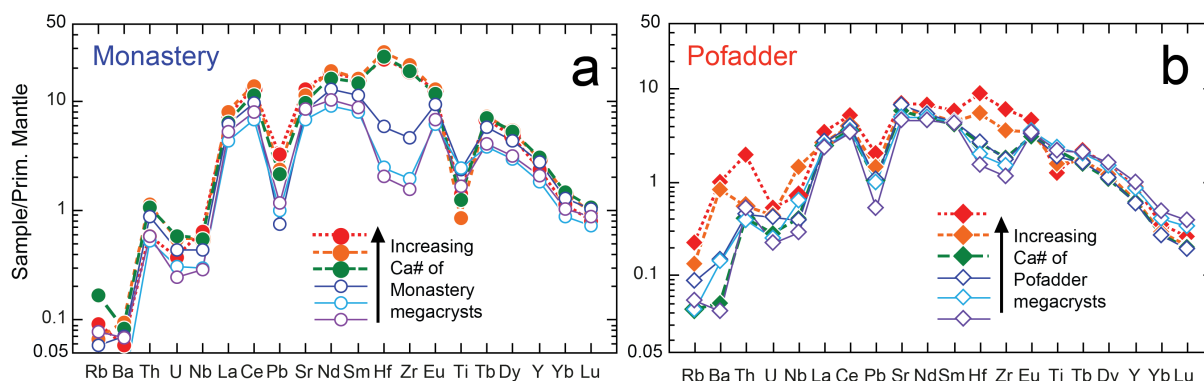
Figure 3. Primitive mantle-normalised incompatible element diagrams for (a) Monastery and (b) Pofadder clinopyroxene megacrysts. Note the depletion in Zr & Hf and the change in these elements with decreasing crystallization temperature (i.e., increasing Ca#). Normalising values from McDonough & Sun (1995)

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