

Geochemistry, petrography, and zircon geochronology of MARID xenoliths from the Kaapvaal craton, southern Africa

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Introduction

Upper-mantle metasomatism, both cryptic and modal, is evidenced by mica amphibole rutile ilmenite diopside (MARID) xenoliths entrained in kimberlites (kimberlite *sensu stricto*, Group I kimberlite). The addition of modal metasomatic phases, as well as the incorporation of heat-producing elements and incompatible trace elements, produces a host of lithologies and compositions that are relevant to understanding sub-continental lithospheric mantle (SCLM) stability and modification. Because MARID xenoliths are a direct product of alkali-enriched melt metasomatism, they provide insights into the timing and character of the tectonomagmatic events that modify the SCLM. Nonetheless, relationships between MARID petrogenesis, alkaline magmatism, and the tectonomagmatic history of the Kaapvaal SCLM remain enigmatic. We utilize major element geochemistry, trace element geochemistry, petrography, and U-Pb zircon geochronology on a diverse suite of zircon-bearing MARID xenoliths from the Kimberley region (aka. Kimberley pool kimberlites) of South Africa to address the hypothesis that MARIDs and lamproites (orangeites, Group II kimberlites) form from cogenetic metasomatic agents.

Methods

Petrographic analysis was performed using optical and scanning electron microscopy, backscatter electron imagery, and energy dispersive x-ray spectroscopy to determine textural character and modal mineralogy. Major element oxides of clinopyroxene, phlogopite, and K-richrichterite were measured using electron probe microanalysis (EPMA). *In situ* geochemical data were acquired using laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS), while U-Pb isotopic data were obtained through both LA-ICPMS and isotope dilution thermal ionization mass spectrometry (ID-TIMS) techniques.

MARIDs were distinguished from other metasomatized mantle xenoliths based on mineralogy, major element oxide content, and trace element composition. Here, we are focusing on four samples that were discovered to have zircon. Lithologies studied encompass both archetypal MARIDs (PAUL09, 16, 17) and a “phlogopite-rich mantle xenolith” (PAUL15), which has major and trace element compositions of clinopyroxene (Fig. 1) and phlogopite that is indistinguishable from the MARID compositions described in Grégoire et al. (2002) and Fitzpayne et al. (2018).

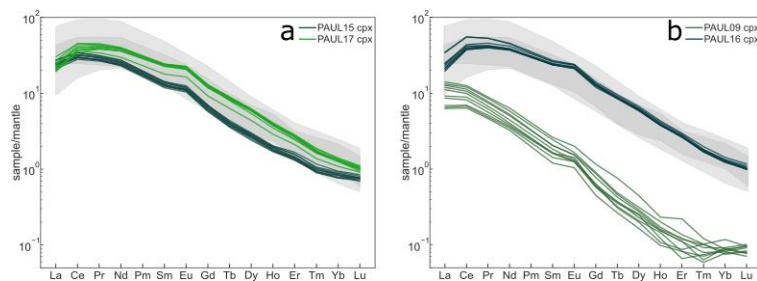


Figure 1: Rare earth element plots of clinopyroxenes normalized to pyrolite (McDonough and Sun 1995). Each MARID is represented by a different color, and each analysis is represented by a separate line. Grey regions represent the range of measurements from Grégoire et al. (2002) and Fitzpayne et al. (2018).

Results

Three MARID samples (PAUL09, 16, 17) yielded concordant zircon analyses in the range of ~75–120 Ma (Fig. 2), with rare earth element (REE) patterns and high-field strength element contents that fall between lamproite and kimberlite zircon domains in trace element bivariate space (Belousova et al. 2002; Itano and Sawada, 2024). Like its clinopyroxene, zircon from PAUL09 (Fig. 2c) exhibit more depleted REE patterns, with trace element compositions more closely resembling a mixture of doleritic and lamproitic influences. In some samples, the youngest zircon dates correlate with the highest zircon REE content.

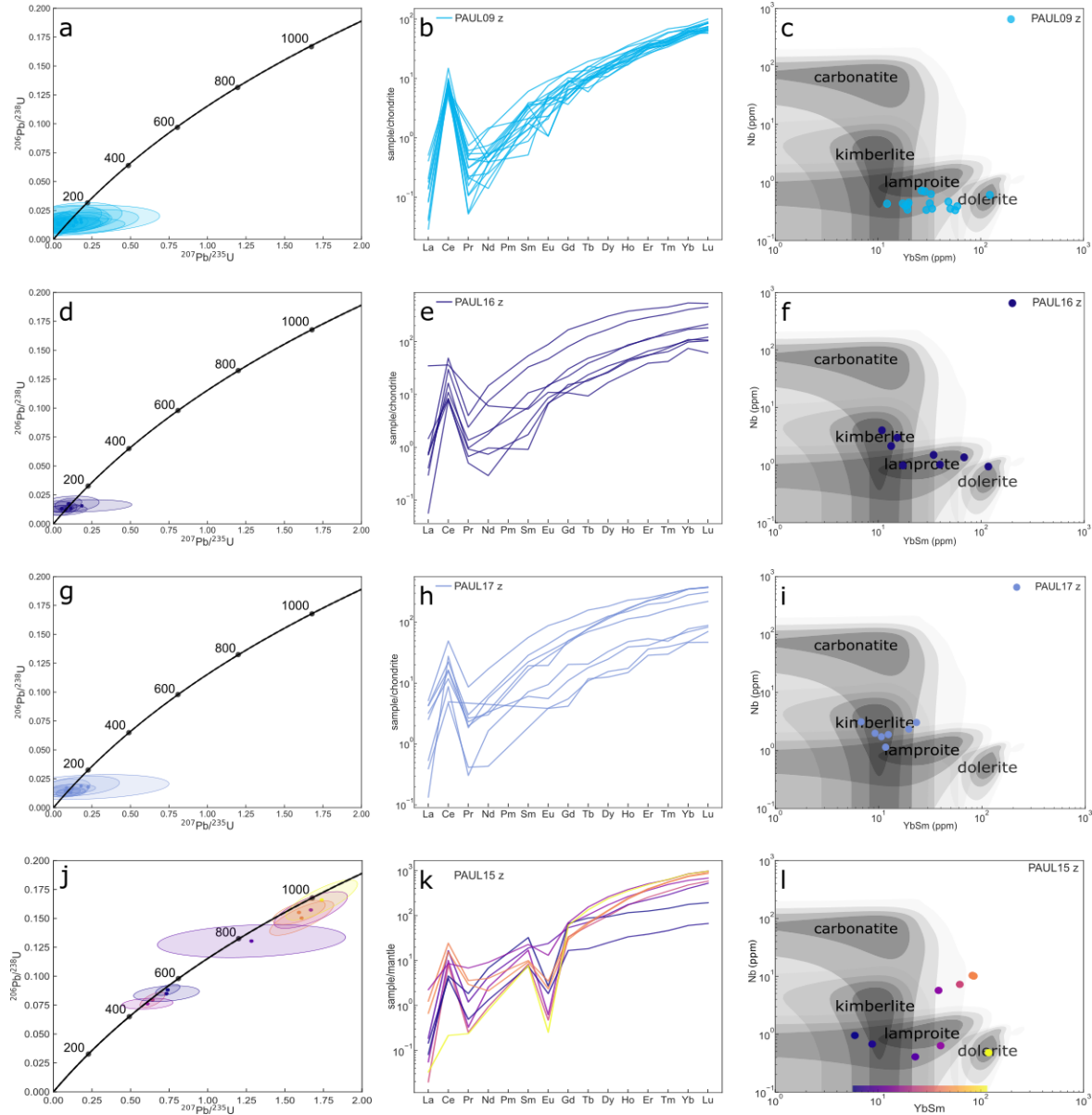


Figure 2: Each row is zircon data from an individual sample. The last sample is colored by Yb/Sm to correlate geochronological and geochemical parameters visually. (left) Concordia diagrams. (middle) Rare earth element plots normalized to pyrolite (McDonough and Sun 1995). (right) Trace element bivariate diagrams. Grey regions are quintiles calculated using a kernel density estimate of data compiled by (Itano and Sawada 2024) after Belousova et al. (2002).

Sample PAUL15 contains a surprising record of Neoproterozoic and Mesoproterozoic zircon ages with indications of mixing between the two components in concordia space and geochemical plots. These Proterozoic zircons exhibit greater trace element enrichment, with higher light REE concentrations and prominent Eu anomalies than Cretaceous MARID zircon. Across these crystals, there are variable Eu anomalies, heavy REE contents, and heavy REE slopes, which could reflect different extents of metasomatism and/or the changing chemical nature of the metasomatic agent(s) between carbonatitic and lamproitic compositions.

Conclusions

The significant span of Cretaceous to Proterozoic zircon ages indicates that multi-episodic metasomatism can be preserved within the U-Pb isotope systematics of zircon - even at shallow mantle depths. Within and between individual zircon crystals, age and trace element covariance, as well as $^{206}\text{Pb}/^{238}\text{U}$ and $^{207}\text{Pb}/^{235}\text{U}$ concordance, demonstrate that age variation is not a product of simple diffusive Pb loss. Within samples, age distributions of ~20-40 Myr spanning the timing of both lamproitic and kimberlitic magmatism around the Kimberley region are standard. Across all samples, many zircons post-date regional orangeite magmatism and are essentially coeval with (or predate) Kimberley pool eruptions. The covariance between zircon age and trace element geochemistry suggests real variations in crystallization timing and the preservation of multi-episodic Early and Late Cretaceous metasomatism in MARIDS at the limits of the LA-ICPMS age resolution.

The presence of MARID zircon as young as the Cretaceous and as old as the Mesoproterozoic indicates that “MARID-style” metasomatism has occurred episodically throughout the chemical and thermal evolution of the SCLM. Notably, the preservation of prior metasomatic events despite subsequent metasomatism is demonstrably possible. The link between intra-cratonic, alkaline magmatism and metasomatism is complex. Although there is no clear temporal relationship at LA-ICPMS scale age resolutions, variations in trace element geochemistry with time support the hypothesis of geochemically dynamic, multi-source, and episodic metasomatism in the cratonic SCLM that is linked to alkaline magmatism. With high-precision TIMS zircon geochronology, these complex temporal relationships can be more clearly established.

References

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