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Imaging the cratonic mantle lithosphere-kimberlite system beneath Kimberley (Kaapvaal craton) with in-situ U-Pb and geochemical analyses

Leo J. Millonig[1,2], Aratz Beranoaguirre[1,2], Daniel J. Schulze[3], Sonja Aulbach[1,2]
[1]Institute for Geosciences, Goethe-Universität, Frankfurt am Main, Germany
l.millonig@em.uni-frankfurt.de; beranoaguirre@em.uni-frankfurt.de; s.aulbach@em.uni-frankfurt.de
[2]Frankfurt Isotope and Element Research Center (FIERCE), Goethe-Universität, Frankfurt am Main, Germany
[3]Department of Chemical and Physical Sciences, University of Toronto, Mississauga ON, Canada,
daniel.schulze@utoronto.ca

Introduction

Constraints on the pre-eruption evolution of the cratonic lithosphere are critical to understanding continent evolution as part of the supercontinent cycle and its diamond and metal endowment, and to inform geophysics-based models of the lithospheric structure. Metasomatism precursory to kimberlite eruptions is a long-known phenomenon that affects the cratonic lithospheric mantle globally (Wass and Rogers 1980). It is proposed to involve interaction of the cold and refractory lithospheric mantle with proto-kimberlite melts, accompanied by heating, enrichment and oxidation (e.g., Kobussen et al. 2008; Creighton et al. 2009). On the one hand, this ultimately facilitates successful kimberlite eruption (e.g., Giuliani et al. 2014), on the other hand, heating and oxidation may adversely affect the survival of the cratonic diamond inventory (Fedortchouk et al. 2019). These events may also cause a redistribution and focussing of volatiles and metals in mid-lithospheric discontinuities (e.g., Aulbach et al. 2021). The result is a lithosphere column that is diverse and complex with respect to its composition, mineralogy, thermal and redox state. However, obtaining a coherent picture and unravelling this multi-stage evolution is in part hampered by the focus of many studies on particular rock or sample types (peridotite vs. eclogite xenoliths, or xenoliths vs. xenocrysts), which therefore can only investigate a limited part of the whole-lithosphere system.

We have assembled a comprehensive sample suite from Kamfersdam, a lesser-known kimberlite in the Kimberley kimberlite cluster, Kaapvaal craton, with a so far poorly characterised mantle suite. This suite is rather unique in the Kimberley kimberlite cluster, as it represents a single column of mantle material, whereas most other Kimberley area xenoliths described in the literature are from the dumps of large xenoliths with mixed pipe sources. The samples comprise diverse xenoliths, including sheared and non-sheared types, rare harzburgites to common lherzolites, MARID including rutile- and zircon-bearing specimens, rutile-dominated xenoliths, Granny Smith xenoliths, glimmerites, the kimberlite itself, as well as megacrysts (e.g., zircon) and eclogite xenoliths. The latter two are otherwise very rare in the Kimberley area kimberlites. Literature U-Pb dates and geochemical analyses of zircon from a MARID xenolith indicate resolvable differences between its age (~120 Ma), and that of the host kimberlite (~87 Ma), and a geochemical zonation suggestive of rapid changes in fluid/melt composition (Hamilton et al. 1998). Although 120 Ma coincides with a period of lamproite magmatism in the Kaapvaal craton, typical mantle-like $\delta^{18}O$ values for zircon are distinct from those of the lamproites, precluding a direct genetic link. In contrast, Cr-poor garnet megacrysts also have mantle-like $\delta^{18}O$ (Valley et al. 1998; Schulze et al. 2001), and radiogenic isotope compositions that have been linked to their kimberlite host magma (Smith et al. 1995).

We now have a much wider range of analytical techniques at our disposal, allowing high-precision U-Pb dating and geochemical analysis of various minerals. Currently, we are preparing this uniquely diverse Kamfersdam mantle sample suite for in-situ geochemical analyses of garnet and clinopyroxene, and U-Pb isotope analyses of zircon, rutile, perovskite ± garnet (Millonig et al. 2020). When combined with conventional and novel oxy-thermobarometry, this will allow us to delineate the physicochemical evolution of the regional lithospheric mantle-kimberlite system with unprecedented detail, shedding light on the events that could have adversely affected its diamond inventory.

Analytical results

Zircon and garnet xenocrysts from the heavy mineral concentrates of the Kamfersdam kimberlite were subjected to U-Pb dating by LA-ICPMS. In addition, we obtained major and trace element data from garnet xenocrysts.

Zircon U-Pb dates yielded two prominent clusters at ~92 and ~87 Ma (Fig. 1). Garnet U-Pb dates, on the other hand, range between ~110 and ~92 Ma. The vast majority of garnet xenocrysts are harzburgitic, lherzolitic, or pyroxenitic in composition (Fig. 2).

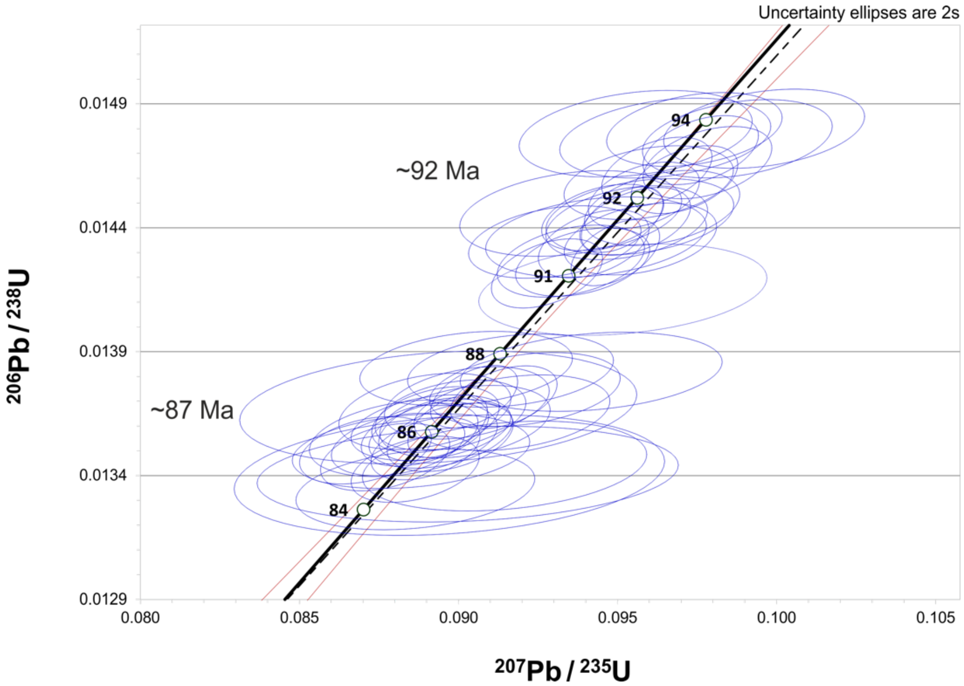

Figure 1. Wetherill plot for zircon U-Pb data from zircon xenocrysts from the Kamfersdam heavy mineral concentrate showing two age clusters at ~87 Ma and ~92 Ma. Only concordant analysis (95-105% concordancy) are shown.

Conclusions (preliminary)

This U-Pb data set indicates that zircon and garnet record similar, but also different events in the subcontinental cratonic mantle that, in the case of garnet, can predate the kimberlite eruption by >20 myr. The garnet xenocryst major element data indicates a lithospheric column beneath Kamfersdam that is dominated by fertile lithologies. Garnet REE patterns range from "normal" LREE-depleted, including most pyroxenitic garnets, with positive slopes in the MREE and HREE, to strongly sinuosoidal, as is typical for derivation from lherzolitic to harzburgitic source rocks (e.g., Stachel et al. 1998).

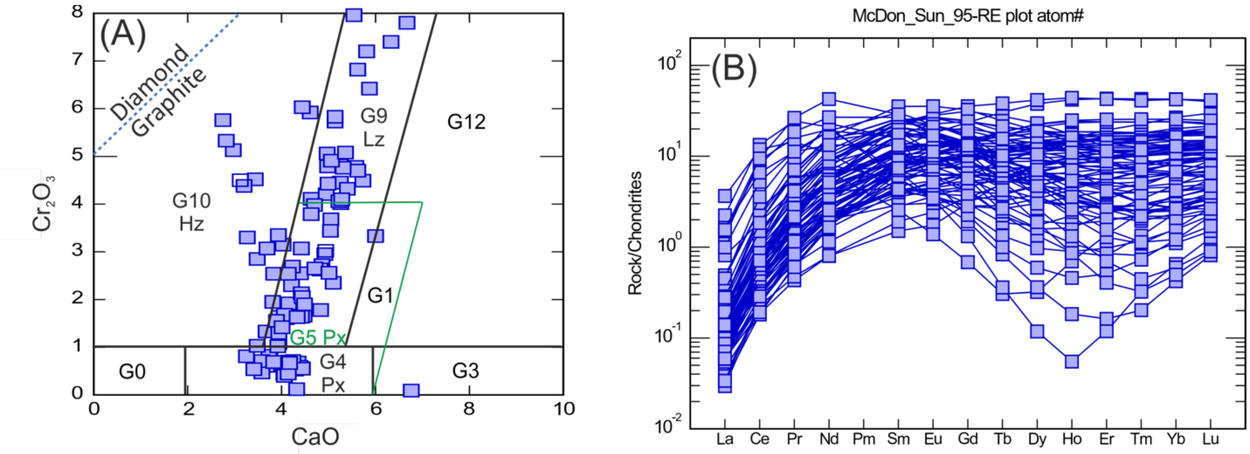

Figure 2. (A) CaO vs. Cr_2O_3 (wt.%) plot for garnet xenocrysts from the Kamfersdam heavy mineral concentrate, with compositional fields after Grütter et al. (2004) with G10 = harzburgite (Ca-undersaturated), G9 = lherzolite (Ca-saturated) and G4 and G5 = pyroxenitic comprising almost all samples in this study. (B) Chondrite-normalized rare earth element plot for the garnet xenocrysts shown in (A).

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