

Lithospheric mantle sampling of kimberlites and lamproites using Al-in-olivine thermometry

Merrily M. Tau¹, Geoffrey H. Howarth¹, and Andrea Giuliani²

¹*Department of Geological Sciences, University of Cape Town, South Africa*

²*Department of Earth Sciences, ETH Zurich, Switzerland*

Introduction

Olivine is the dominant constituent of kimberlites and carbonate-rich olivine lamproites (CROL) from the Kaapvaal craton, comprising 40-50 vol.% of these rocks. It occurs as rounded to subhedral macrocrysts (>0.5 mm) and euhedral to subhedral microcrysts (<0.5 mm), the majority showing sharp compositional zoning between xenocrystic cores and magmatic rims. The xenocrystic cores display variable compositions (Mg# = 75 – 95) corresponding to those that characterize mantle xenoliths, including granular and sheared peridotites as well as megacrysts (Giuliani, 2018). The abundant olivine xenocrystic cores offer great potential for characterizing the subcontinental lithospheric mantle (SCLM) traversed by kimberlites and CROL and to reveal predominant sampling depths and whether material from within the diamond stability field was sampled and to which extent.

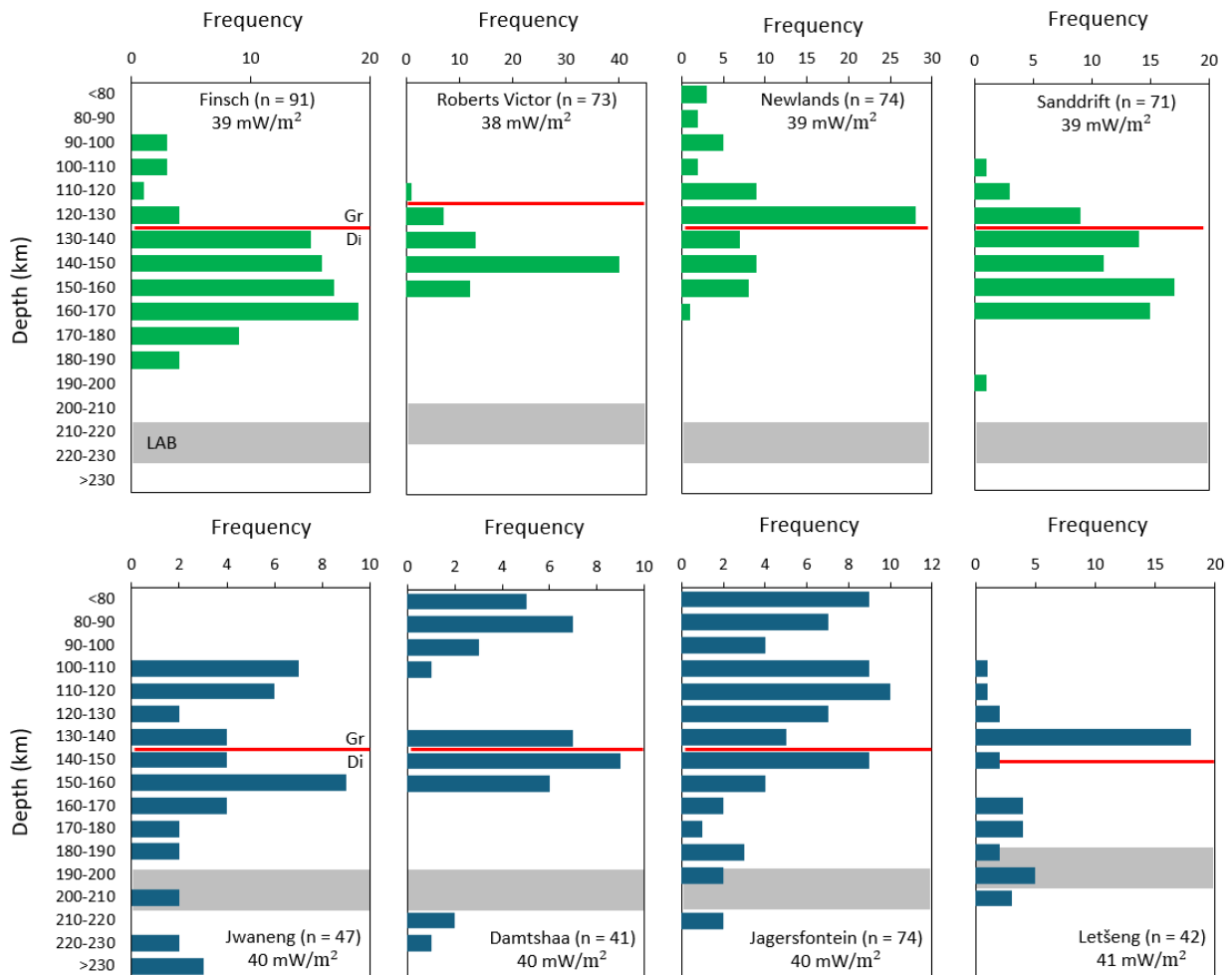
Results and Discussion

We present electron microprobe (EPMA) and laser ablation (LA-ICP-MS) trace element data for xenocrystic olivine cores from on-craton (Finsch, Newlands, Roberts Victor, and Star) and craton margin (Sanddrift) CROL and on-craton (Jwaneng, Jagersfontein, Monastery, Buffelboudfontein, Benfontein) and craton margin (Damtshaa, Karowe, Letšeng, Kao, Goedeheop, and Andriesfontein) kimberlites from across the Kalahari craton. Over 80 grains were analysed per locality. Olivine cores from the CROL are predominantly Mg-rich with Mg# of 90.0 – 95.0 and Ni = 2320 - 4500 ppm. More Fe-rich (Mg# <90) olivine cores constitute less than 4% of the analysed grains. The olivine population is more variable in kimberlites, with Fe-rich cores comprising between 10% (e.g., Jagersfontein) and 55% (e.g., Damtshaa) of the analysed grains.

The compositional criteria of Bussweiler et al. (2017) and Soltys et al. (2020) were used to screen out olivine derived from mantle lithologies other than coarse granular peridotites. Using the Al-in-olivine geothermometer (i.e., Bussweiler et al., 2017), coupled with mantle xenolith-derived paleo-geotherms for each location, equilibration P-T-depth are estimated for each olivine core sourced from garnet peridotite lithologies. Histograms of sampling depths show variable distribution patterns (Figure 1). Finsch and Sanddrift show similar uniform sampling over large intervals (130-180 km and 120-170 km, respectively), whereas Roberts Victor and Newlands show more focussed unimodal sampling predominantly at 140-150 km and 120-130 km, respectively. Jwaneng olivines show main sampling peaks at 100-120 km and 150-160 km. Monastery and Letšeng, which are proximal localities, both show sampling peaks centred at 130-

140 km. Damtshaa and Karowe, which are also close to each other, both display sampling peaks centred at 140-150 km. Jagersfontein show broad multimodal sampling over a large interval of 100-160 km. A significant proportion of olivine cores (17 and 27 vol.%, respectively) from Damtshaa and Jagersfontein show very low-Al (<10 ppm), suggesting derivation from shallower (<100 km) garnet-spinel peridotite lithologies. Calculated Al-in-olivine temperatures for these cores should therefore be treated with caution. Buffelboudfontein display focussed sampling but at 200-220 km, that is beyond the LAB.

The formation of sheared peridotites and Cr-poor olivine megacrysts have been attributed to proto-kimberlite metasomatism and linked to the destruction of diamonds at the base of the lithosphere (Giuliani et al., 2023). For instance, Jwaneng contains a smaller proportion (43 %) of high-temperature olivines (T >1300 °C) coupled with a high diamond grade, whereas Karowe, Damtshaa, Letšeng, and Kao comprises abundant high-temperature olivines proportion (53-81 vol.%) and lower diamond grades. Furthermore, sampling patterns generally correlates with diamond grades. For example, the dominant sampling peak for Roberts Victor lies entirely within the diamond window, consistent with high diamond grades at this locality (de Wit et al., 2016). Conversely, sampling peaks for Newlands and Letšeng lie in the graphite window, hence low diamond grades at these localities (de Wit et al., 2016). Therefore, Al-in-olivine geothermometry offers great potential in enhancing the evaluation of the diamond grade of kimberlites and CROL globally.



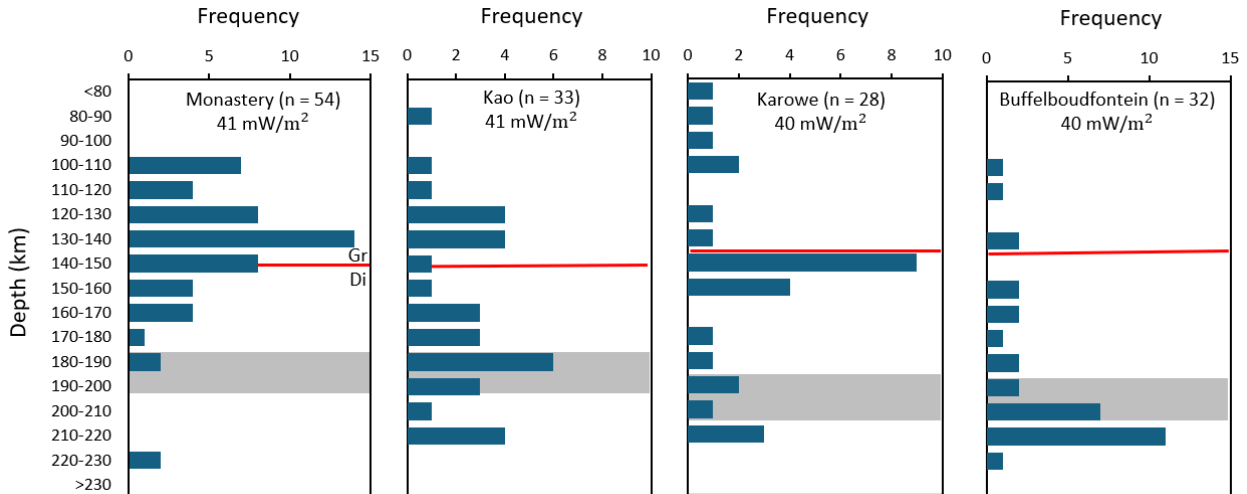


Figure 1: Histograms showing the depth distribution of olivine xenocrysts from kimberlite (blue) and CROL (green) localities in the Kalahari craton. Pressure-temperature conditions of peridotitic olivine in equilibrium with garnet peridotites are based on the Al-in-olivine thermometer of Bussweiler et al. (2017) and the local paleo-geotherms from Bell et al. (2003) and Grütter (2009). Red line represents the graphite-diamond (Gr-Di) transition based on Day (2012); Area shaded in grey shows the lithosphere-asthenosphere boundary (LAB); n = number of olivine cores presented.

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