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Age and origin of the lithospheric mantle below the Ancient Gneiss Complex, Eswatini.

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Introduction

The Ancient Gneiss Complex (AGC) and Barberton Greenstone Belt (BGB) of the eastern Kaapvaal Craton region have been studied extensively to establish the tectonic processes governing early craton formation. This region experienced tectono-magmatism at 3.2 Ga and there is an ongoing debate about whether this event is associated with subduction processes that mark the start of plate tectonics (e.g., Moyen, 2006; Kröner et al., 2018). To better understand the tectonic evolution in this region, we are studying mantle xenocrysts from the Dokolwayo carbonate-rich olivine lamproite (previously called Group II kimberlites) in Eswatini. These xenocrysts allow us to elucidate the origin, composition, and evolution of the lithospheric mantle beneath the AGC. Additionally, they enable us to determine the thermo-barometric conditions of the lithospheric mantle, diamond stability at the time of eruption, and the timing of subduction.

Major and trace element compositions

Our xenocryst suite consists of eclogitic garnets (G4 and G4D), peridotitic garnets (G9 and G10D), clinopyroxenes, along with olivines, chromites, and eclogitic kyanites. Olivine has Mg# ([Mg/Mg + Fe] ×100) between 89.8 and 93.6. The majority of olivines (n = 18) have Mg# that correspond to harzburgite and lherzolite. Only five olivines have high Mg# > 92.7 that indicate derivation from depleted dunitic residues produced by primary melt depletion.

Peridotitic garnets (n = 53) are predominantly fertile lherzolitic (CaO 4.2–5.9 wt.% and Cr_2O_3 1.3–7.9 wt.%) and only a few (n = 2) are depleted harzburgitic (CaO 2.4–3.6 wt.% and Cr_2O_3 1.2–6.9 wt.%) (Fig. 1). The two harzburgitic G10 garnets display sinusoidal REE_N patterns with depletion in $LREE_N$ (where REE_N refers to chondrite normalisation), peaking at Sm, and steep slopes of $MREE\text{-}HREE_N$, reflecting the original pattern of a partial melting residue. The majority of lherzolitic G9 garnets (n = 43) show normal REE_N patterns, with depleted $LREE_N$ and relatively flat $MREE_N$-$HREE_N$ (Lu/Gd_N = 1.5) (Fig. 2). Seven lherzolitic G9 garnets display fractionation within the $MREE_N$-$HREE_N$, suggesting re-enrichment by a low-T fluid metasomatic agent, as observed in the negative Ti and Y anomalies and high Zr. One garnet is heavily enriched in $LREE_N$ with flat $MREE_N$-$HREE_N$, implying second-stage chemical overprint possibly by the kimberlite melt, which would have re-enriched the garnet in incompatible elements.

Eclogitic G4 garnets (n = 72) have Cr_2O_3 < 1 wt.%, and CaO between 2.4 and 5.9 wt.%. 63% of these eclogitic garnets have Na_2O > 0.07 wt.% and classify as G4D (Grütter et al., 2004), suggesting a strong association with diamonds. All eclogitic garnets show normal REE_N patterns, negative Sr anomalies, and only slightly positive Eu anomalies (Eu/Eu* = 0.99–1.27) calculated as $Eu_N/\mathrm{sqrt}(Sm_N \times Gd_N)$ (Fig. 2). The majority of eclogitic garnets, 83%, are gabbroic (Eu/Eu* > 1.05), reflecting plagioclase-bearing oceanic lithosphere protoliths.

Chrome-diopsides (n = 17) show moderate to extreme enrichment in $LREE_N$ (La/Sm_N = 0.9–3.8), a progressive depletion in $HREE_N$ (Lu/Gd_N = 0.1), and relative depletion in HFSE (Nb, Ti, Zr). These compositions are similar to clinopyroxene from the J4 fertile lherzolite (Stachel et al., 2022) (Fig. 2). Four omphacites have Na/Na + Ca > 0.2 and K_2O < 0.01 wt.%, indicating a low-pressure origin. These omphacites show enrichment in incompatible elements with depletion in $MREE_N$-$HREE_N$ and positive Sr anomalies, characteristic of a plagioclase-bearing protolith. Among these, one omphacite displays a humped REE_N pattern peaking at Nd_N ($La/Sm_N = 0.4$) and a positive Eu anomaly of 2.2.

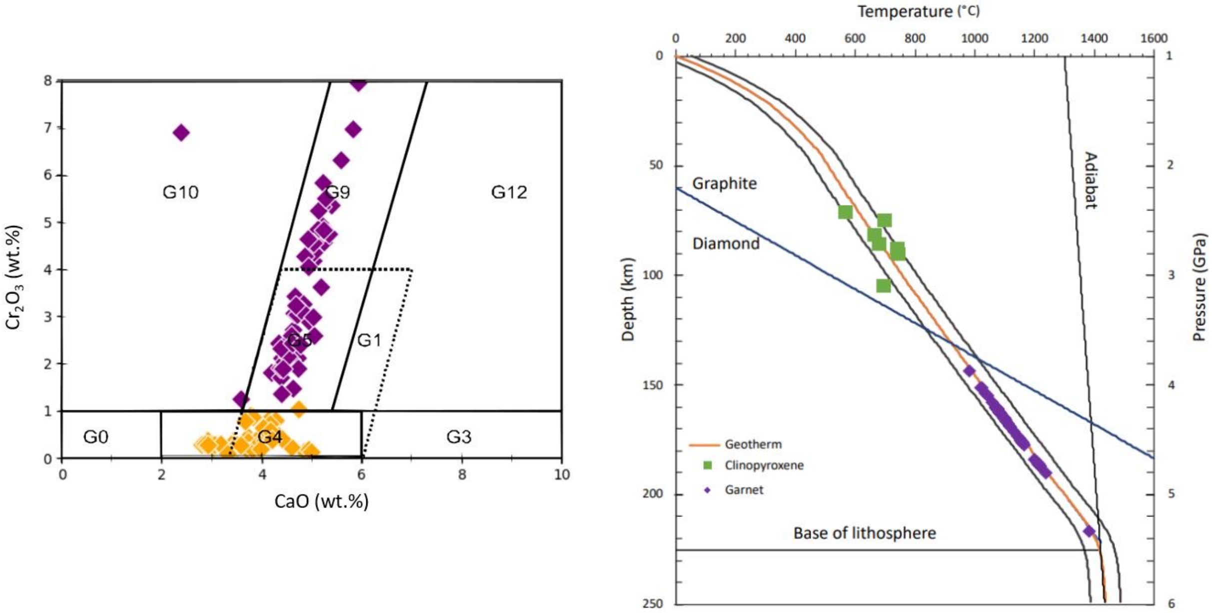

Figure 1: Left: Cr_2O_3 vs. CaO diagram with a G-number nomenclature classifying garnets from Dokolwayo (following Grütter et al., 2004). Orange symbols are eclogitic garnets and purple symbols are peridotitic. Right: FITPLOT geotherm calculated using clinopyroxene pressure and temperature estimates (Nimis and Taylor, 2000), along with projected Ni-in-garnet temperatures (Canil, 1999).

Evidence for subduction

Eclogites from the lithospheric mantle are often interpreted as originating from the oceanic lithosphere and being emplaced into the mantle through subduction (Jacob, 2004). Omphacites from Dokolwayo have demonstrated evidence of plagioclase accumulation in their protolith in a low-P environment. However, eclogitic garnets, even those possibly derived from low-pressure stability fields, do not exhibit positive Sr anomalies which offers limited substantiation for subducted oceanic lithosphere. Future work includes $\delta^{18}O$ analysis on the eclogitic garnets to assess whether the $\delta^{18}O$ values vary significantly from the 5.5‰ mantle value (Mattey et al., 1994) which would be interpreted as evidence for hydrothermally-altered oceanic crust protoliths. Nine lherzolitic garnets contain high-Cr contents ($Cr_2O_3 > 5$ wt.%) and show low Lu/Er_N suggesting that they formed from partial melting at low pressures in the spinel stability field (Stachel et al., 1998) and possibly reached greater depths through subduction.

Geothermobarometry

Clinopyroxenes yield temperatures between 567 and 750 °C and pressures from 2.3 to 3.4 GPa (Nimis and Taylor, 2000). The FITPLOT geotherm produced from Dokolwayo clinopyroxenes shows that the lithospheric mantle is around 220–230 km thick, with diamond stability > 860 °C. Peridotitic garnets yield Ni-in-garnet temperatures between 980 and 1210 °C (Canil, 1999). When these temperatures are extrapolated onto the clinopyroxene-derived geotherm, they are derived from depths between 150 and 220 km, in the diamond stability field (Fig. 1).

Age of the lithospheric mantle

To determine the age of the lithospheric mantle below the AGC and assess whether it is similar in age to the Paleo-Mesoarchaean crust in the AGC, Lu-Hf isotopic analysis will be performed on both peridotitic and eclogitic garnets. If isochron ages are obtained for the eclogitic garnets, this will allow us to constrain the age of subduction in this region and provide insights into the geodynamic processes below the AGC.

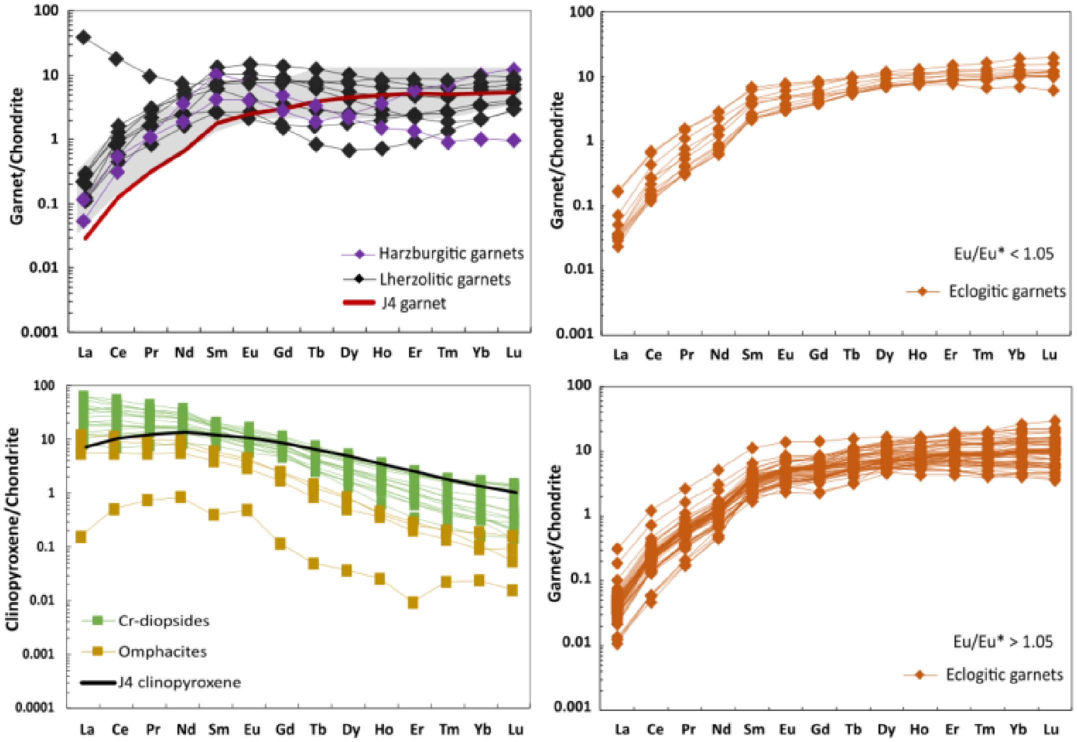

Figure 2: Chondrite-normalised REE patterns of xenocrysts from Dokolwayo. The shaded area in the top left represents the normal patterns of Dokolwayo`s lherzolitic garnets. For comparison, garnet and clinopyroxene from J4 fertile lherzolite are plotted (Stachel et al., 2022). Normalisation values are from McDonough and Sun (1989).

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