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 xenocrystals 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 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 Cr2O3 1.3–7.9 wt.%) and only a few (n = 2) are depleted harzburgitic (CaO 2.4–3.6 wt.% and Cr2O3 1.2–6.9 wt.%) (Fig. 1). The two harzburgitic G10 garnets display sinusoidal REE patterns with depletion in LREE, peaking at Sm, and steep slopes of MREE–HREE, reflecting the original pattern of a partial melting residue. The majority of lherzolitic G9 garnets (n = 43) show normal REE patterns, with depleted LREE and relatively flat MREE–HREE (Lu/Gd = 1.5) (Fig. 2). Seven lherzolitic G9 garnets display fractionation within the MREE–HREE, 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 with flat MREE–HREE, 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) show Cr2O3 < 1 wt.%, and CaO between 2.4 and 5.9 wt.%. 63% of these eclogitic garnets have Na2O > 0.07 wt.% and classify as G4D (Grütter et al., 2004), suggesting a strong association with diamonds. All eclogitic garnets show normal REE patterns, negative Sr anomalies, and only slightly positive Eu anomalies (Eu/Eu* = 0.99–1.27) calculated as Eu5/sqrt(Sm5 × Gd5) (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 (La/Sm5 = 0.9–3.8), a progressive depletion in HREE (Lu/Gd5 = 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 K2O < 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\(_2\)O\(_3\) 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\(_2\)O\(_3\) > 5 wt.%), 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).

**References**


