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## What inclusions in diamond tell us about the lithospheric mantle beneath Snap Lake Kimberlite Dyke (Northwest Territories, Canada)

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### Introduction

The Snap Lake kimberlite dyke is located on the southern Slave Craton, approximately 200 km northeast of Yellowknife, NWT. While many diamond mines have already been studied in detail, limited data exists for Snap Lake diamonds and their inclusions. Previous studies (Pokhilenko et al. 2001; Pokhilenko et al. 2004) have inferred, through the observation of rare high-Cr majoritic garnet inclusions, the presence of an unusually thick lithospheric mantle root (> 200 km). At depths corresponding to the diamond stability field, this mantle root is shown to be mostly harzburgitic (Pokhilenko et al., 2004).

This research characterizes the various diamond substrates in the lithospheric mantle as well as the conditions of diamond formation and mantle residence based on a set of 147 inclusion-bearing diamonds generously provided by De Beers Group. For a subset of 87 inclusion-bearing diamonds nitrogen content/aggregation state and stable isotope data is paired with the major-element geochemistry of the accompanying mineral inclusions. In addition, garnet, clinopyroxene, and olivine inclusions were analyzed for their trace-element patterns, including rare earth elements in garnet and clinopyroxene.

The aim of this research is to verify the suggested presence of unusually thick lithospheric mantle beneath the southeastern Slave Craton at approximately 530 Ma and provide important information regarding the paragenesis and chemical characteristics of local diamond substrates.

### Analytical Results and Discussion

Based on inclusion chemistry it is inferred that diamond formation occurred primarily in peridotitic mantle (93%), with a minor component forming in eclogitic mantle (6%), and a single diamond studied showing a rare mixed paragenesis (1%). The peridotitic inclusion suite consists of garnet, olivine, chromite, clino- and orthopyroxene, sulphide, and rare native iron rimmed by wustite, while the eclogitic inclusion suite consists of garnet, SiO<sub>2</sub>, Ni-poor sulphide, and potassium feldspar. From the single mixed paragenesis diamond, a peridotitic garnet, a presumably eclogitic SiO<sub>2</sub>, and an eclogitic sulphide were recovered. The presence of a mixed paragenesis diamond as well as several chemically distinct, lherzolic-harzburgitic garnet pairs recovered from single diamonds indicate diamond formation in an evolving chemical environment. In contrast to the findings of Pokhilenko et al. (2001, 2004), there is an absence of majoritic garnet within the diamond population examined here. Previous studies have estimated up to 33% majorite component in garnets recovered from the Snap Lake kimberlite dyke (Pokhilenko et al., 2001, 2004), whereas in our sample set the calculated majorite component in peridotitic garnets (0.0 to 1.6%; calculated following Locock (2018)) is not significant within analytical uncertainty.

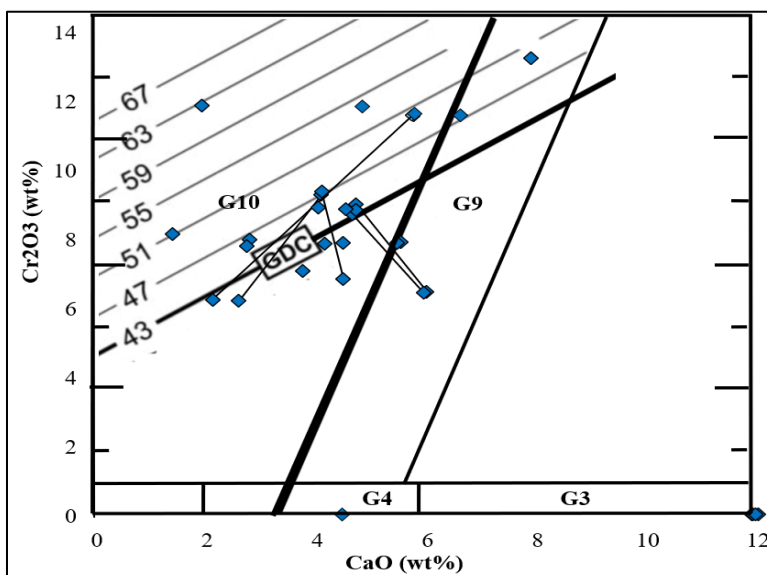


Figure 1.  $\text{Cr}_2\text{O}_3$  versus  $\text{CaO}$  for the studied garnets from Snap Lake showing the garnet classes G10 (harzburgitic), G9 (lherzolitic), G3 (high-Ca eclogitic) and G4 (low-Ca eclogitic/pyroxenitic) after Grütter et al. (2004). Tie lines connect co-existing garnets recovered from single diamonds.

Sinusoidal to weakly sinusoidal  $\text{REE}_N$  patterns for the majority of peridotitic (harzburgitic and lherzolitic) garnets indicate widespread metasomatic enrichment through similar types of fluids/melts. Geothermobarometry results indicate diamond formation occurred along a cool  $36 - 38 \text{ mW/m}^2$  paleogeotherm at temperatures ranging from  $920$  to  $1230 \text{ }^\circ\text{C}$ , between  $120$  and at least  $210 \text{ km}$  depth.

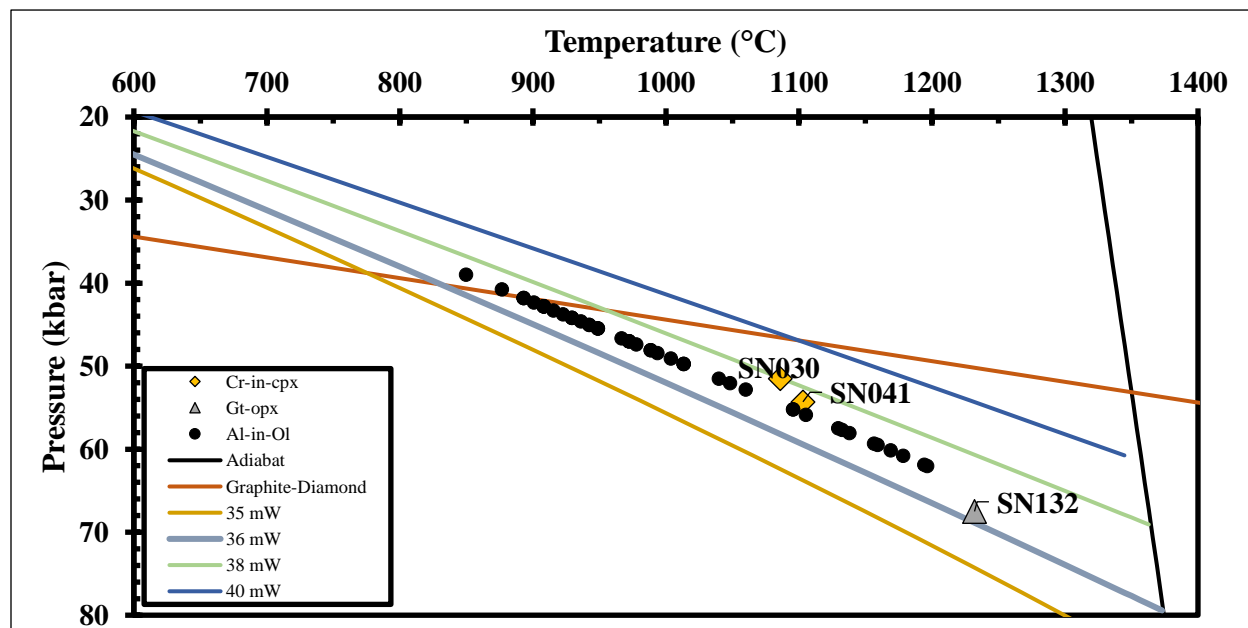


Figure 2. Geothermobarometry results for two clinopyroxene inclusions (Nimis & Taylor, 2000) and one non-touching garnet-orthopyroxene pair (Nickel & Green, 1985 and Harley, 1984). P-T conditions for 50 single olivine grains were calculated using the Al-in-Ol thermometer of Bussweiler et al. (2017) projected onto a  $37 \text{ mW/m}^2$  model geotherm. The plotted model geotherms ( $35\text{--}40 \text{ mW/m}^2$  surface heat flow) are from Hasterok and Chapman (2011) and the graphite-diamond transition is from Day (2012).

Overall, nitrogen abundances, measured on diamond fragments with FTIR, range from below detection (< 10 at.ppm) to 1190 at.ppm with a large variation in nitrogen aggregation state from 0–95 %B. Nitrogen-based mantle residence temperatures range from 1050–1280 °C and agree with geothermobarometry results. SIMS analyses resulted in  $\delta^{13}\text{C}$  values in a tight range from -8.0 to -1.3 ‰, with a median of -4.2 ‰ and an average of -4.3 ‰. The  $\delta^{13}\text{C}$  values of the peridotitic and eclogitic suites differ very little with ranges from -8.0 to -1.3 ‰ (median = -4.2 ‰, average = -4.3 ‰) and -6.2 to -3.9 ‰ (median = -4.7 ‰, average = -4.7 ‰), respectively. This agreement in carbon isotope compositions of the peridotitic and eclogitic diamond suites and the accepted mantle range, however, is not conclusive in establishing a mantle origin of carbon for the entirety of the sample set. More likely, both diamond suites formed during multiple growth events, from distinct melts/fluids potentially tapping different carbon sources, including asthenospheric  $\text{CH}_4$ -rich fluids, carbonated melts/fluids, or subducted marine carbonates – all of which can have  $\delta^{13}\text{C}$  values within the mantle range. Snap Lake diamonds show a wide range in  $\delta^{15}\text{N}$  values from -20 to +11 ‰ possibly reflecting (1) the presence of spatially restricted, strongly  $^{15}\text{N}$ -depleted primordial reservoirs due to incomplete homogenization of N in the Archean mantle, (2) involvement of  $^{15}\text{N}$ -enriched subducted sediments and altered oceanic crust and (3) normal mantle-derived nitrogen ( $\delta^{15}\text{N}$  near -5 ‰), all contributing to diamond formation.

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