12TH INTERNATIONAL KIMBERLITE CONFERENCE
30 YEARS OF DIAMONDS IN CANADA
8–12 July 2024 • Yellowknife

12th International Kimberlite Conference Extended Abstract No. 12IKC-71, 2024

Mesoproterozoic diamond formation in the Sask craton mantle root: A far-field link to the Mackenzie large igneous event?

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Introduction

Most mined diamonds ultimately derive from Archean lithospheric mantle that underpins the Archean nuclei of cratons. Recent studies, however, have indicated the importance of Proterozoic mantle and/or diamond formation in the Proterozoic for the creation of economic diamond deposits. The small Sask craton in Canada, despite Archean crustal basement ages of 3.3-2.1 Ga (Collerson et al., 1989; Bickford et al., 2005), has a diamond-bearing lithospheric mantle root that was stabilised in the Paleoproterozoic, with Re-Os ages of peridotitic mantle xenoliths dominantly between 2.4 and 1.7 Ga (Czas et al., 2020). The relatively young age of the Sask mantle root raises questions about the origin of diamond in the Fort à la Corne (FalC) kimberlites, in particular when and under what conditions diamonds formed underneath such an unusual craton, and what role, if any, the Paleoproterozoic Trans Hudson Orogen (THO: 1.9 to 1.7 Ga; Rayner et al., 2005) played in diamond genesis.

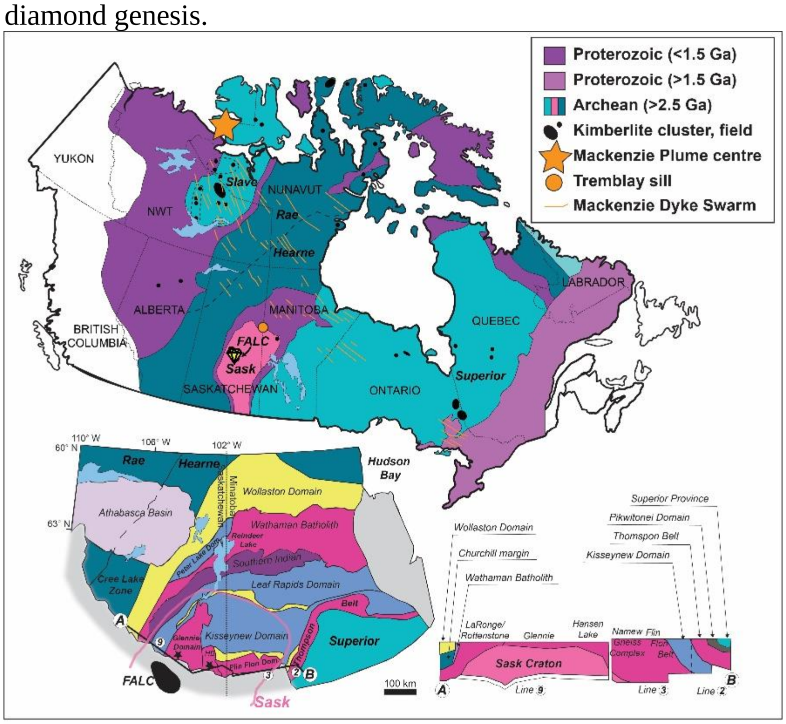

Figure 1: The distribution of cratons, Proterozoic belts, and kimberlites within Canada is illustrated in this map, adapted from Fahrig and Jones (1969) and Czas et al. (2020). The detailed map of the Trans Hudson Orogen (THO) and a cross-section of the Sask craton and THO were constructed using LITHOPROBE Line 9, 3, 2, adapted from Lewry et al. (1994) and Bickford et al. (2005). Archean cratonic crust is highlighted in dark blue, teal, and pink, with black symbols indicating kimberlite clusters. Proterozoic crust is shaded in purple and dark pink, while very light purple represents Phanerozoic crust. The Sask craton is depicted in light pink and is surrounded by the THO in dark purple. The FalC kimberlites are marked in black. The Sask craton is exposed within the THO and is identified with stars. The orange star over Victoria Island indicates the head of the Mackenzie plume. Narrow

orange lines on the map indicate the Mackenzie dyke swarm, and an orange circle represents the Tremblay sill, dated at 1267 ± 2 Ma (Fahrig and Jones, 1969; LeCheminant and Heaman, 1989).

Methods

Fertile lherzolite garnet (*n*=8) and clinopyroxenes (*n*=5) were extracted from eleven different diamonds. Inclusions were digested in a concentrated HF-HNO_3 mixture and placed on a hotplate at 185 °C for a maximum of 5 days. The Sr and rare earth element (REE) fractions were extracted using the miniaturised chemical procedure by Koornneef et al. (2015). The separation of Sm and Nd from the REE fractions was obtained with the LN resin columns (Pin and Zalduegui, 1997). Strontium, Sm and Nd isotope analyses were performed on a Thermo Scientific Triton Plus at the University of Alberta following a similar set-up as the one described in Timmerman et al. (2017).

Results and Discussion

FalC diamonds dominantly formed in unusually fertile lherzolitic substrates (Banas et al., this confrenece). In this study we analysed Sm-Nd isotope systematics of 13 individual silicate inclusions from 13 lherzolitic diamonds from the Star kimberlite at FalC. Based on highly distinct εNd initial values, two groups of inclusions are identified that yield separate isochron ages within error of each other. Group 1 inclusions - characterised by mostly elevated εNd values (-3 to 13) - are indicative of old, fertile to depleted substrates, whereas Group 2 inclusions have strongly negative εNd values (-14.9 to -9.3) requiring input from an ancient LREE-enriched component. Group 1 consists of seven garnets (Nd 1.9-2.6 ppm and Sm 1.3-1.8 ppm) and five clinopyroxene inclusions (Nd 6.9-7.9 ppm and Sm 0.01-0.13 ppm). Group 2 includes three garnets (Nd 1.9-2.6 ppm and Sm 1.4-1.7 ppm) and three clinopyroxenes (Nd 7.7-8.1 ppm and Sm 1.4-1.5 ppm). Clinopyroxenes from both groups have very similar $^{87}Sr/^{86}Sr$ initial ratios, between 0.7031 – 0.7047. Regression of the inclusions from the two age groups defines two Sm-Nd isochrons agreeing within error and defines an age of ~1270 Ma. A single diamond-forming event is also confirmed by the similar N-abundance (range from 1.0 to 116.0 at.ppm), low N-aggregation state (Type IIa to Type IaAB) and $\delta^{13}C$ ratios (average at -15.0 ‰).

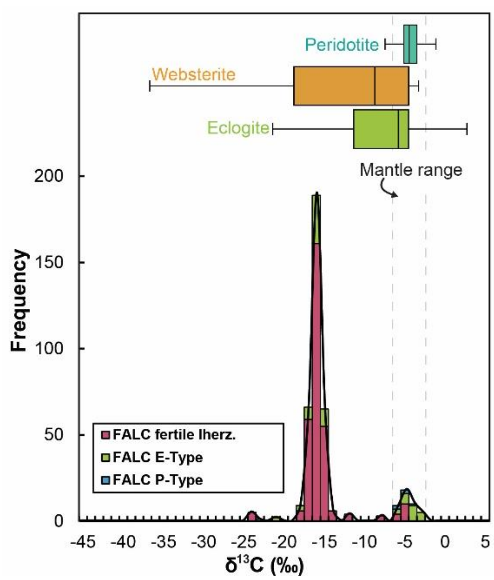

Figure 2: Histogram of $\delta^{13}C$ values for FalC diamonds, classified as fertile lherzolite (pink bars; n= 313), eclogitic (green bars; n= 74), and peridotitic (blue bars; n= 5) for individual SIMS analyses. The main mode of $\delta^{13}C$ values is observed at -15.3 ‰. The boxes represent the interquartile ranges, while the middle lines correspond to the median values of the population. The extent of the whiskers correlates with the minimum and maximum $\delta^{13}C$ values. The grey dashed lines represents the mantle range for $\delta^{13}C$ (-5 ± 2 ‰; Cartigny et al., 2014).

The Sask diamond formation event defined here occurred well after the THO and is within error of the 1270 ± 4 Ma Mackenzie plume in Northern Canada (LeCheminant and Heaman, 1989). There is evidence for impact of the Mackenzie dyke swarm on the Sask craton in the form of the Tremblay diabase sill (LeCheminant and Heaman, 1989) with a U-Pb baddeleyite age of 1267 ± 2 Ma (Ernst and Baragar, 1992). These results clearly refute any exclusive association of diamond deposits with cratons underpinned by Archean lithospheric mantle. Moreover, the strong temporal association of Sask diamond formation with a large igneous province (LIP) magmatic event – a phenomenon often considered diamond-unfriendly – indicates that the trigger for LIPs may play an important role in diamond formation, in far-field regions.

References

Banas, A., Stachel, T., Pearson, D.., Read, G., n.d. Diamonds from Fort à la Corne – post-Archean formation in exceptionally cool and fertile lherzolitic substrates. In International Kimberlite Conference: Extended Abstracts 12.

Bickford, M.E., Mock, T.D., Steinhart III, W.E., Collerson, K.D., Lewry, J.F., 2005. Origin of the Archean Sask craton and its extent within the Trans-Hudson orogen: evidence from Pb and Nd isotopic compositions of basement rocks and post-orogenic intrusions. Canadian Journal of Earth Sciences 42, 659–684.

Cartigny, P., Palot, M., Thomassot, E., Harris, J.W., 2014. Diamond formation: A stable isotope perspective. Annual Review of Earth and Planetary Sciences 42, 699–732.

Collerson, K.D., Lewry, J.F., Schmus, R.W. Van, Bickford, M.E., 1989. Sm-Nd isotopic constraints on the age of the buried basement in Central and Southern Saskatchewan : implications for diamond exploration. Summary of Investigations 1989. Saskatchewan Geol. Surv, Misc. Rep. 89, 168–171.

Czas, J., Pearson, D.G., Stachel, T., Kjarsgaard, B.A., Read, G.H., 2020. A Palaeoproterozoic diamond-bearing lithospheric mantle root beneath the Archean Sask Craton, Canada. Lithos 356, 105301.

Ernst, R.E., Baragar, W.R.A., 1992. Evidence from magnetic fabric for the flow pattern of magma in the Mackenzie giant radiating dyke swarm. Nature 356, 511–513.

Fahrig, W.F., Jones, D.L., 1969. Paleomagnetic evidence for the extent of Mackenzie igneous events. Canadian Journal of Earth Sciences 6, 679–688.

Kjarsgaard, B.A., Heaman, L.M., Sarkar, C., Pearson, D.G., 2017. The North America mid-Cretaceous kimberlite corridor: Wet, edge-driven decompression melting of an OIB-type deep mantle source. Geochemistry, Geophysics, Geosystems 18, 2727–2747.

Kjarsgaard, B.A., Leckie, D.A., Zonneveld, J.-P., 2007. Geology and diamond distribution of the 140/141 kimberlite, Fort a la Corne, central Saskatchewan, Canada; discussion [modified]. Lithos 97, 422–428.

Koornneef, J.M., Nikogosian, I., van Bergen, M.J., Smeets, R., Bouman, C., Davies, G.R., 2015. TIMS analysis of Sr and Nd isotopes in melt inclusions from Italian potassium-rich lavas using prototype 1013Ω amplifiers. Chemical Geology 397, 14–23. https://doi.org/10.1016/j.chemgeo.2015.01.005

LeCheminant, A.N., Heaman, L.M., 1989. Mackenzie igneous events, Canada: Middle Proterozoic hotspot magmatism associated with ocean opening. Earth and Planetary Science Letters 96, 38–48.

Lewry, J.F., Hajnal, Z., Green, A., Lucas, S.B., White, D., Stauffer, M.R., Ashton, K.E., Weber, W., Clowes, R., 1994. Structure of a Paleoproterozoic continent-continent collision zone: a LITHOPROBE seismic reflection profile across the Trans-Hudson Orogen, Canada. Tectonophysics 232, 143–160.

Pin, C., Zalduegui, J.S., 1997. Sequential separation of light rare-earth elements, thorium and uranium by miniaturized extraction chromatography: Application to isotopic analyses of silicate rocks. Analytica Chimica Acta 339, 79–89.

Rayner, N.M., Stern, R.A., Bickford, M.E., 2005. Tectonic implications of new SHRIMP and TIMS U-Pb geochronology of rocks from the Sask Craton, Peter Lake Domain, and Hearne margin, Trans-Hudson Orogen, Saskatchewan. Canadian Journal of Earth Sciences 42, 635–657.

Timmerman, S., Koornneef, J.M., Chinn, I.L., Davies, G.R., 2017. Dated eclogitic diamond growth zones reveal variable recycling of crustal carbon through time. Earth and Planetary Science Letters 463, 178–188.