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

12th International Kimberlite Conference Extended Abstract No. 12IKC-45, 2024

Sublithospheric Diamonds and Indicator Minerals from DO-27 Kimberlite, Slave Craton, Canada – Geochemistry, Age and Origin

Qiwei Zhang[1], Suzette Timmerman[1, 2], Irina Malakhova[1], Thomas Stachel[1], Robert Luth[1], Barrett Elliott[3], Ingrid Chinn[4], Michael Seller[5], Fabrizio Nestola[6], Joshua Davies[7], Richard Stern[1], Bruce Kjarsgaard[8], D. Graham Pearson[1]

[1] University of Alberta, Edmonton, Canada, qiwei2@ualberta.ca, malakhov@ualberta.ca, tstachel@ualberta.ca, bob.luth@ualberta.ca, rstern@ualberta.ca, gdpearso@ualberta.ca
[2] University of Bern, Bern, Switzerland, suzette.timmerman@unibe.ch
[3] Northwest Territories Geological Survey, Yellowknife, Canada, Barrett_Elliott@gov.nt.ca
[4] De Beers Exploration, Johannesburg, South Africa, Ingrid.Chinn@debeersgroup.com
[5] De Beers Exploration, De Beers Canada Inc, Toronto, Canada, Michael.Seller@debeersgroup.com
[6] University of Padova, Padova, Italy, fabrizio.nestola@unipd.it
[7] Université du Québec à Montréal, Montréal, Canada, davies.joshua@uqam.ca
[8] Geological Survey of Canada, Ottawa, Canada, bruce.kjarsgaard@canada.ca

Introduction

Sublithospheric diamonds can comprise the most valuable diamonds in a given deposit and dominate the production value of some mines (e.g., Smith et al. 2017). These diamonds are also of great scientific value for the unique insights they provide into Earth's deep mantle (e.g., Stachel et al. 2000; Pearson et al. 2014; Timmerman et al. 2023). The DO-27 kimberlite, Northwest Territories, has long been known to contain sublithospheric diamonds (Davies et al. 1998). Nitrogen content and aggregation state analyses of a new suite of 435 diamonds, while not fully representative of the entire DO-27 diamond population, reveal that ~44% are either nitrogen-free (Type II) or contain fully-aggregated nitrogen (Type IaB). This finding indicates the possibility of a very high proportion of sublithospheric diamonds and establishes an excellent opportunity to study the ages and origin of superdeep diamonds. Additionally, a large suite (N= ~ 6,200) of indicator minerals (garnet and clinopyroxene) from the DO-27 kimberlite was examined to identify potential distinctive compositional characteristics that may be indicative of the presence of superdeep diamonds, by comparing the indicator mineral chemistry to those from non-superdeep diamond-bearing kimberlites from the Slave Craton and elsewhere.

Analytical methods

Inclusions in DO-27 Type II and Type IaB diamonds were initially characterised by Raman spectroscopy. Subsequently, identified Ca-silicate inclusions were ablated whole, while still in the diamond, using an offline laser ablation method (McNeill et al. 2009). A 5% aliquot of the dissolved ablation products were analysed for trace elements on an Inductively Coupled Plasma Mass Spectrometer (ICPMS) equipped with a JET interface and APEX-Omega unit. The Sr-Nd-Pb fractions of the remaining 95% analyte were separated by column chromatography and analysed on a Thermal Ionization Mass Spectrometer (TIMS) equipped with 4×10^{13} Ohm amplifiers. Afterwards, other inclusions (e.g., enstatite, ferropericlase) were liberated from the host diamonds. Major element compositions of t liberated inclusions and kimberlite indicator minerals (KIM) were obtained via electron probe micro-analyzer (EPMA) using wavelength-dispersive spectrometry and a fully focused beam. Detection limits vary among elements and minerals but typically are lower than 0.02 wt.%.

Ages and origin of the DO-27 sublithospheric diamonds

Typical mineral associations found in DO-27 Type II and Type IaB diamonds are Ca-silicates (retrogressed CaSi-perovskite) ± enstatite (retrogressed bridgmanite) ± ferropericlase, indicating a lower-mantle (>660 km) origin (Fig. 1a). The high Mg# of bridgmanite (median Mg#=94.7) and ferropericlase (median Mg#=85.9) implicate a meta-harzburgitic host rock for the diamonds. This strongly melt-depleted signature contrasts with the high abundance of Ca-silicate inclusions, some of which are variably enriched in incompatible elements and have enriched Sr-Nd-Pb isotope signatures, which collectively indicate the host rock was metasomatized by carbonatitic melts/fluids, likely released from a relatively cold subducted slab in the lower mantle. The U-Pb systematics of the Ca-silicates define two ages of diamond crystallisation of ~1.0 Ga and 1.7 Ga (Fig. 1b); the latter represents the oldest age reported for sublithospheric diamond formation so far. This is the first direct chronological evidence from lower mantle diamonds that places a minimum age for the onset of cold deep subduction at ~1.7 Ga, and provides a time marker for the recycling of crustal carbonates into Earth's deep mantle (Zhang et al. 2024).

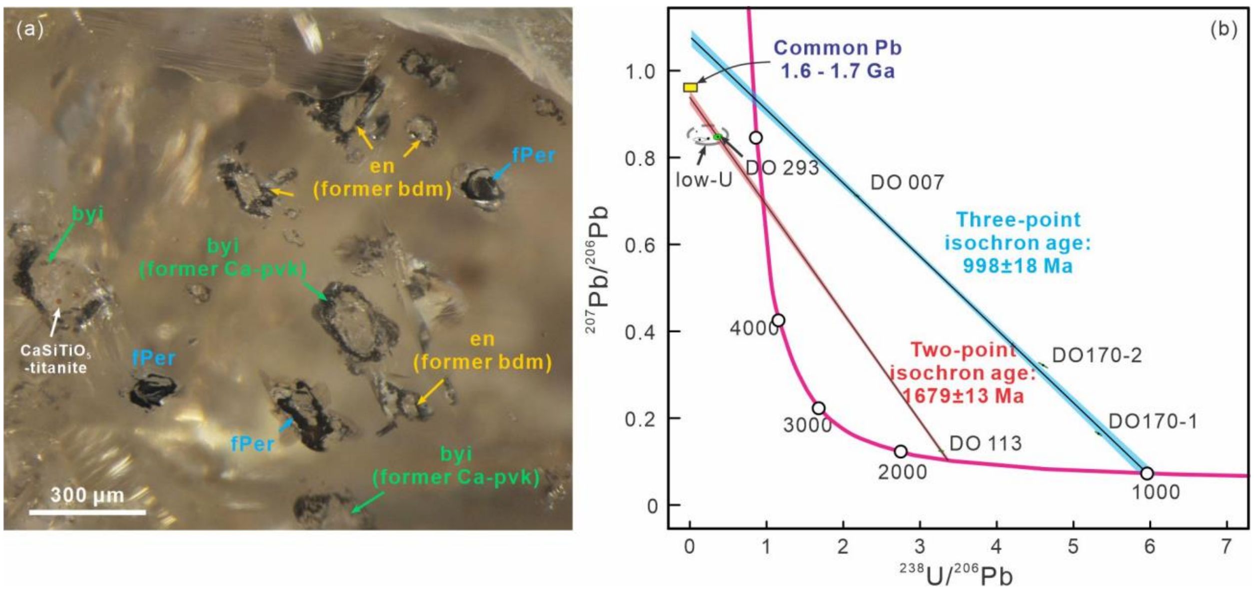

Figure 1: (a) Representative inclusion assemblage in a DO-27 superdeep diamond, with fPer = ferropericlase, bdm = bridgmanite, Ca-pvk = CaSi-perovskite, en = enstatite, byi = breyite. (b) Tera-Wasserburg U-Pb Concordia plot of DO-27 Ca-silicates. Two different isochron ages were defined by the regression of two Ca-silicate inclusions (high-U DO-113 and low-U DO-293) and the regression of three other high-U Ca-silicate inclusions (DO-170-1,-2 and DO-007), via regression model-3 of IsoplotR. The compositions of three other low-U Ca-silicates show little radiogenic Pb. The figure was modified after Zhang et al. (2024).

Compositions of DO-27 kimberlite indicator minerals

DO-27 KIM analysed comprise ~1900 chrome diopsides and ~4300 peridotitic garnets. The compositions and equilibrium P-T conditions of Cr-diopsides resemble those typically found in cratonic peridotites and define a ~38 mWm^{-2} model geotherm, indicating a thick lithosphere (~ 240 km) with a large diamond window beneath the DO-27 kimberlite (Fig. 2b), similar to Ekati and Diavik. About 8% of the KIM garnets are high-Cr, low-Ca G10 garnets, extending to a minimum pressure of 6.2 GPa (~190 km; PCr). The Ni-in-garnet thermometer (Nimis et al. 2024) gives a range in temperatures of ~800 to ~1350 °C. Such P-T conditions indicate a lithospheric origin, consistent with the complete absence of majoritic components (superdeep signatures) in the DO-27 KIM garnet suite. DO-27 KIM garnets, however, have a higher percentage (~30%) of high-TiO_2 peridotitic garnets (class G11 of Grütter et al. (2004)) compared to KIM garnets and peridotitic xenolith garnets from most non-superdeep diamond-bearing kimberlites on the Slave

Craton (Fig. 2a). Superdeep diamond geochronology has suggested a link between these diamonds and peridotitic material accreted to the base of the lithospheric mantle before kimberlite eruption (Timmerman et al. 2023). Because G11 garnets are derived from the lowermost lithosphere, they could provide a link to this accretion process and are hence a potential indirect indicator of the presence of sublithospheric diamonds. This model is being evaluated further.

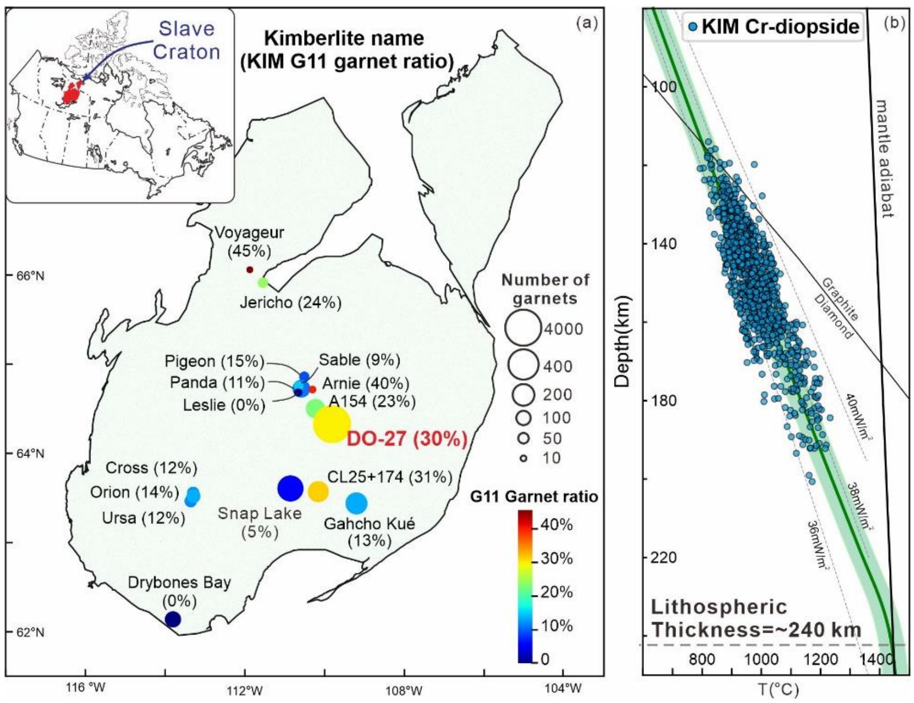

Figure 2: (a) G11 ratio (relative percentage of G11 among peridotitic garnets) of KIM garnets and peridotitic xenolith garnets from kimberlites on the Slave Craton. (b) DO-27 conductive paleogeotherm constructed from single clinopyroxene thermobarometry (Nimis et al. 2020) of KIM Cr-diopsides.

References

Davies R, Griffin W, Pearson N, et al. (1998) Diamonds from the deep: pipe DO-27, Slave Craton, Canada. International Kimberlite Conference: Extended Abstracts 7:170-172

Grütter HS, Gurney JJ, Menzies AH, et al. (2004) An updated classification scheme for mantle-derived garnet, for use by diamond explorers. Lithos 77:841-857

McNeill J, Pearson DG, Klein-BenDavid O, et al. (2009) Quantitative analysis of trace element concentrations in some gem-quality diamonds. J Condens Matter Phys 21:364207

Nimis P, Preston R, Perritt SH, et al. (2020) Diamond's depth distribution systematics. Lithos 376:105729

Nimis P, Zanetti A, Franz L (2024) A revision of the Ni-in-garnet geothermometer with special regard to its pressure dependence. Lithos 468:107513

Pearson D, Brenker F, Nestola F, et al. (2014) Hydrous mantle transition zone indicated by ringwoodite included within diamond. Nature 507:221-224

Smith EM, Shirey SB, Wang W (2017) The very deep origin of the world's biggest diamonds. Gems Gemol 53:388-403

Stachel T, Harris JW, Brey GP, et al. (2000) Kankan diamonds (Guinea) II: lower mantle inclusion parageneses. Contrib Mineral Petrol 140:16-27

Timmerman S, Stachel T, Koornneef JM, et al. (2023) Sublithospheric diamond ages and the supercontinent cycle. Nature 623:752–756

Zhang Q, Timmerman S, Stachel T, et al. (2024) Sublithospheric diamonds extend Paleoproterozoic record of cold deep subduction into the lower mantle. Earth Planet Sci Lett 634:118675