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

12th International Kimberlite Conference Extended Abstract No. 12IKC-Key04, 2024

Sublithospheric diamond ages and their geodynamic implications

Suzette Timmerman[1], **Qiwei Zhang**[2], **Thomas Stachel**[2], **Karen V. Smit**[3], **Jeffrey W. Harris**[4], **Steven B. Shirey**[5], **D. Graham Pearson**[2]
[1] *University of Bern, Bern, Switzerland, suzette.timmerman@unibe.ch*
[2] *University of Alberta, Edmonton, Canada, qiwei2@ualberta.ca, tstachel@ualberta.ca, gdpearso@ualberta.ca*
[3] *University of Witwatersrand, Johannesburg, South Africa, karen.smit@wits.ac.za*
[4] *University of Glasgow, Glasgow, United Kingdom, jeff.harris@glasgow.ac.uk*
[5] *Carnegie Institution for Science, Washington, USA, sshirey@carnegiescience.edu*

Introduction

Over the past decades, dating inclusions in lithospheric diamonds has advanced from analysing tens of pooled inclusions to single sulphide Re-Os analyses and single silicate Sm-Nd analyses, resulting in a global dataset for lithospheric diamond ages (Smit et al. 2022) and the linking of these ages to tectonomagmatic events. On the other hand, dating of inclusions in sublithospheric diamonds is incredibly limited, mainly due to the rarity of dateable inclusions (e.g., sulphide, majorite, and Ca-silicate phases) in already scarce sublithospheric diamonds. Yet, sublithospheric diamonds are important from both a scientific and economic perspective, representing the deepest pristine samples of Earth’s mantle and some of the most valuable diamonds recovered. Understanding the chemical signatures of sublithospheric diamond in a broader geological context requires the isotopic dating of their mineral inclusions. Here we will review the recent progress in the isotopic analyses of inclusions in sublithospheric diamonds and discuss their link to the global supercontinent cycle and emplacement history.

Analytical methods

In lithospheric diamonds, inclusions that are suitable for dating are usually extracted through breakage of the diamond host. For isotopic analyses of inclusions in sublithospheric diamonds such a method is futile, due to retrogression or unmixing into different mineral phases upon ascent to shallower depths. In such complex mineral assemblages, parent/daughter (e.g., U/Pb, Rb/Sr) fractionation can occur between phases. Additionally, in the presence of fluid at the diamond-inclusion interface, high diffusivity of elements and differential partition coefficients may also result in parent/daughter fractionation.

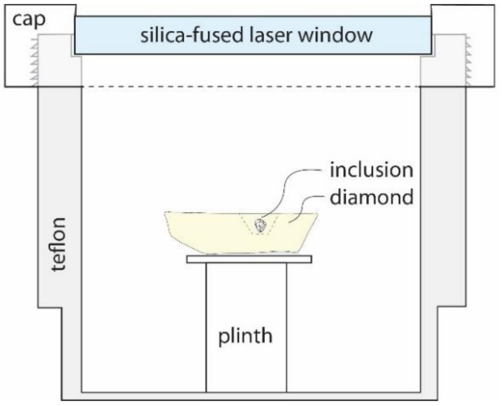

Fig. 1: Schematic diagram of the closed laser ablation cell, redrawn and modified after McNeill et al. (2009). Continuous high-frequency rastering of an area with a laser creates an ablation pit. This arrangement allows the ablation of entire inclusions, plus any associated fluid “film” and some of the diamond host. The ablated material stays within the high-purity teflon “closed” laser ablation cell and is afterwards collected during an acid-flux of the cell. It is processed through chromatography prior to isotope analyses with thermal ionisation mass spectrometry. Clear, transparent diamond hosts with few other solid or fluid inclusions contribute little to the ablated product.

An unmixed Ca-Ti silicate inclusion from Juína (Brazil), with an *in situ* SIMS spot analysis recording an age of 101 ± 7 Ma (Bulanova et al. 2010), potentially has fractionated U/Pb between the different phases, where the obtained U-Pb age likely reflects the time of kimberlite eruption rather than the time of diamond formation. With the full recovery of complex sublithospheric inclusions being extremely difficult, especially because these inclusions are particularly prone to fragmentation with a large pressure release during breakage of diamonds, an off-line laser ablation method is recommended because it allows complete sampling of these complex inclusions (Fig. 1; McNeill et al. 2009). This method was recently successfully applied to sublithospheric Ca-silicate inclusions (Timmerman et al. 2023; Zhang et al. 2024).

Sublithospheric diamond ages

In the study of Timmerman et al. (2023), Type II and Type IaB diamonds with sublithospheric mineral assemblages were studied from Juína (Brazil) and Kankan (Guinea). Ca-silicate inclusions were ablated from 12 diamonds, and analysed for Rb-Sr, Sm-Nd, and U-Pb isotope systematics. In addition, an Fe-sulphide was extracted through diamond breakage and analysed for Re-Os isotope systematics. Remarkably, these four isotopic systems yielded overlapping age results, ranging from 450–650 Ma (Timmerman et al. 2023). The major, trace, and/or isotopic signatures in these inclusions can be related to recycled material. Together with the diamond formation ages, the geochemical signatures suggest that at the time of Gondwana assembly, sublithospheric diamond formation was favoured by focusing subducting slabs into the deep mantle beneath the supercontinent (Fig. 2). This places the 'modern-oceanic mantle-like' Nd-Sr isotopic compositions of pooled majoritic garnet inclusions from Juína, Brazil (Harte and Richardson 2012) into the late Neoproterozoic-Paleozoic diamond formation subduction setting for this area, based on comparable initial Sr isotopic compositions to Ca-silicate inclusions (Timmerman et al. 2023).

A recent study by Zhang et al. (2024) on Ca-silicate inclusions in sublithospheric diamonds from the DO-27 kimberlite, Slave Craton, Canada, yielded ages of 1.0 and 1.7 Ga. These results will be presented at the 12IKC by Zhang et al. (this volume) and confirm the link to the subduction events involved in the assembly of the Rodinia and Nuna supercontinents.

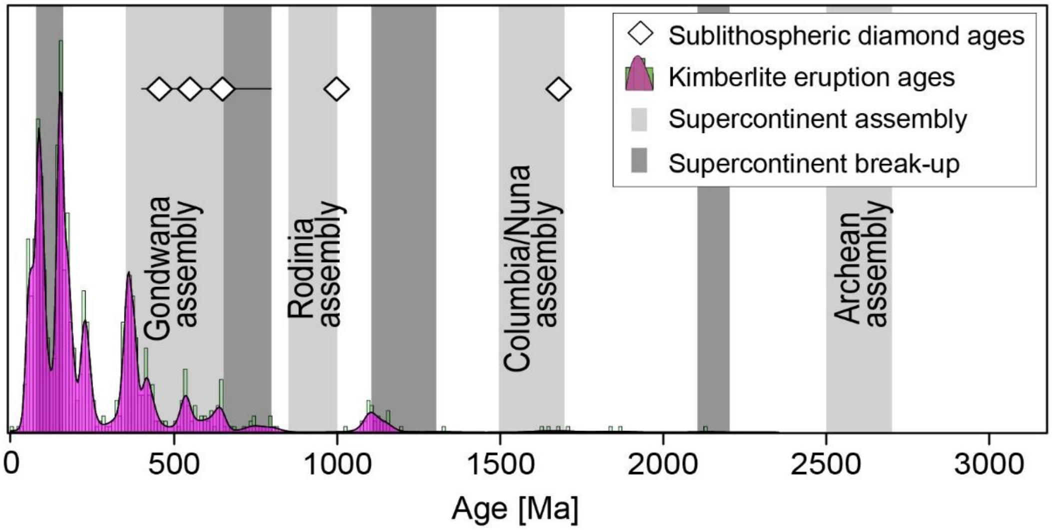

Fig. 2: Sublithospheric diamond ages (Timmerman et al. 2023: Zhang et al. 2024) relative to kimberlite emplacement ages (kimberlite database; Heaman et al. 2019). Sublithospheric diamond ages correlate with supercontinent assembly times (Condie et al. 2015) and associated subduction processes that accompany their assembly.

Geodynamic implications

The large time difference (>300 Myr) between diamond formation in the sublithospheric mantle and eruption to Earth's surface by kimberlitic magmas raises the question of where these diamonds reside after formation, and how they survive until eruption. Timmerman et al. (2023) show that plate tectonic models indicate major northward movement (>6000 km) of the supercontinent Gondwana, shortly after Juína and Kankan diamond formation at 650–450 Ma in the sublithosphere beneath the (current) South Pole location. If diamonds resided in the sublithosphere beneath the circum-Gondwana subduction system, they would have been displaced relative to their final crustal emplacement locations at Juína and Kankan in the Cretaceous. In order for these diamonds to erupt through the Amazonian and West-African cratonic lithosphere, the diamonds and continental lithosphere must have migrated together during continental drift. The most likely way is through emplacement of diamonds to the base of the lithosphere (Fig. 3), a model that is supported by a lower pressure mode at ~300 km depth in the global geobarometry compilation of majoritic garnet inclusions in sublithospheric diamonds. A mechanism for diamonds to move from the sublithosphere to the base of the lithosphere is with the rise of buoyant, depleted, recycled material. We propose that this process of attaching depleted material to cratonic roots operates globally, and is an effective way to create thick continental lithosphere that has long-term (billion-year scale) stability.

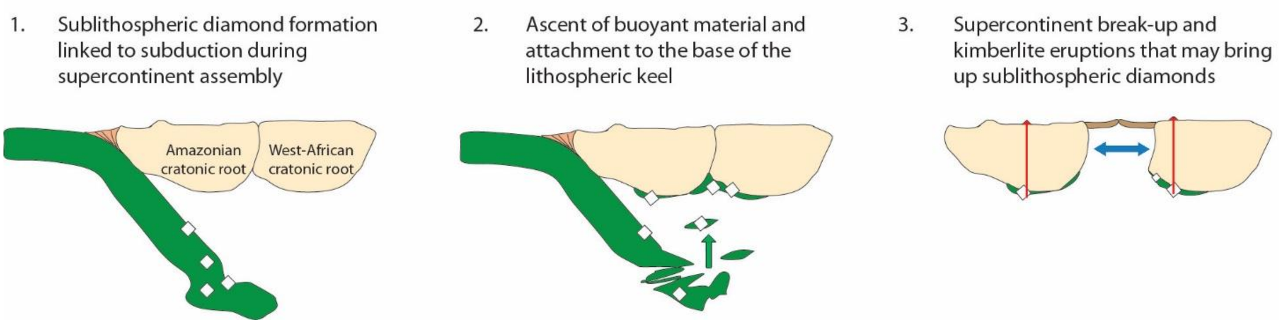
1. Sublithospheric diamond formation linked to subduction during supercontinent assembly
2. Ascent of buoyant material and attachment to the base of the lithospheric keel
3. Supercontinent break-up and kimberlite eruptions that may bring up sublithospheric diamonds

Fig. 3: Cartoon of the evolution from sublithospheric diamond formation beneath Gondwana, to ascent to the base of the lithospheric keel, prior to later (late Cretaceous) eruption to the Earth's surface in kimberlites.

References

Bulanova GP, Walter MJ, Smith CB, Kohn SC, Armstrong LS, Blundy J, Gobbo L (2010) Mineral inclusions in sublithospheric diamonds from Collier 4 kimberlite pipe, Juina, Brazil: subducted protoliths, carbonated melts and primary kimberlite magmatism. Contrib Mineral Petrol 160:489-510

Condie K, Pisarevsky SA, Korenaga J, Gardoll S (2015) Is the rate of supercontinent assembly changing with time?. Precambrian Research 259:278-289

Harte B, Richardson S (2012) Mineral inclusions in diamonds track the evolution of a Mesozoic subducted slab beneath West Gondwanaland. Gondwana Research 21(1):236-245

McNeill J, Pearson DG, Klein-BenDavid O, Nowell GM, Ottley CJ, Chinn I (2009) Quantitative analysis of trace element concentrations in some gem-quality diamonds. J Phys Condens Matter 21(36):364207

Smit KV, Timmerman S, Aulbach S, Shirey SB, Richardson SH, Phillips D, Pearson DG (2022) Geochronology of diamonds. Rev Mineral Geochem 88(1):567-636

Heaman LM, Phillips D, Pearson DG (2019) Dating kimberlites: Methods and emplacement patterns through time. Elements 15(6):399-404

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

Zhang Q, Timmerman S, Malakhova I, et al (this volume) Sublithospheric Diamonds and Indicator Minerals from DO-27 Kimberlite, Slave Craton, Canada– Geochemistry, Age and Origin. 12IKC-958