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Subduction involved in generating thick Archaean cratonic keels? Insights from >2.83 Ga detrital diamonds from Tree River, Slave Craton, Canada

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Introduction

The generation of thick, buoyant 'keels' of mantle lithosphere beneath the cratons likely drove the long-term stabilisation of these ancient tracts of continental crust. Cratonic keels protect the overlying crust from recycling and their formation is proposed to have driven the sub-aerial emergence of the continents (Pearson *et al.*, 2021). The mechanisms and timing of cratonic keel formation remain highly controversial, in part due to the scarcity of direct mantle samples from this time.

The Power of Archaean Detrital Diamonds

Diamonds hosted within Archaean sediments are rare direct samples of the Archaean mantle and provide tantalising windows into the processes that formed cratonic keels. These diamonds have a demonstrably Archaean age, owing to their occurrence as detrital components within some of the earliest sediments to cover Earth's continents. Furthermore, they are distinct from Phanerozoic kimberlite-hosted diamonds in that Archaean diamonds were removed from mantle conditions during the Archaean and have existed in the upper crust for the past 2.8 Gyr. This eliminates the potential for thermal and chemical overprinting and makes these diamonds some of the most pristine samples of the Archaean mantle currently available. Detrital diamonds in Archaean sediments were first reported alongside alluvial gold in the ~3.1-2.7 Ga Witwatersrand basin, Kaapvaal Craton (Raal, 1969). Subsequent discoveries were made in ~2.7 Ga volcaniclastic sediments in the Superior Craton at both Wawa (Stachel *et al.*, 2006) and Knee Lake (Pezzera et al, this volume). Recently, Timmerman et al (2022) retrieved three alluvial microdiamonds (<500μm) from the >2.83 Ga Tree River region, Slave Craton.

Sample Location and Descriptions

Here we report the recovery of a further 25 microdiamonds from 26.4 kg of material from the same sedimentary unit as Timmerman et al (2022) at Tree River (67°10'00.29"N, 112°10'47.13"W). These diamonds range in size from 75 to 400 μm and possess complex morphologies due to polycrystalline growth and fragmentation, with several octahedral features additionally recognised. At least seven possess brown spots from radiation damage (Fig. 1), diagnostic of billion-year residencies in sediments and ruling out modern contamination. The host sedimentary rock is a 15-20 m, thick quartz-pebble conglomerate located at the base of a sequence thought to correlate to the Central Slave Cover Group. Economically significant gold grades of 36.3 g/t are also reported, adding to the similarities with Wits basin sediments.

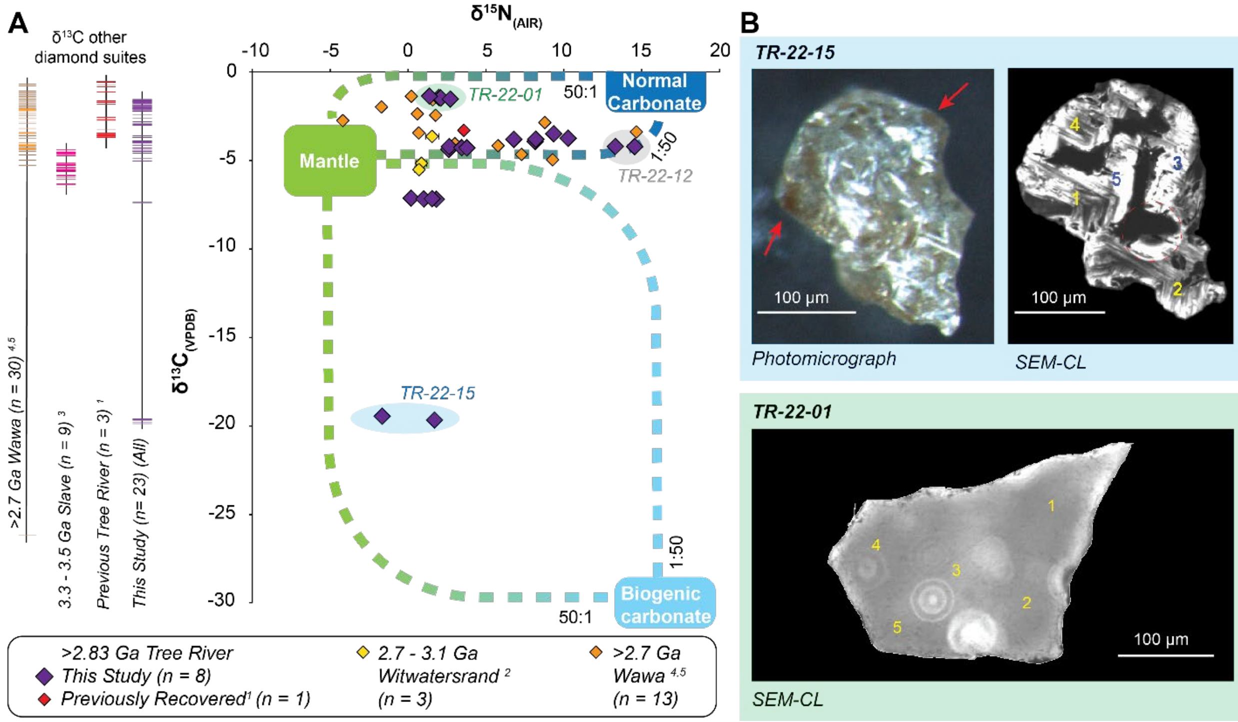

Figure 1: A) C and N isotope data for Tree River diamonds (purple). Number of diamonds (n) indicated for each previous Mesoarchaean detrital diamond suite. Select diamonds are highlighted. [1]Timmerman et al. (2022), [2]Smart et al. (2016), [3]Aulbach et al. (2009), [4]Stachel et al., (2006), [5]De Stefano, (2011). **B)** Images of select diamonds. Red arrows highlight brown radiation spots. CL-image showing clear radiohalos for diamond TR-22-01.

Methods

Diamonds were recovered at the Saskatchewan Research Council via caustic fusion. Fourier-Transform Infrared Spectroscopy (FTIR) was conducted at the University of Alberta using the Thermo Nicolet nexus 470 FT-IR spectrometer. In situ measurements of $\delta^{13}C$, $\delta^{15}N$ and nitrogen concentrations were subsequently measured with SIMS using the Cameca IMS-1280 multi-collector ion microprobe at the Canadian Centre for Isotopic Microanalysis (CCIM). Four prospective diamonds were analysed for inclusions using the Rigaku-Oxford Diffraction Supernova diffractometer at the University of Padua.

Results

Five diamonds have appreciable nitrogen (Type I) with concentrations of ~100-800 ppm, while one is identified as Type II with no nitrogen. Three were Type IaA and two were Type IaAB with B-centre components of 10% and 18%. Using nitrogen concentrations and aggregation state, temperatures of mantle residency were modelled with durations of 100 and 650 Myr, corresponding to mantle removal for the Tree River diamonds at ~2.9 and 3.5 Ga, respectively. This maximum age corresponds to the age of the oldest Slave Craton diamonds dated through inclusions (Westerlund *et al.*, 2006). The two Type IaAB diamonds give residency temperatures of between 1110-1150ºC and 1140-1190ºC. Carbon and nitrogen isotope compositions provide one of the widest ranges reported for an Archaean diamond suite (Fig. 1). One diamond (TR-22-15) represents the oldest strongly $\delta^{13}C$ depleted diamond at ~-19.5‰, with the remaining 22 diamonds ranging from -7.2 to -1.3‰. Nitrogen concentrations are high enough to measure $\delta^{15}N$ in seven stones and range from -1.7 to +14.5‰, with one (TR-22-12) possessing one of the highest $\delta^{15}N$ for an Archaean diamond. Three inclusions – garnet, clinopyroxene, and magnesite – were found, all hosted within the strongly $\delta^{13}C$ depleted stone (TR-22-15). The cpx has a unit cell volume of 431.4 Å^3, hinting at a jadeite-bearing (omphacitic) composition. Future work will attempt to expose and measure the garnet composition.

Discussion

Numerous mechanisms have been proposed to form Archaean lithospheric mantle keels. Cold initial state models, such as slab-stacking, have previously been proposed for the Slave Craton to explain the presence of diamond-stabilising keels by 2.9 Ga. Cold Archaean thermal fields, most consistent with slab-stacking, were previously calculated using elastic barometry and nitrogen aggregation thermochronology on the single olivine-bearing Type IaAB diamond recovered from Tree River (Timmerman *et al.*, 2022). The temperatures calculated based on our larger diamond suite are consistent with these cool Archaean lithospheric root conditions. The occurrence of both Type IaA and IaAB stones results from different mantle residence temperatures and/or durations for this diamond suite. The presence of ~18% aggregated nitrogen in TR-22-01 implies that the diamond resided either at higher temperatures (~1250ºC for 10 Myr residency, ~1190ºC for 100 Myr) or for a longer period in the lithospheric mantle root (~1140ºC for 650 Myr). This implies the presence of roots localised in terms of suitable P-T conditions for diamond formation and/or residence up to 3.5 Ga before a larger root was assembled during the Mesoarchaean. The isotopic composition of these diamonds can be used to trace the source of the diamond-forming fluid, with implications for the geodynamic processes that may have been active in the cratonic keel assembly. Smart et al. (2016) used the isotopic composition of three apparently Mesoarchean-aged Witwatersrand detrital diamonds to argue that subduction of nitrogen-rich sediments contributed surface nitrogen to the diamond-forming fluids, potentially as far back as 3.5 Ga. This was based on $\delta^{15}N$ values of -0.5 to +2.7‰. Whilst somewhat elevated above the typical mantle range ($\delta^{15}N$ -5 ± 3‰, Cartigny *et al.* 2014), the Wits diamonds are still within the typical range of peridotitic diamonds (Stachel *et al.*, 2022). In contrast, the Tree River diamonds are definitively >2.83 Ga and contain $\delta^{15}N$ up to +14.5‰, providing far stronger support for recycling of nitrogen-rich sediments into the Archaean cratonic root than the Wits diamonds. Furthermore, whilst the Wits diamonds have $\delta^{13}C$ values which are indistinguishable from that average mantle composition (-5 ± 2‰, Cartigny *et al.* 2014), the Tree River diamonds have a $\delta^{13}C$ range that extends both higher and lower than that typical of mantle-derived carbon (-0.3 to -19.7‰). Such extreme variation in these two stable isotope systems requires the input of surface-derived material into the diamond-forming fluid reservoir within the Archaean Slave cratonic keel. $\delta^{13}C$ values of ~-20‰ require either extensively bio-altered oceanic crust or biogenic carbonate as a source (Li *et al.*, 2019). The presence of clinopyroxene and garnet inclusions within this strongly $\delta^{13}C$ depleted diamond provides further strong support for an eclogitic paragenesis. This is consistent with slab-stacking, a process that would involve imbrication and/or subduction of surficially-derived sediments and crust. Our new diamond suite expands on previous Mesoarchaean detrital diamond suites and provides the most robust diamond-based evidence of subduction/imbrication processes occurring at 2.9 Ga, possibly as far back as 3.5 Ga.

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