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Large scale rejuvenation of lithospheric mantle beneath Jwaneng, Botswana: implication for diamond growth and destruction

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Introduction

The Jwaneng kimberlite cluster (~235 Ma) on the western margin of the Kalahari Craton, Botswana, hosts the most valuable diamond mine on Earth. The regional subcontinental-lithospheric mantle (SCLM) has a complex tectono-magmatic history potentially influenced by multiple events that include the Bushveld large igneous province (LIP), Proterozoic and Pan African orogens and break-up of the Rodina supercontinent. To understand the impact of these events on the SCLM and their role in diamond formation and destruction, we present a petrological, major, trace and platinum group element and Sr-Nd-Hf-Os isotope study of 23 mantle xenoliths from Jwaneng. These data are integrated with published Jwaneng diamond inclusion ages and new ages from peridotitic garnet inclusions to obtain a holistic view of SCLM evolution.

Analytical Results

The xenolith suite comprises two garnet-harzburgites, 19 garnet-lherzolites, a garnet-websterite, and a spinel lherzolite, selected due to well-preserved primary mineralogy. Equilibrium pressures and temperatures (Nimis and Grutter 2010) range from 3.6 GPa and 840ºC to 6.5 GPa and 1500ºC. Shallower and cooler samples, <1050ºC, lie close to a 38 mW/m^2 geotherm whereas deeper samples scatter about a 45 mW/m^2 geotherm (Fig. 1). Based on geothermobarometry and petrography the sample suite was divided into two groups. Group I (n=6) samples have an equigranular texture and equilibration temperatures and pressures below 1050°C and 4.7 GPa (low-T peridotites), whereas Group II (n = 17) samples have a porphyroclastic texture and equilibration temperatures and pressures above 1120°C and 4.7 GPa (deformed high-T peridotites). A large proportion of Group II xenoliths (41%, Group IIa) record mineralogical disequilibrium with purple chrome-rich pyrope garnet overgrown by more Fe-rich Cr-poor orange pyrope (Fig. 1). The Group I peridotites contain relatively forsterite-rich olivine (Mg# ~92.0). Garnet REE patterns are typically sigmoidal with fractionated HREE patterns and Yb_N between ~2 and 10 (Fig. 2). These garnets have highly variable Nd and Hf isotope ratios with ε_{Ndi} and ε_{Hfi} as extreme as -58 and + 157 respectively. In contrast, Group II xenoliths host relatively forsterite-poor olivine (Mg# 88-90.5), LREE depleted (Ce_N = 0.2) and have generally unfractionated HREE (Yb_N 8-20). Of the 12 garnets and clinopyroxenes analysed, eight have positive ε_{Ndi} (up to +8) with only three recording evidence of limited time-integrated LREE enrichment (-0.6 to -3.3). All ε_{Hfi} indicate time-integrated melt depletion (+1 to +137). Group I low-T peridotites have Pd depleted PGE patterns (~0.02 x chondrite) and Re depletion ages (T_{RD}) ≥ 2.5 Ga (Fig. 2). The garnet websterite has elevated PGE contents and an even older Re model age (T_{MA} ~4 Ga). In contrast Group II high-T peridotites have variable PGE patterns from ~chondritic to Pd depleted (~0.05 x chondrite) and T_{RD} between 0.6 to 2.1 Ga (Fig. 2). The Sm-Nd systematics of seven peridotitic garnet inclusions in diamonds indicate formation from the Mesoarchaean to the latest Precambrian.

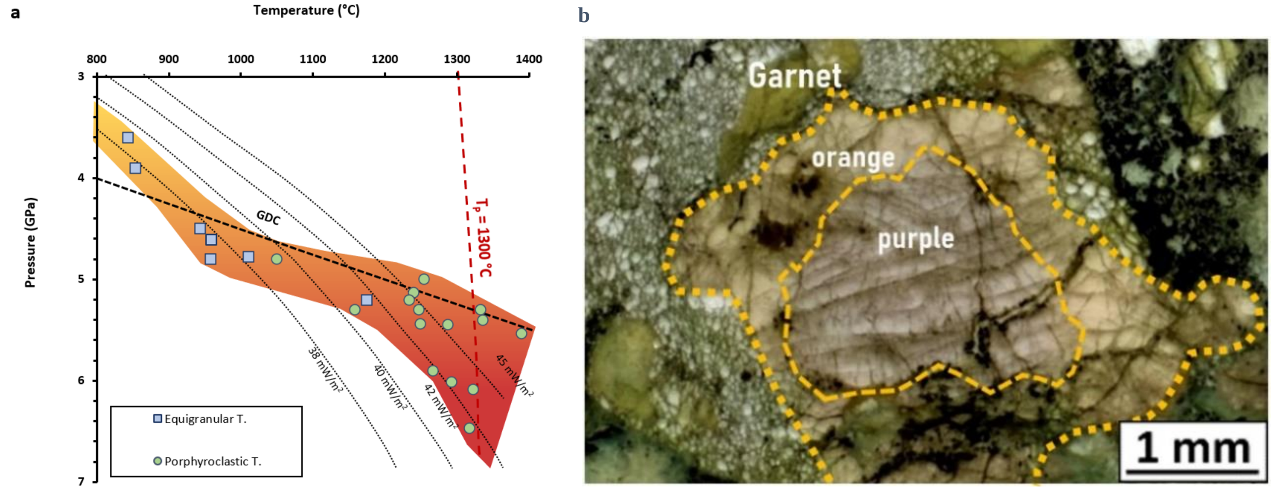

Figure 1: a) P-T diagram of Jwaneng peridotites based on the $P_{NG85}^{Grt-Opx}$–$T_{NG09}^{Grt-Opx}$. Geotherms from Pollack & Chapman (1977). GDC, graphite-diamond equilibrium boundary. Red dashed line, mantle adiabat with 1300°C potential temperature. b) Thin section image of garnet from high-T sample DLA821, showing zonation from orange (rim) to purple (core).

Discussion & Conclusions

The Os isotope data of the entire xenolith suite correlate with olivine Mg# and pressure (r^2 0.66-0.69 respectively). The low-T equigranular peridotites, characterised by marked Pd depleted PGE patterns and Archaean Re-Os systematics record extreme Nd and Hf isotope ratios indicating that the shallower part of the SCLM was assembled by the Mesoarchaean following extensive degrees of partial melting (≤40%) and in most cases, metasomatism in the Archaean. The garnet pyroxenite has Os-Hf-Nd isotope systematics suggesting Archaean melt crystallisation in the SCLM. In contrast, the deeper high-T porphyroclastic peridotites record far more variable and lower degrees of partial melting and Re-Os systematics (Fig. 2). These observations suggest that the SCLM records either less and younger melting with depth and/or that deeper parts underwent extensive re-fertilisation or progressive accretion from below.

The mineral compositions and geothermobarometry of the Jwaneng xenoliths (Fig. 1a) clearly support a multi-stage history of the SCLM with the shallower relatively cool highly melt depleted lithosphere underlain by more fertile and warmer lherzolitic peridotites. A simple layered structure with wholescale delamination of deeper lithosphere as implied at Premier (Zhang et al. 2022) is not supported by the combined xenolith, xenocryst and diamond data. Kimberlite garnet and clinopyroxene xenocryst data span geotherms equivalent to 38 to > 45 mW/m^2. Moreover published diamond G-10 garnet inclusion data suggest that at least locally, "cold" diamondiferous SCLM is present to depths of ~210 km (~6.5 GPa Stachel et al. 2004). New Sm-Nd isotope systematics of garnet inclusions indicate diamond formation in the Mesoarchaean and Mesoproterozoic. Cathodoluminescence zonation, Re-Os and Sm-Nd ages on eclogitic sulphide and eclogitic-websteritic silicate inclusions in diamonds (e.g., Gress et al. 2021) record multiple dissolution events and major diamond growth at ~2.0-1.8 and ~0.85 Ga and within error of kimberlite eruption at 235 Ma. The latter event is also recorded in the metasomatic overprint of the high-T porphyroclastic peridotite xenoliths. Xenoliths without this recent metasomatism (Group IIb) have coherent Hf-Nd-Os systematics consistent with 5-10% melt depletion at 2.0-1.8, 1.5 and 0.85 Ga.

This integrated dataset indicates the Jwaneng SCLM was extensively modified after initial formation in the Mesoarchaean. Major tectono-magmatic events led to local delamination and accretion of less melt depleted SCLM. Xenoliths and diamonds indicate a role for the Bushveld LIP (Molopo Farm magmatism) at ~2.0

Ga, the Proterozoic Kheis-Okwa-Magondi Orogens (1.8-1.5 Ga) and continental break-up of the Rodina supercontinent at ~0.85 Ga. In addition, magmatism associated with kimberlite activity at 0.235 Ga led to widespread metasomatism and additional diamond formation.

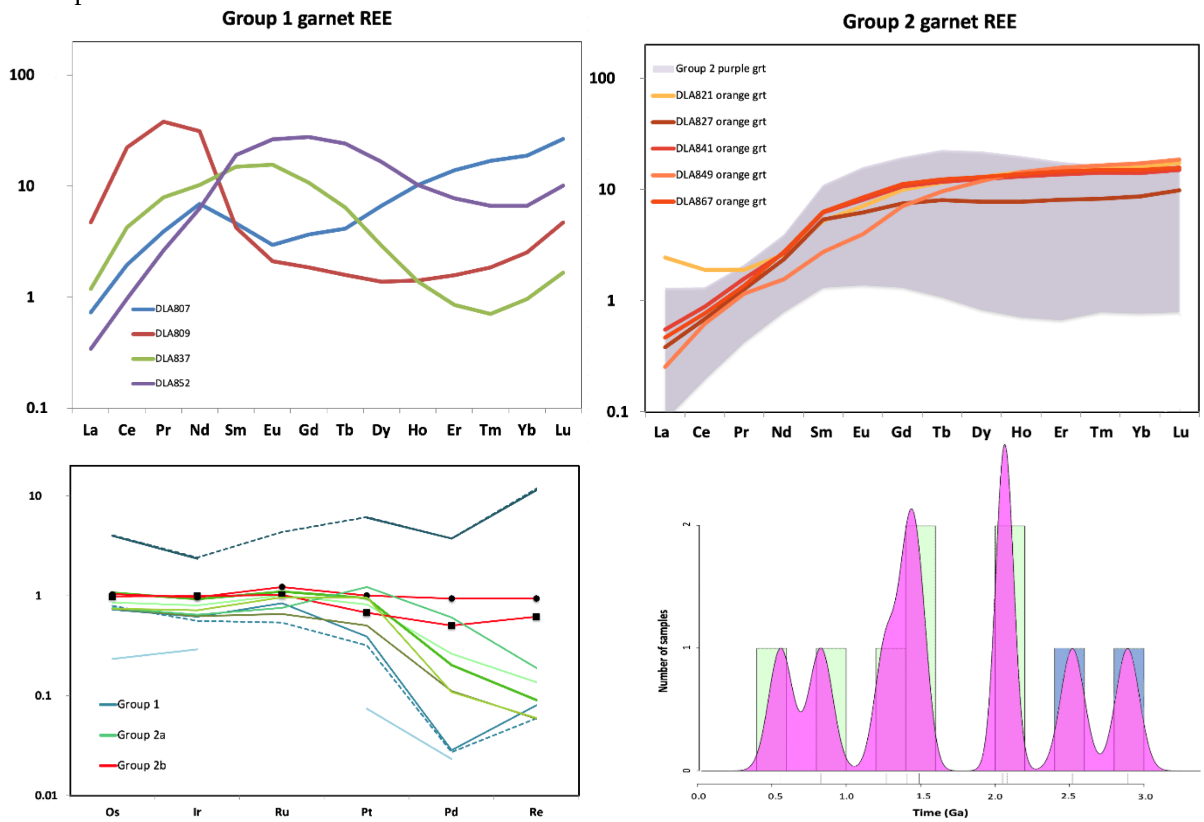

Figure 2: a & b) Chondrite normalised REE patterns of garnets from group 1 and 2 xenoliths. c) Primitive Upper Mantle normalised PGE patterns of Jwaneng peridotite xenoliths. d) Re depletion ages from Jwaneng presented as histogram, kernel density estimates and rug plot. An Archaean pyroxenite not plotted.

References

Gress MU, Pearson DG, Chinn IL, Thomassot E, Davies GR (2021). Mesozoic to Paleoproterozoic diamond growth beneath Botswana recorded by Re-Os ages from individual eclogitic and websteritic inclusions. Lithos 388-389

Nimis P, Grütter H (2010) Internally consistent geothermometers for garnet peridotites and pyroxenites. Contributions to Mineralogy and Petrology, 159, 411-427

Pollack HN, Chapman, DS (1977) On the regional variation of heat flow, geotherms, and lithospheric thickness. Tectonophysics, 38(3-4), 279-296

Shirey Walker (1998) The Re-Os isotope system in cosmochemistry and high-temperature geochemistry. Ann Rev Earth Planet Sci, 26, 423-500

Stachel T, Viljoen KS, McDade P, Harris JW (2004) Diamondiferous lithospheric roots along the western margin of the Kalahari Craton-the peridotitic inclusion suite in diamodns from Orapa and Jwaneng. Contrib Mineral Petrol, 147, 32-47

Zhang Q, Morel MLA, Liu J, Legros H, Luguet A, Viljoen KS, Davies GR, Pearson DG (2022) Re-healing cratonic mantle lithosphere after the world's largest igneous intrusion: Constraints from peridotites erupted by the Premier kimberlite, South Africa. Earth Planet Sci Lett, 598, 1-13