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Polycrystalline diamond aggregates and their role in Earth's deep carbon cycle

DORRIT E JACOB[1], RICHARD A STERN[2], JANINA CZAS[3], MAGNUS REUTTER[4], SANDRA PIAZOLO[5] AND THOMAS STACHEL[2]

[1]Australian National University
[2]University of Alberta
[3]Natural Resources Canada, Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0G1, Canada
[4]Johannes Gutenberg University
[5]University of Leeds

Polycrystalline diamond aggregates (PDAs) are small rocks composed mostly of diamond grains, but often containing also peridotitic, eclogitic and/or websteritic minerals as accessory phases. While not of commercial value, they can comprise up to 20% in abundance in some diamond mines and are only reported from group I kimberlites so far. PDAs are formed rapidly in Earth's mantle, and therefore preserve heterogeneity not often seen in monocrystalline diamond.

We present here a comprehensive study of forty-three PDAs and their mineral intergrowths from the Venetia diamond mine (RSA) with diamond grain-sizes < 1 mm. The diamonds have heterogeneous and complex cathodoluminescence (CL) signatures that are best explained by multiple, separate diamond growth episodes from compositionally distinct COH fluids/melts. EBSD results show near-random orientation of the diamond grains indicating minimal crystal plastic deformation and current grain boundaries that do not coincide with CL growth stages.

The diamonds show a large range of nitrogen concentrations (0.5 to 2,891 at. ppm), $\delta^{15}N$ (- 4.3 to + 16.8 ‰) and $\delta^{13}C$ values (- 27.8 to - 7.6 ‰). The positive $\delta^{15}N$ median of + 6.4 ‰ and negative $\delta^{13}C$ median of - 21.2 ‰ indicate derivation of the diamond-forming fluid from organic materials in subducted oceanic crust and lithosphere. Two PDAs have $\delta^{13}C$ and $\delta^{15}N$ values typical for Earth's mantle.

Thirty-three PDAs contain websteritic garnets, or peridotitic garnets and clinopyroxenes and/or micas. Unradiogenic εNd_i values in the garnets (- 15.9 to - 29.7) and clinopyroxene (- 8.3) and $\delta^{18}O$ values of 6.49 to 8.09 ‰ in websteritic garnets are consistent with an origin from subducted altered oceanic crust and support the findings from N and C systematics in the diamonds. Nitrogen aggregation data for the diamonds range from 25 % to 100 %B. We explain the geochemical and isotopic heterogeneity of diamonds and silicates with a model of episodic melt/fluid - rock interaction involving a reducing asthenospheric melt in the cratonic roots or the thermal boundary layer and suggest that large volumes of PDA are formed in the cratonic roots and thermal boundary layer by this mechanism, making them an important reservoir for carbon storage.