Can microdiamonds be used to predict the distribution of large Type IIa macrodiamonds? A case study at the Letseng Mine

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Introduction

The Letseng Diamond Mine combines relatively low grade ore (1.7 carats per 100 tonne) with large, exceptional quality Type IIa diamonds. The Letseng Diamond Mine is located in the Maloti Mountains of Lesotho and comprises two late Cretaceous kimberlites (Bowen et al., 2009). Since 2006 Letseng has produced four of the 20 largest, white gem quality diamonds ever recovered. Letseng is the highest average dollar per carat kimberlite diamond mine in the world, averaging US$1695 per carat in 2016. The value at Letseng is driven by the relatively high proportion of Type II stones in the macrodiamond population. Due to the low grade of the deposit and the rareness of large Type IIa macrodiamonds, we evaluated the possibility to employ microdiamonds to predict the distribution of Type IIa diamonds.

Sample Suites and Analytical Techniques

Micro- and macrodiamonds from the Letseng Mine were analysed by FTIR (Fourier Transform Infrared) Spectroscopy and SIMS (Secondary Ion Mass Spectrometry) to assess a genetic relationship between microdiamonds and Type IIa macrodiamonds. The macrodiamond parcel was screened with a ZVI Yehuda Colorimeter, which detects Type IIa stones, and was intended to contain mostly Type IIa diamonds. The microdiamond parcel contained the full spectrum of diamonds recovered from processing. A total of 67 macrodiamonds and 254 microdiamonds were analysed by FTIR to determine their bulk nitrogen content and aggregation state. A total of 67 macrodiamonds and 305 microdiamonds were analysed for nitrogen content and carbon isotope composition by SIMS.

Nitrogen Characteristics

FTIR analysis identified 67% of the (preselected) macrodiamonds as Type IIa. The remaining 33% contained between 8 and 224 atomic ppm nitrogen and their nitrogen aggregation ranged from Type IaA to IaB (Figure 1). The low nitrogen content of the Type Ia macrodiamonds may be a consequence of sampling bias. FTIR and SIMS analyses show a good correlation in the Type classification.

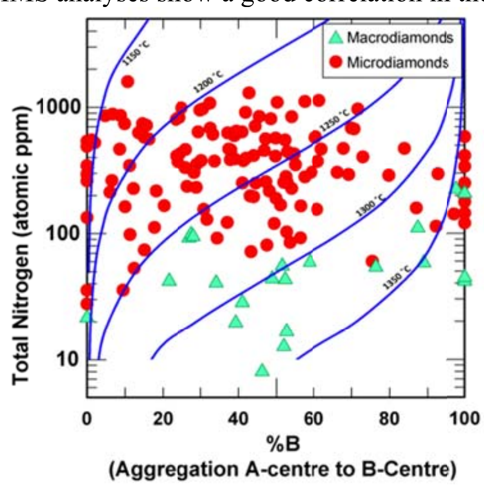

Figure 1. Nitrogen contents and aggregation states (relative proportion of nitrogen in B-centers) for Type I diamonds from Letseng. Solid lines are isotherms (°C) for a mantle residence time of 1 Ga (after Taylor et al., 1990; Leahy and Taylor, 1997).

FTIR analysis identified 46% of the microdiamond parcel as Type IIa, whereas SIMS analysis classified only 19% as Type IIa. This difference is attributed to different spatial resolutions of the techniques and the inhomogeneity of the diamonds themselves. Based on the FTIR analyses, the Type Ia microdiamonds have nitrogen contents of 28 – 1595 atomic ppm, with nitrogen aggregation ranging from Type IaA to Type IaB (Figure 1). SIMS analyses resulted in nitrogen contents of 9 – 2335 atomic ppm.

Diamond Morphology

The morphology of the examined macrodiamonds is dominated by a flattened, elongate resorbed ("dodecahedral") shape. In the literature, this shape has been referred to as "irregular" or "shapeless". This is a highly unusual morphology and has been recognized as a common characteristic of Type IIa diamonds from around the world (Wilks and Wilks, 1991). Other shapes exhibited by the macrodiamonds include octahedra, rounded dodecahedra, twin and irregular (Figures 2 and 3a).

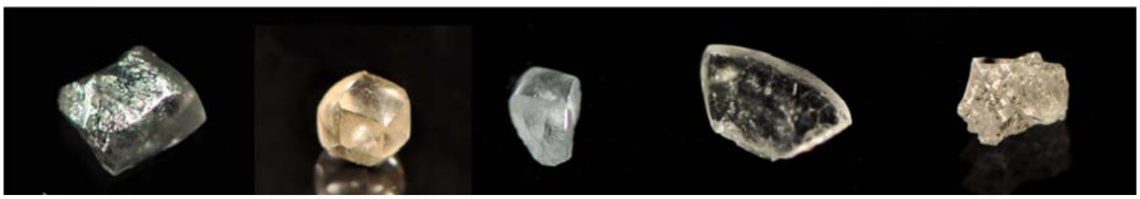

Figure 2. Macrodiamond shapes observed within the studied parcel from left to right: Octahedron, rounded dodecahedroid, flattened elongate dodecahedroid, macle, and irregular.

The most common morphology in the microdiamond population are octahedral shapes (36%) with various degrees of resorption. Other shapes observed in the microdiamond population include aggregates (26%), fragments (15%), polycrystalline forms (10%), macles (9%) and irregulars (3%). Rounded dodecahedra, cubes and flattened, elongate dodecahedra are very rare. This morphological distribution is significantly different to that observed in the macrodiamond population (Figure 3b).

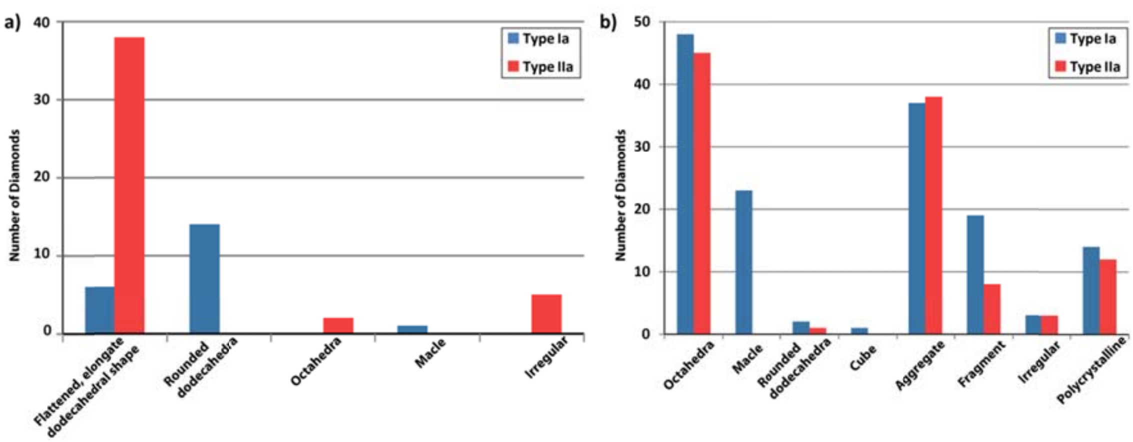

Figure 3. The distribution of **a)** macrodiamond and **b)** microdiamond shapes as function of diamond Type as determined by FTIR.

Carbon Isotope Characteristics

The Type IIa microdiamonds have a narrow range in carbon isotope ($\delta^{13}C$) values around the mantle value of -5‰ and overlap the carbon isotopic signature of Type Ia micro- and macrodiamonds (Figure 4a). This narrow distribution agrees with previously published data on small macrodiamonds from Letseng (McDade and Harris, 1999). Due to this similarity it is suggested that microdiamonds and Type Ia macrodiamonds likely have similar paragenetic origins: predominantly peridotitic with minor eclogitic and websteritic components.

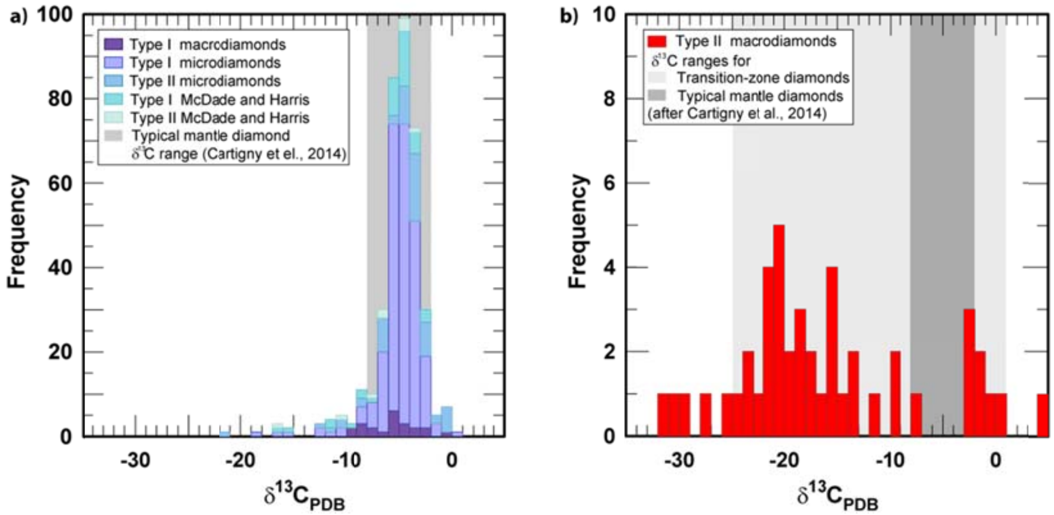

Figure 4. Carbon isotope histograms of **a)** Type Ia micro- and macrodiamonds and Type IIa microdiamonds, **b)** Type IIa macrodiamonds.

Type IIa macrodiamonds show a broad range in carbon isotope values from -32 to +4‰ with an absence of values about -5‰ (Figure 4b). This is highly distinct from the microdiamond and Type Ia macrodiamond suites, indicating the Type IIa macrodiamonds have a different paragenetic source altogether. Combining the broad range in carbon isotope values, documenting both strong enrichment and depletion of $\delta^{13}C$, with the absence of diamonds with mantle-like carbon, Letseng Type IIa diamonds likely formed from carbon sourced from subducted material. Consequently, the Letseng Type IIa macrodiamonds analysed are largely, if not exclusively, of eclogitic and/or websteritic affinity. Smith et al. (2016) provided inclusion-based evidence that large Type IIa diamonds relate to sublithospheric sources, which could link the Letseng Type IIa macrodiamonds to remnant oceanic slabs residing in the transition zone and/or lower mantle.

Conclusions

The broad carbon isotope distribution of Type IIa macrodiamonds is distinct from the Type Ia and Type IIa microdiamond and Type Ia macrodiamond samples analysed, indicating the Type IIa macrodiamonds are derived from distinct carbon sources and, by inference, diamond substrates in the Earth's mantle. The strongly resorbed nature of the supposedly superdeep Type IIa macrodiamonds may be an indication that the microdiamonds have a very low survival potential during ascent through the convecting mantle. Consequently, microdiamonds may not be an appropriate proxy for understanding the Type IIa macrodiamond distribution at Letseng and warrants further investigation. Future work should focus on establishing relationships with associated minerals to definitively constrain the paragenesis and depth of diamond formation of the large Type IIa stones.

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