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Microinclusions in monocrystalline octahedral diamonds and coated diamonds from Diavik, Slave Craton: Clues to diamond genesis

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ABSTRACT

Detailed in-situ analyses of trace-element patterns, N contents, N aggregation state and $\delta^{13}C$ define two populations of gem-quality diamonds in the A154 kimberlite; these probably formed at different times and from different media. Four octahedra with 500–1200 ppm N and 12–35% B aggregation represent an older population; flat REE patterns and low Ba + K indicate that they crystallised from fluids similar to those in many monocrystalline diamonds worldwide. The second population includes coated octahedra and uncoated etched octahedra. On two etched stones, abundant flat-based trigons bottom out 10–15 μm below the faces of the stones, in a layer with abundant microinclusions (0.5 μm diameter) enriched in LREE, Ba and HFSE. Four coated octahedra with 800–1200 ppm N and 11–20% B aggregation have trace-element patterns consistent with growth from a fluid with high LREE + Ba, similar to that in the microinclusion-rich layers of the etched octahedra; the contents of LREE and Ba, and Ba/La, increase toward the rims. The coats on these stones typically have higher Ba than the outer cores, but Ba/La may be either higher or lower. $\delta^{13}C$ is relatively constant (−5.5 to −4.7‰) across one etched octahedron but drops to −9.7‰ in the microinclusion layer. The core of a coated stone has $\delta^{13}C$ like that of the microinclusion layer (−9.8 to −10.5‰), but $\delta^{13}C$ drops to −13.9‰ in the coat. In the coated stones, core-to-rim decreases in the degree of N aggregation are not correlated with N content, but are accompanied by increases in Ba and LREE. This pattern, the lack of $\delta^{13}C$ zoning in the one stone analysed, and homogeneous CL images suggest that the coated stones have grown continuously from a range of evolving fluids. The opaque coats appear to represent a final late stage of accelerated growth in some diamonds, rather than random overgrowths on pre-existing diamonds. Zoning patterns and FTIR data are consistent with the growth of the coated and etched gem-quality stones at 1200–1250 °C in the deep lithosphere shortly before their entrainment in the kimberlite.

1. Introduction

Fibrous structures in cubic fibrous diamonds, and the opaque coats found on some monocrystalline diamonds, are produced by rapid growth, which favours entrapment of microinclusions (e.g. Sunagawa, 1984; Boyd et al., 1994). Rapid growth occurs when changes in growth conditions increase the degree of carbon supersaturation, which is a function of temperature and the chemical potential (Sunagawa, 1984). In the mantle these changes may be related to the influx of new fluids, a rise in temperature due to magma intrusion, or changes in oxygen fugacity. The chemical and isotopic compositions of fibrous coats on monocrystalline diamonds have been used to suggest that the coats are related to growth events different from those recorded in the cores (e.g. Boyd et al., 1987; Navon et al., 1988; Boyd et al., 1992; Yelisseyev et al., 2004; Tomlinson et al., 2005). Such coats typically have higher contents of major- and trace elements (a higher density of microinclusions) with compositions genetically related to carbonatitic and kimberlitic fluids (e.g. Klein-BenDavid et al., 2004; Tomlinson et al., 2005; Rege, 2005; Weiss et al., this issue; Zedgenizov et al., this issue). Coats usually have higher N contents and lower degrees of N aggregation than the cores. These characteristics have been interpreted as consequence of rapid growth shortly before the kimberlite eruption (Boyd et al., 1987, 1992; Yelisseyev et al., 2004). The C (and N) isotope compositions of coats are also usually distinct from those of the cores. The C isotopic composition of the cores is variable, covering much of the range for worldwide diamonds (Cartigny, 2005) while the coats typically have a more restricted $\delta^{13}C$ range, from −4.1 to −7.5‰ (Boyd et al., 1987,

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1992; Cartigny et al., 2003). Coated diamonds reported from Diavik, however, expanded the C isotopic composition of the coats to −12.8‰ (Klein-BenDavid et al., 2007), suggesting that the restricted range found before was limited by the low number of occurrences documented.

As pointed out above, previous studies of coated diamonds suggest different events for the formation of the cores and coats. Here we report the results of a study of coated and monocrystalline diamonds from the A145S kimberlite, part of the Diavik Mine, Slave Craton, Canada and show that some monocrystalline diamonds show characteristics similar to those of coated diamonds, and have grown from similar fluids. The results have implications for the genesis of both monocrystalline diamonds and their coats.

2. Samples and methods

2.1. Sample preparation

The samples are eight gem-quality octahedral diamonds (3–4 g; Fig. 1) from the Diavik Mine (Slave Craton, Canada); four of these have opaque coats, similar to those described by Klein-BenDavid et al. (2007) and Yelisseyev et al. (2004). All diamonds were provided by Rio Tinto Ltd. Diamonds DVK106 and DVK107 are sharp-edged white transparent octahedra and lack etching features on the octahedral faces. DVK109 and DVK111 are similar, but have abundant trigons (triangular etch pits) on some or all faces. DVK127, DVK129, DVK135 and DVK155 are transparent octahedra, overgrown by opaque coats. Laser-cut plates up to 1 mm thick (parallel to 110) were manufactured at Argyle diamonds, Australia. Two half-diamonds (DVK109 and DVK127) were polished at GEMOC (Macquarie University) specifically for SIMS analyses.

2.2. Trace element analyses

LA-ICPMS (laser ablation-inductively coupled plasma mass spectrometry) analyses were done following the methods described by Rege et al. (2004); further description is given by Weiss et al. (2008). Diamond plates and half-stones were analysed using a custom-built Nd:YAG 266 nm UV laser system (Quantel Brilliant) coupled to an Agilent 7500 mass spectrometer (100 μm spot size, energy at 15 mJ and frequency at 10 Hz) in the Geochemical Analysis Unit at Macquarie University. The analyses were done after 100 s of background measurement and 120 s of sample ablation (65 μm-depth pit), using a multi-element doped cellulose pellet as external standard (Rege, 2005) and ^{13}C as internal standard. The cellulose standard was ablated under the same conditions as the samples, except for a lower energy (5 mJ). The isotopes analysed were ^{23}Na, ^{25}Mg, ^{27}Al, ^{39}K, ^{42}Ca, ^{49}Ti, ^{51}V, ^{55}Mn, ^{57}Fe, ^{59}Co, ^{60}Ni, ^{65}Cu, ^{66}Zn, ^{71}Ga,

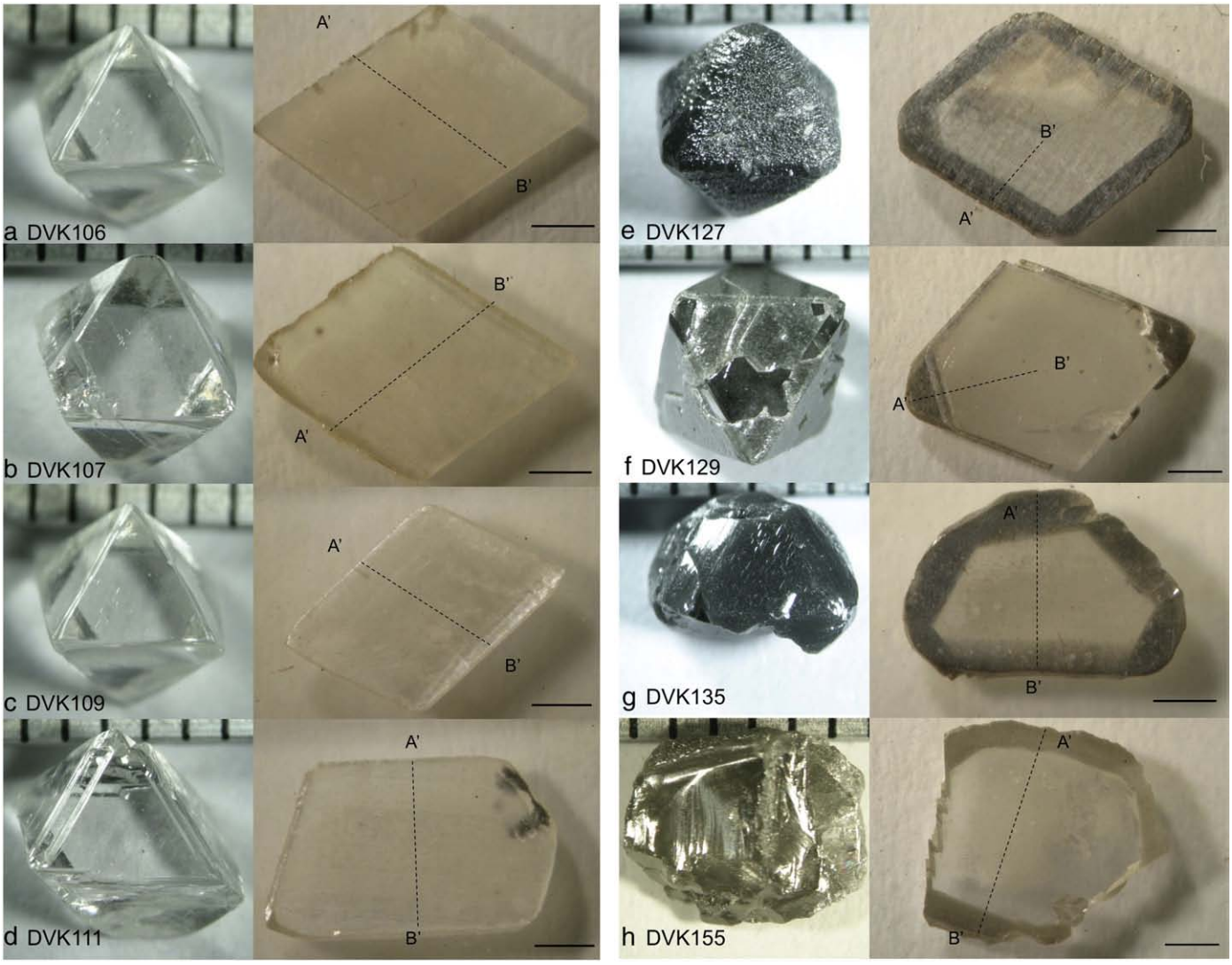

Fig. 1. Photographs of whole stones and plates; scale bars in mm. Dotted lines A'–B' show the position of the traverses.