In-situ analysis of diamonds and their inclusions from the Diavik Mine, Northwest Territories, Canada: Mapping diamond growth

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Eighty-nine diamonds from the A154 South kimberlite pipe at the Diavik diamond mine, Northwest Territories, Canada, were selected from run of mine production on the basis of morphology and visible inclusions. The diamonds were cut and polished to expose included mineral grains and to allow for imaging of internal structure. Internal zonation of the diamonds was imaged using cathodoluminsence (CL). Included minerals in diamond were analysed in-situ for major element composition using microbeam methods. Diamonds and their inclusions from the Diavik mine have been previously investigated by Donnelly et al. (2007) and involved fragmentation of the diamonds to liberate the inclusions.

Morphologies

Octahedra, cubes, cubo-octahedra (mixed growth form, e.g. Zedgenizov & Harte, 2004) and their derivatives through resorption and other mantle processes are present in the diamond population. Examples of boart (framesite) are also present. Twinned octahedra (including macles) and cubes occur. More common, although not true twins due to lack of symmetry, are intergrown octahedra and cubes. Many of the cubes are coated with steel-grey coloured, opaque fibrous diamond (fig. 1). Although some are transparent and gem-quality. These coats form a sharp boundary with the underlying gem-quality diamond. Opaque coats sometimes occur on octahedra as well. Resorption of octahedra leads to a continuum of morphologies ranging from a slight rounding of corners ({100}) and edges ({110}) to fully rounded trioctahedroids (aka "rounded dodecahedra") (fig. 1).

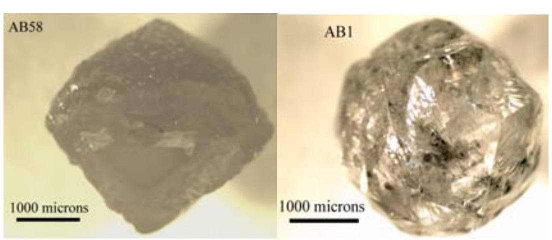

Fig. 1 Coated cube (left) and trioctahedroid (right)

Resorption of cubes is strongest in the {100} direction, leading to "hopper" type diamonds in some cases (fig. 2). The resorption of cubo-octahedra results in tetrahexahedroids and "naval-mine" types when there is some preservation of the {111} faces. The interstitial areas between the {111} faces of the "naval-mine" types often have a botryoidal texture (fig. 2).

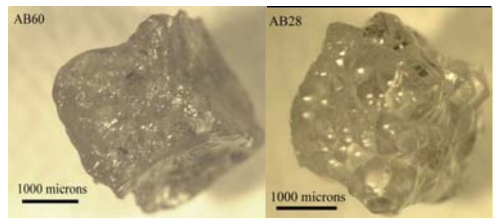

Fig. 2 "Hopper" (left) and "naval-mine" type (with botryoidal surfaces) diamonds.

A variety of resorption features occur in the sample population including ribbing, shield lamellae, serrate lamellae, hillocks, ruts, trigonal pits tetragonal pits, hexagonal pits, knob-like asperities, crescentic steps, and various curvilinear surfaces. Stepped growth of {111} faces is exhibited with many of the octahedra.

UV Fluorescence

70% of the cubo-octahedral stones and their derivatives display yellow fluorescence in response to UV light, a higher proportion than that of the cubic forms (40%), and much higher than that of the octahedral forms (10.2%). One deformed, pale pink octahedron with glide planes made visible to due to slight resorption has exceptionally bright white-yellow fluorescence. Another unresorbed octahedron has dark red fluorescence.

Internal Structure

CL images of some stones show significantly complex internal structure and unusual emission spectra. The images clearly demonstrate the incorporation of syngenetic mineral inclusions at early (e.g., olivines, sulfides, ferropericlases) and later (chromites) growth stages. Some inclusions are present as "cores" of irregulary-shaped diamond of contrasting CL response compared to the bulk of the surrounding material (fig. 3).

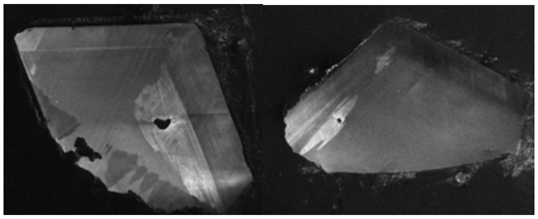

Fig. 3 CL images of different octahedra cut along the{110} plane. Images are ~3mm along diagonal. Note chromite inclusions in regions of high contrast.

There is significant variation in the population with regards to growth history. Many stones exhibit strong oscillatory zonation (fig. 4).

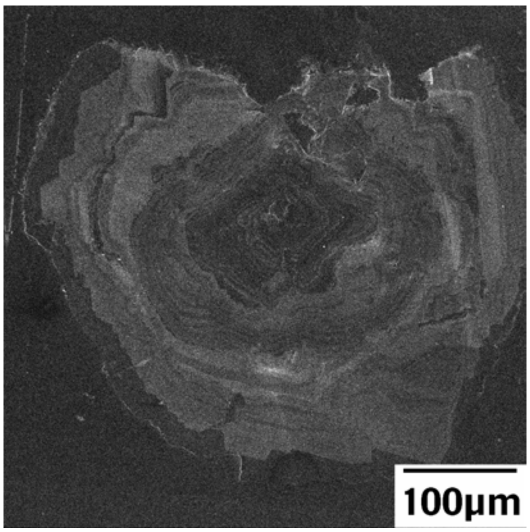

Fig. 4 CL image of a trioctahedroid (same as in fig. 1) cut along the {100} plane. Note concentric/oscillatory zoning.

Other diamonds have fewer, thicker zones of homogeneous contrast, suggesting fewer periods of diamond growth that persist over prolonged periods of time and under more stable conditions. The opaque fibrous diamond that forms as a coat on many of the stones has little to no CL response. In some cases, fibrous diamond has formed a coat over a previously fragmented diamond. This indicates brittle deformation of diamonds within the mantle later followed by rapid precipitation of the coat (fig. 5).

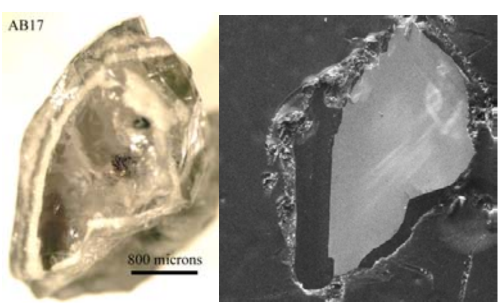

Fig. 5 Irregular fragment with multiple coats of fibrous diamond exposed (left) and CL image of same diamond (right). Note the lack of CL response of the coat.

Cubes typically have a much weaker CL response than do octahedra.

Mineral Inclusions

Inclusions of Mg-chromite (MgO≈12.5 wt. %, Cr_2O_3≈64.4 wt. %), forsteritic olivine (Mg/(Mg+Fe)≈0.927, NiO≈0.34 wt. %), diopside (Mg/(Mg+Fe)≈0.920-0.934, 1.35-2.3 wt. % Cr_2O_3), and enstatite (Mg/(Mg+Fe)≈0.943, Cr_2O_3≈0.27 wt. %) represent the P-type (mostly lherzolitic in this case) paragenesis in order of decreasing abundance. No diamonds with E-type inclusions have been identified as yet. Diamonds of potentially deep origin are present in the population as indicated by ferropericlase inclusions (Mg/(Mg+Fe)≈0.87, 1.24-1.40 wt. % NiO). Sulfide mineral inclusions occur in diamonds of both P-type and undetermined parageneses. Both homogeneous (e.g. pyrrhotite) and heterogeneous (e.g. unmixing monosulfide solid solution) sulfide inclusions occur (fig. 6).

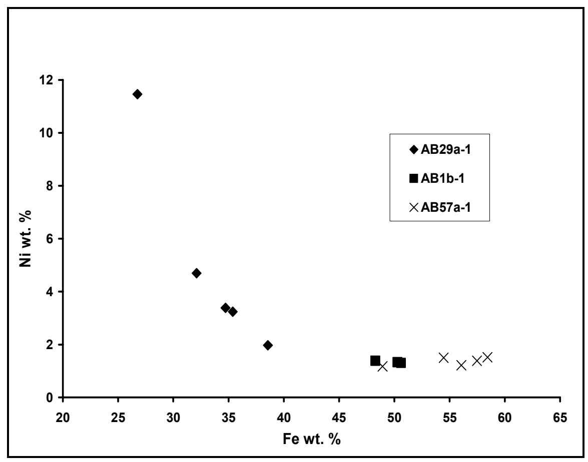

Fig. 6 Ni vs. Fe wt. % content of three sulfide inclusions in different diamonds. Note inclusion heterogeneity.

Fe content of the sulfides varies inversely with Ni, Cu, and Co content. These inclusions all appear to be monosulfides as indicated by the restricted sulfur content: 34.55-36.06 wt. %. The compositional heterogenieties of the sulfides are not clearly expressed in backscatter electron images as the average atomic number does not vary significantly.

Geothermobarometry

One coarse grained, polycrystalline diamond aggregate was found to have two inclusions of diopside. The CL image of the diamond showed one to be in a core region of one of the larger component crystals, and the other to be in a zone of secondary diamond growth filling in the space between two larger crystals. Using the clinopyroxene geothermobarometer of Nimis & Taylor (2000), the diopside in the core region equilibrated at 58.2 kbar and 1343°C, a position perturbed to higher temperature off of a geothermal gradient with a surface heat flow of 42 mW/m^2. This suggests that perhaps that region of diamond formed in an environment similar to that of sheared/porphyroclastic peridotite described first by Harte (1977). The second diopside inclusion equilibrated at 51 kbar and 1182°C. This position plots onto a geothermal gradient with a surface heat flow of 42 mW/m^2. The data indicate that the diamond experienced a significant thermal event during its formation in the mantle early on, followed by more stable conditions during secondary growth. Analysis of diopside inclusions in other diamonds also plotted onto the 42mW/m^2 gradient. This gradient is in agreement with findings by Donnelly et al. (2007).

References

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