DIAMOND GROWTH HISTORIES AT PREMIER MINE

Ingrid Chinn, Carina Pienaar and Carol Kelly
De Beers Geoscience Centre, South Africa

INTRODUCTION

Premier Mine is renowned for the recovery of extremely large, high value Type II (nitrogen free) diamonds such as the Cullinan. However, the origin of these large Type II diamonds is still poorly understood. Twenty-seven inclusion-bearing diamonds were polished into thin plates for cathodoluminescence (CL) studies and infra-red traverses. This enabled comparison of the growth and deformation histories, nitrogen contents and nitrogen aggregation characteristics of peridotitic and eclogitic stones. The diamonds studied range between 0.3 and 1.0 carats, and comprised four peridotitic, twenty-two eclogitic, and one of unknown paragenesis.

METHODS

Cathodoluminescence images were acquired using a Technosyn cold cathode CL attachment, operating at 810 µA and 12 kV. Spectra were acquired with a Nicolet Magna 760-IR spectrometer, over the infra-red range from 4000 to 650 cm^{-1}. An aperture of 100 µm was used at a resolution of 8 cm^{-1}. Deconvolution of baselined spectra was performed using a least-squares fit of the A, B and D components (D. Fisher, pers. comm.). Absorption coefficients of 16.5 and 79.4 ppm.cm for the A and B components respectively were used (Boyd *et al*., 1994, 1995).

RESULTS

Most of the diamonds examined exhibit octahedral zonation, with the intensity of blue luminescence correlating with nitrogen content. Dark areas of luminescence are commonly associated with mineral inclusions, particularly eclogitic garnets. Nitrogen data from infra-red traverses confirm the low nitrogen (or Type II) nature of these zones. It is possible that aluminium (an electron acceptor) from the garnet acts as a getter for the nitrogen, which is an electron donor. Secondary Ion Mass Spectrometry (SIMS) analysis would be required to demonstrate whether the nitrogen contents of these areas are significantly lower than areas of bright luminescence, or whether the nitrogen is contained in infra-red inactive defects together with carbon (as opposed to nitrogen). Alternatively, the nitrogen may partition into the inclusions instead of the diamond matrix.

TYPE II DIAMONDS

A single Type II (nitrogen free) diamond was recognised, which contained bright green chrome diopside inclusions, indicating a peridotitic (lherzolitic) paragenesis. The diamond is an irregular resorbed aggregate and exhibits very unusual CL within nested octahedral growth zones (Figure 1). Type II diamonds normally exhibit weak dark blue luminescence. Because the diamond is nitrogen free, the observed zonation is not due to different levels of infra-red active nitrogen impurities, but may be related to differences in plastic deformation levels. Deformation-induced lamination lines were observed on the stone prior to polishing.

Figure 1: CL image of polished plate cut from a lherzolitic Type II stone (AP30) from Premier.

TYPE I DIAMONDS

Two groups may be distinguished among the Type I diamonds. A plot of total nitrogen content versus nitrogen aggregation state (Figure 2) shows the isothermal trends of the six labeled diamonds belonging to the High Aggregation State Group. All of the High Aggregation State Group diamonds contain more than 40% nitrogen as B defects, except for AP28 which trends towards lower aggregation states (for nitrogen contents below 200 ppm) comparable to the Low Aggregation State Group.

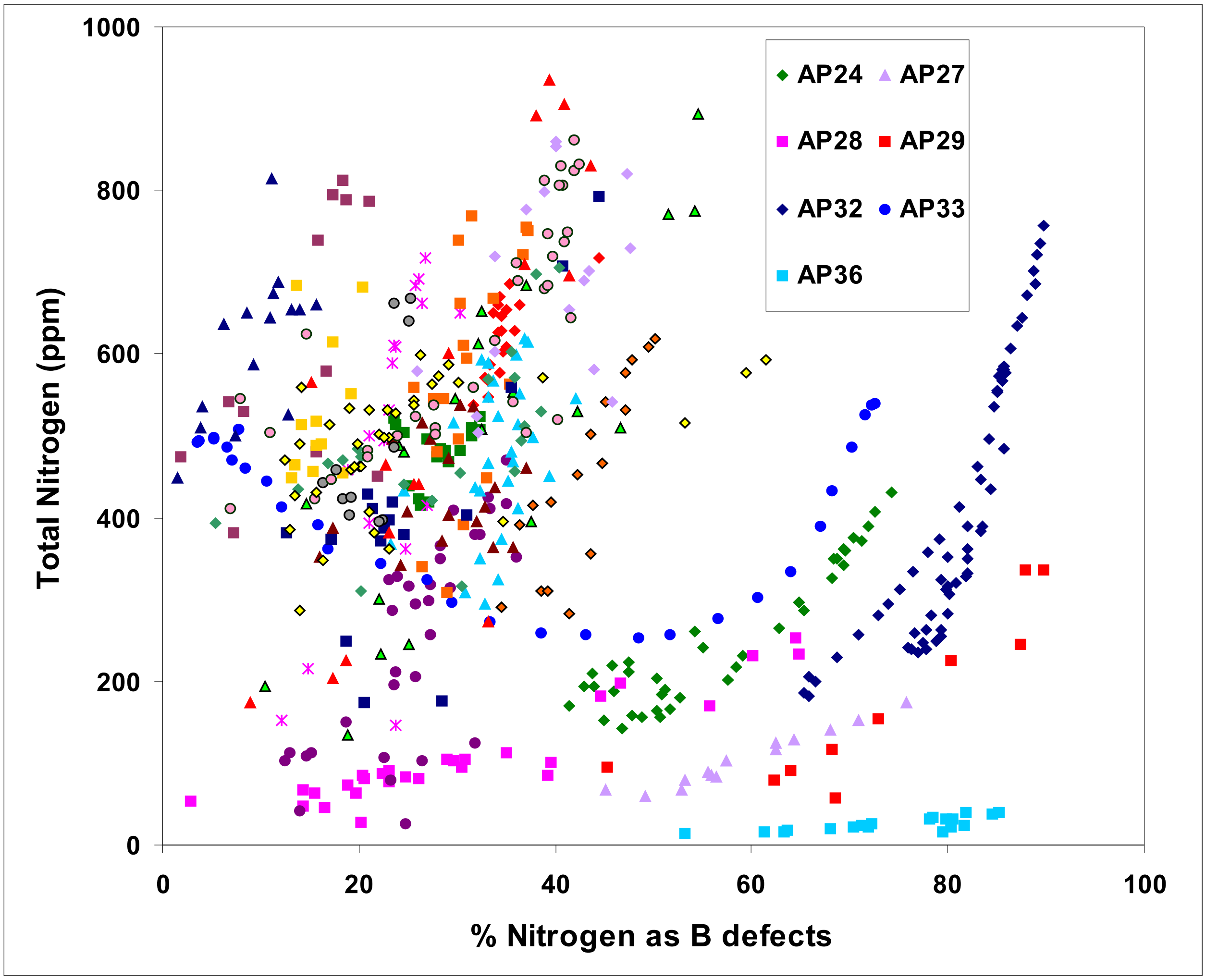

Figure 2: Plot of total nitrogen content versus nitrogen aggregation state. For simplicity only analyses from diamonds from the High Aggregation State Group, and anomalous diamond AP33 are labeled. Nineteen diamonds comprise the Low Aggregation State Group.

An anomalous eclogitic diamond (AP33, Figure 3) contains a well-defined core region (with bright luminescence) with affinities to the High Aggregation State Group. Towards the rims the nitrogen contents decrease, then increase with continuously decreasing nitrogen aggregation state (Figure 4). This results in nitrogen contents and aggregation states comparable to the Low Aggregation State Group. The latter stage of growth appears to follow continuously from the core, and this spatial relationship suggests that the High Aggregation State growth episode(s) is older than the Low Aggregation State growth episode(s). The trend of decreasing nitrogen aggregation state with increasing nitrogen content for the rim implies that the temperature was decreasing during growth.

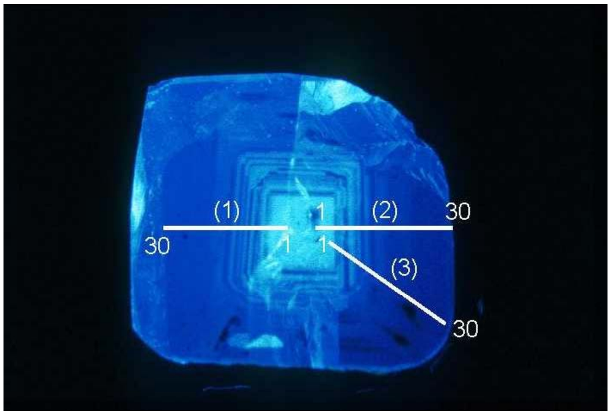

Figure 3: CL image of eclogitic diamond AP33 with core of high nitrogen content (bright luminescence). The positions of three infra-red traverses are indicated.

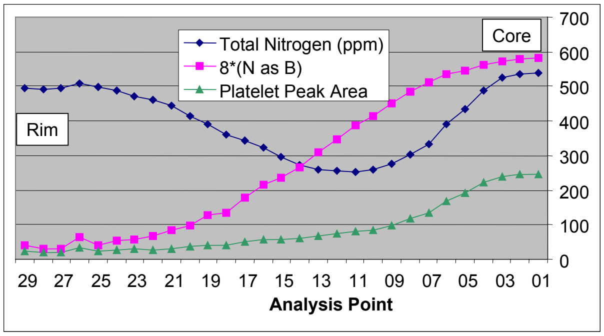

Figure 4: Infra-red traverse data (traverse 1, Figure 3) for diamond AP33. Total nitrogen content decreases, then increases towards the original core levels, from core to rim. Nitrogen aggregation state (N as B defects) and platelet peak area decrease continuously from core to rim.

High Aggregation State Group

Six diamonds show well-defined isothermal trends of increasing nitrogen aggregation state with increasing nitrogen content. This suggests that these diamonds grew in a single growth episode at relatively constant temperature. Both eclogitic (n=2) and peridotitic (n=3) diamonds appear to have grown during this growth event. A single diamond of unknown paragenesis also falls within this group.

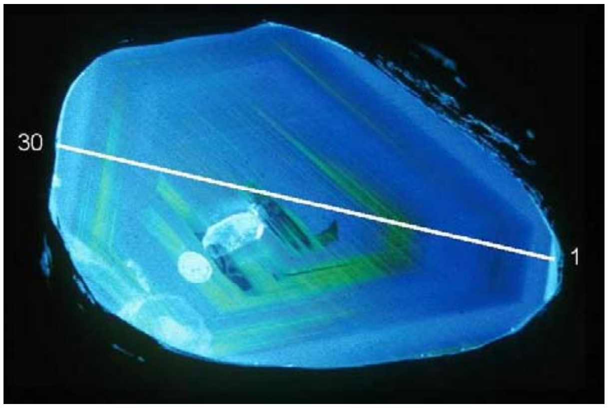

Figure 5: CL image of peridotitic diamond AP28 with octahedral zonation and zones of low nitrogen content associated with a purple garnet inclusion (bright reflections). Deformation lamellae may be seen as lines of yellow-green luminescence.

The lherzolitic Type II stone (which cannot be assigned to the High or Low Aggregation State Groups) and two of the peridotitic diamonds (AP27 and AP28, Figure 5) are much more resorbed than the majority of eclogitic stones comprising the Low Aggregation State Group. However, peridotitic stone AP29 (High Aggregation State Group) is relatively unresorbed. The octahedral zonation in the more resorbed peridotitic Type I stones is more subdued, with less variation in total nitrogen content than for most of the eclogitic diamonds and diamond AP29. All three resorbed peridotitic stones show evidence of plastic deformation in their CL images. Peridotitic stone AP29 may be distinguished from the other High Aggregation State Group diamonds by its lack of deformation and resorption. This may suggest the presence of two peridotitic parageneses at Premier, but insufficient diamonds were examined to confirm this suggestion.

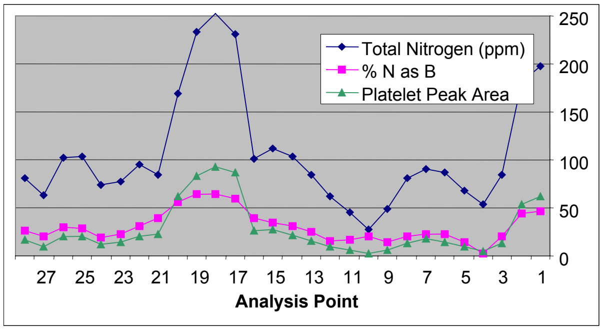

Figure 6: Infra-red traverse data for peridotitic diamond AP28. The close correspondence between the trends is compatible with single stage growth at relatively constant temperature.

The average nitrogen content for the two eclogitic diamonds is higher than that of the three peridotitic diamonds of the High Aggregation State Group (328 ppm compared with 119 ppm). Conversely, eclogitic diamond AP36 contains very low nitrogen contents (<50 ppm) and appears to have large zones of Type II diamond intergrown with Type I diamond. Thus diamond paragenesis may not be distinguished in terms of nitrogen content.

Low Aggregation State Group

Isothermal trends are not well-defined for the 19 diamonds of the Low Aggregation State Group. The inclusions noted in this group are exclusively eclogitic. Many of the diamonds show an initial decrease in nitrogen from core to rim, but this may be followed by a further increase (and even another decrease) in nitrogen content. In some instances low nitrogen/Type II zones complicate the interpretation of infra-red data from core to rim (Figures 7, 8). Despite this complexity, changes in the total nitrogen content are generally mirrored by the nitrogen aggregation state and platelet peak area. This suggests single-stage growth at constant temperature.

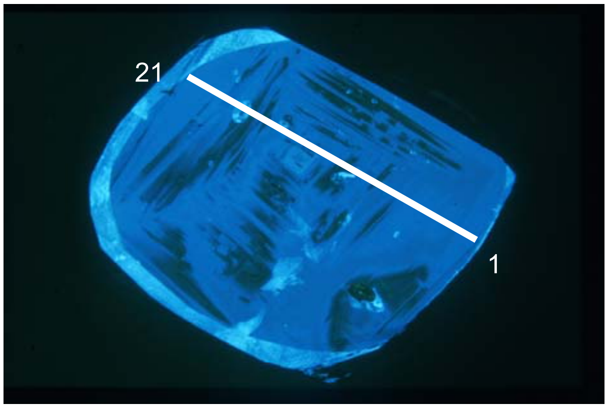

Figure 7: CL image of eclogitic diamond AP39 with a small core region of bright luminescence (high nitrogen) and zones of low nitrogen/Type II diamond, particularly around garnet inclusions.

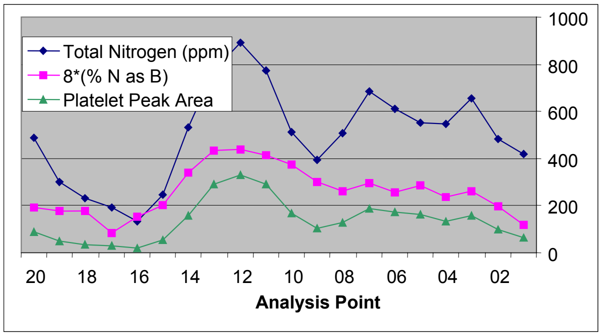

Figure 8: Infra-red traverse data for eclogitic diamond AP39. Note elevated nitrogen content in the core region and correspondence of trends.

CONCLUSIONS

Detailed analyses of inclusion-bearing diamonds are essential to understanding the relationship between different diamond growth episodes in the mantle. The isothermal trends of the peridotitic and eclogitic diamonds from the High Aggregation State Group are consistent with an older (or hotter) growth event at relatively constant temperatures. This episode involved both peridotitic and eclogitic diamond growth.

Rim overgrowth of diamond with infra-red characteristics akin to the Low Aggregation State Group on a core of High Aggregation State Group diamond growth (AP33) suggests that the High Aggregation State Group growth is older than the Low Aggregation State Group growth episode(s). The non-isothermal trend of decreasing aggregation state with increasing nitrogen content for this rim growth implies that temperatures were decreasing during this rim growth, unlike for the other eclogitic Low Aggregation State Group diamonds.

A single lherzolitic Type II diamond was identified, and is more likely to be related to the High Aggregation State Group, which contains the three Type I peridotitic diamonds.

REFERENCES

Boyd, S.R., Kiflawi, I., Woods, G.S., 1994. The relationship between infrared absorption and the A defect concentration in diamond. Philosophical Magazine B. 69, 1149-1153.

Boyd, S.R., Kiflawi, I., Woods, G.S., 1995. Infrared absorption by the B Nitrogen aggregate in diamond. Philosophical Magazine B. 71, 351-361.

Contact: IL Chinn, PO Box 82232 Southdale, South Africa, 2195, E-mail: ingrid.chinn@debeersgroup.com