Fourier Transform Infra-red (FTIR) Spectroscopy of Newlands diamonds

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The Newlands kimberlite cluster is a member of the Barkly West group located NW of Kimberley, South Africa. The Newlands kimberlite is Cretaceous in age (~114 Ma: Smith et al., 1985) and is of Group II affinity. Spectra were obtained for over 300 diamonds (or fragments thereof); 42 from 15 harzburgites, 5 from 4 lherzolites, 55 from 18 eclogites, and approximately 200 run-of-mine diamonds of unknown paragenesis. Menzies (1998) and Gurney and Menzies (1998) describe the diamond-bearing xenoliths in detail. Multiple spectra were taken of xenolith diamonds as the crystals were whole or fragments and not cut into plates.

Diamond-bearing Eclogites: Each of the xenoliths contained several diamonds, some more than ten. The diamonds display a variety of morphologies, ranging from cubic to octahedral to dodecahedral, and include aggregates. They also range in colour from colourless through off white to grey/yellow. Many of the eclogitic diamonds contain black inclusions of what appears to be graphite or sulphides as small grains or clouds.

Diamond-bearing Peridotites: The diamonds, in general, show two associations. Firstly they occur as small (<2 mm) colourless octahedra. These are equidimensional, sharp edged and show little resorption. Triangular plates and serrate laminae are the predominant growth feature. A few contain multiple inclusions of chromite and occasionally garnet, with one sample containing both together. Secondly, they occur as fine-grained diamond aggregates, which are generally colourless, although some are frosted. Again, they appear to show little resorption with similar growth features to the first group.

The diamonds from all three parageneses (eclogitic, harzburgitic and lherzolitic) that contain detectable levels of nitrogen, without exception, have low aggregation IaAB spectra. The aggregation state of nitrogen ranges from almost pure Type IaA to levels of up to 20% B aggregates. There appears to be no significant difference between the range of aggregation states of the various diamond parageneses. There are, however, significant differences in nitrogen concentration. Harzburgitic diamonds are distinctly lower in nitrogen concentration and platelet peak position. Nearly half of the harzburgitic diamonds are Type II or near Type II, the rest range up to 600 at. ppm N_2 with platelet peaks generally lower than 1369 cm^{-1}. In contrast, all the eclogitic diamonds contain appreciable amounts of nitrogen, commonly in excess of 800 at. ppm and have platelet peaks up to 1378 cm^{-1}. Approximately 1 % of eclogitic and harzburgitic diamonds overlap on the basis of nitrogen concentration and platelet peak position (see figure 1). However, these diamonds are statistical outliers with regards to their paragenesis. It is particularly noteworthy that lherzolitic diamonds fall into this "boundary zone", however the data set is too small to draw any definitive conclusions. Consequently, any diamond containing less than 200 ppm can be confidently ascribed to the harzburgitic paragenesis. Comparison with over 200 run-of-mine diamonds indicates that approximately 75 % of diamonds from Newlands are eclogitic on the basis of nitrogen concentration.

FTIR spectra can provide a quantitative time-temperature window for a diamond or suite of diamonds (as long as certain assumptions are satisfied). Nitrogen aggregation is dependant on both time and temperature, and consequently it can be used to calculate either diamond ages (using pre-determined mantle residence temperatures) or calculate diamond time averaged mantle temperatures (using pre-determined ages)

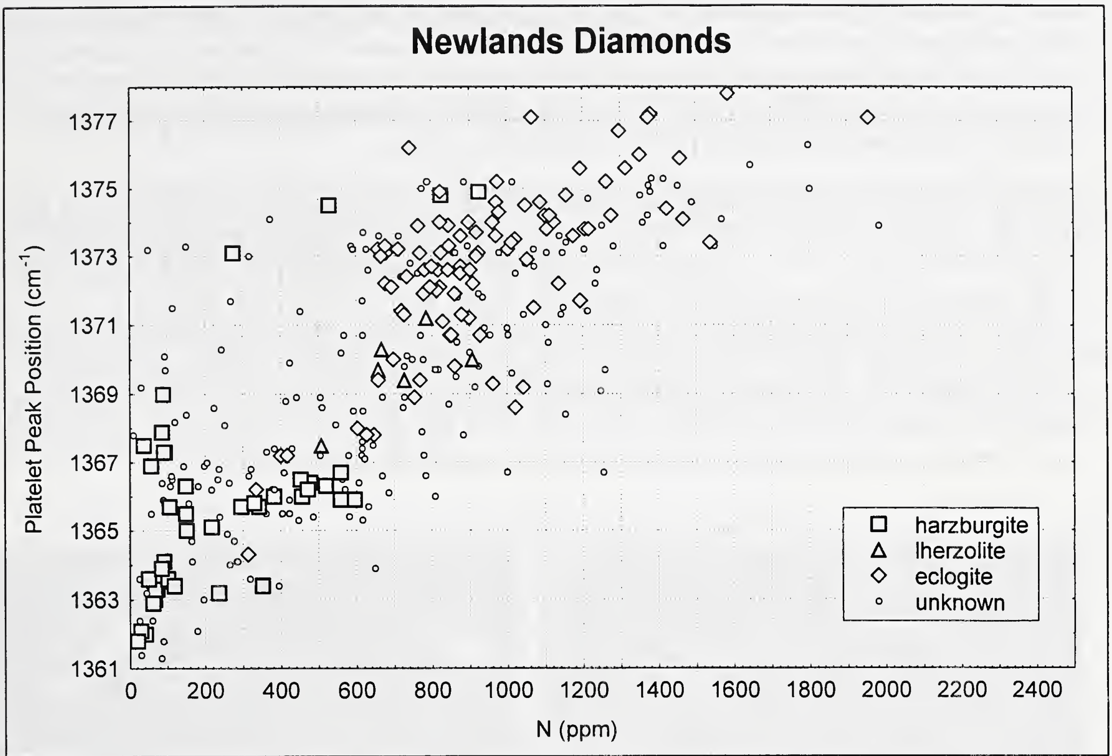

Figure 1 Platelet peak position versus nitrogen concentration for different diamond parageneses.

Rhenium-osmium ages for these diamond-bearing xenoliths are mid to late Archaean (Menzies et al., 1998). This corresponds to time average mantle residence temperatures of between 1060 and 1100 °C for eclogitic diamonds and in excess of 1100 °C for harzburgitic diamonds. The eclogite diamond temperatures overlap calculated equilibrium temperatures for the xenoliths (see Menzies, 1998). Cathodoluminesence indicates that all the eclogitic diamonds have at least two growth periods (see figure 2 a-b). It is likely that each growth period has different nitrogen concentration and aggregation states which would explain the spread in FTIR calculated temperatures. The maximum temperature would reflect the temperature for the first growth phase and the minimum temperature for the second growth phase. The similarity of the ambient xenolith temperatures and diamond time averaged temperatures suggests a relatively stable thermal history for the eclogites and their diamonds. In contrast, the harzburgitic diamonds have time average temperatures greater than ambient xenolith temperatures. Whilst, it is difficult to determine the temperatures accurately due to the low nitrogen concentration and aggregation state, it is suggested that the harzburgites have cooled since formation in the Archaean by more than 100 °C.

Geothermometry on xenolith minerals (see Menzies, 1998) has constrained ambient temperatures to ~1050 to 1100 °C for diamond-bearing eclogites and from ~1000 to 1100 °C for diamond-bearing peridotites. It should be noted that small fluctuations in temperatures can cause significant changes in age estimates. The accuracy of current geothermometers applied to mantle rocks is normally 30 to 50 °C at best, and thus, nitrogen aggregation ages are only diagnostic on a geologic time scale. If the harzburgitic xenoliths had experienced temperatures in the ~1000 to 1100 °C range throughout their history then to achieve the level of nitrogen aggregation observed in their diamonds, their age must be older than the Earth. Two possibilities exist to explain this paradox, either the xenoliths have experienced higher temperatures than those just prior to entrainment in the kimberlite, or the diamonds experienced some form of stress or strain which lowered the nitrogen activation energies and thus increased the aggregation rate. Applying various isochrons reveals that the time-averaged temperatures are approximately 1150 °C over the billion year time period, 1200 °C for hundreds of millions of years, and in excess of 1250 °C for millions of years.

The FTIR study of Newlands diamonds combined with xenolith geothermobarometry and Re-Os xenolith ages is consistent with diamond formation in the Archaean for both eclogitic and peridotitic parageneses. The possibility of being able to correctly classify diamonds based on their FTIR spectra could prove invaluable, particularly in the study of diamond inclusions. It is now possible to analyse sulphide inclusions for Re-Os and thus constrain the age of individual diamonds. However, sulphides occur in both eclogitic and peridotitic diamonds and there are problems in assigning them to the correct paragenesis without independent information. Therefore, the non-destructive technique of FTIR spectroscopy may allow the study of a greater range of inclusions from Newlands to define various mineral inclusions with diamond parageneses.

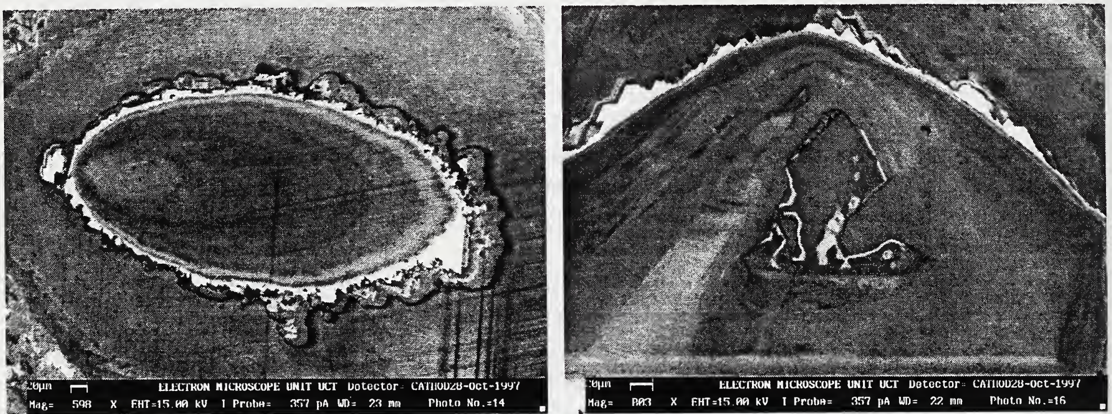

Figure 2 Cathodoluminesence images of eclogitic diamonds. Note the multiple growth phases. (a) Sample AHM K12a (b) AHM K14c

References

Gurney, J.J., and Menzies, A.H., 1998, Small Mines Field Guide (7IKC): (in press)
Menzies, A.H, 1998, Unpub. Thesis (in prep.)
Menzies, A.H., Shirey, S.B., Carlson, R.W, and Gurney, J.J, 1998, Re-Os isotope systematics of diamond-bearing eclogites and peridotites from Newlands Kimberlite: (this volume).
Smith, C.B., Gurney, J.J, Skinner, E.M.W., Clement, C.R., and Ebrahim, N., 1985, Geochemical character of southern African kimberlites: a new approach based on isotopic constraints: Trans. Geol. Soc. Sth. Africa, 88, p. 267-280.