NITROGEN AGGREGATION CHARACTER, THERMAL HISTORY, AND STABLE ISOTOPE COMPOSITION OF SOME XENOLITH-DERIVED DIAMONDS FROM ROBERTS VICTOR AND FINSCH.

W.R. Taylor [1,2] and H.J. Milledge[1]

[1] Dept of Geological Sciences, University College London, London WC1E 6BT, U.K.
[2] Research School of Earth Sciences, Australian National University, GPO Box 4, Canberra 0200, Australia.

Introduction: Diamonds were extracted from eclogite, lherzolite and harzburgite xenoliths (some with known ages) from the Roberts Victor (5 xenoliths) and Finsch (1 xenolith) kimberlites. They have been investigated by infrared (IR) spectroscopy and stable isotope mass spectrometry in order to characterize their growth and thermal history in the upper mantle. The most significant aspect of comparative studies of xenolith-derived diamonds is the knowledge that the group experienced the same mantle history if the diamonds nucleated at the same time or an appropriate subset of it if they nucleated at a later time. This makes genuine dendrochronology possible with such a group.

Methods: Infrared (IR) spectra were obtained from 120μm regions of several diamonds, where possible, from each xenolith using an IR microscope. The spectral data was processed to yield quantitative data on nitrogen content and aggregation state. Opposite faces were polished on some diamonds to reveal internal structure by cathodoluminescence. Carbon and nitrogen isotope measurements were made on pieces broken from the diamonds by D.Shelkov at the Planetary Science Unit, Open University, courtesy of Prof. C.T. Pillinger.

Results: Total nitrogen contents and aggregation states are plotted in Fig. 1 and nitrogen aggregation temperatures T(NA) and platelet indices (PI) (see Mendelssohn and Milledge, 1995) are given in Table 1. Diamonds from the eclogite, both lherzolites and one of the harzburgites show significant differences in aggregation state and nitrogen content between cores and rims due to growth zonation. For some specimens (e.g. RV167) the nitrogen aggregation data fall on well defined isotherms but in other specimens either core and rim mixing lines are apparent (FRB866) or zonation is very complex involving a number of different zones (RV161). In the specimens showing zonation, T(NA) values decrease by 7 - 25°C and PI values increase from core to rim. Such variation is consistent with core to rim growth and aggregation under conditions of falling temperature. Thermal models suggest core to rim growth occurred over a period of 100 Ma or less. The harzburgitic diamonds that show no zonation have T(NA) <1100°C and are either type IaA specimens or are type IaAB with high PI values consistent with long-term residence in the lithosphere under cool conditions.

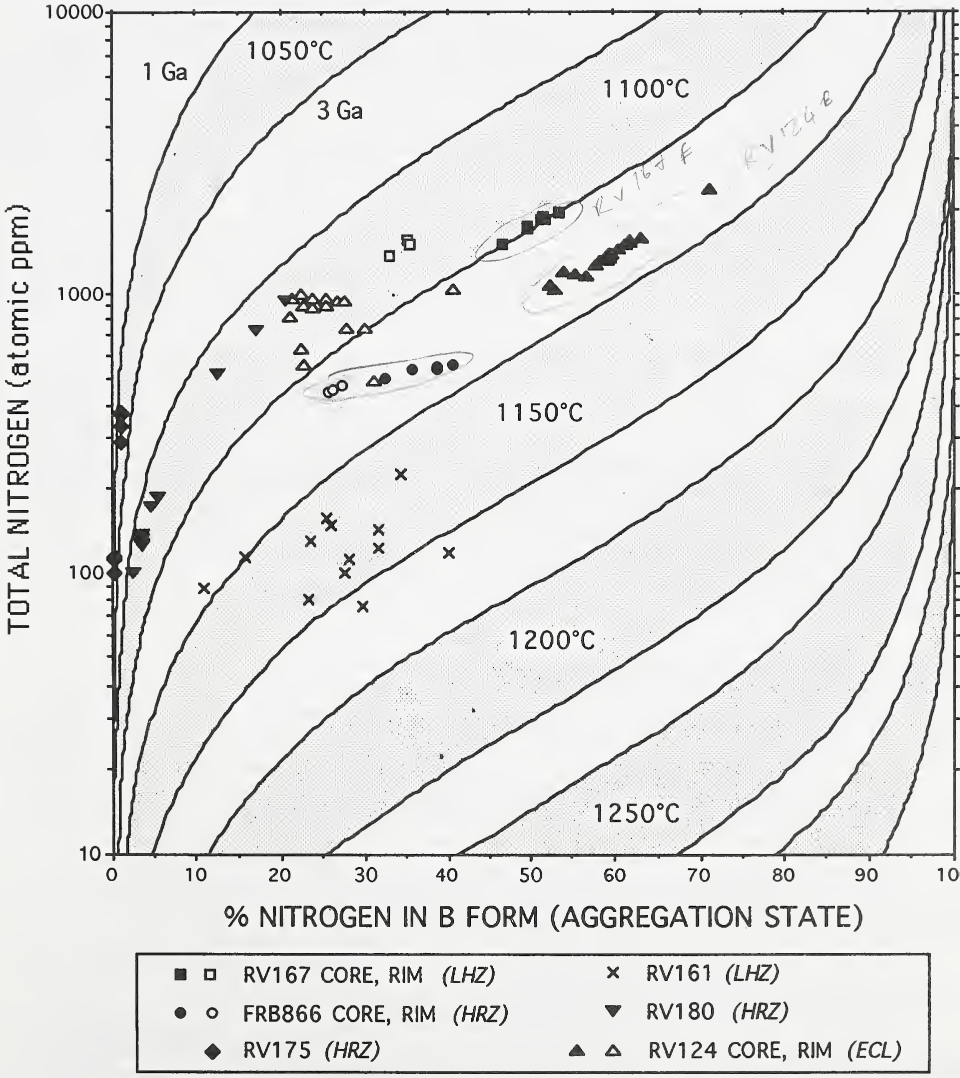
Xenolith temperatures are in all cases lower than core T(NA) values, and with the exception of eclogite RV124, are also lower than rim T(NA) values. This suggests that the diamonds formed under higher temperature conditions than indicated by the prevailing geotherm at the time of xenolith sampling. In the case of the lherzolitic diamonds, the temperature difference is ~100°C suggesting they grew and evolved during a period of significant thermal perturbation of the lithosphere. The relatively high xenolith temperature of eclogite RV124 suggests that it may have been heated at a late stage in its history. This is consistent with the presence of graphite in some parts of the xenolith which imply P,T conditions near the diamond-graphite transition and an elevated local geotherm (>40mWm-2).

The $\delta^{13}C$ composition of all the diamonds fall within the -7 to -3 ‰ range typical of most mantle derived diamonds and variations within diamonds from the same xenoliths are generally <1‰. $\delta^{15}N$ compositions are more variable. In the eclogite, $\delta^{15}N$ varies from slightly positive values in the diamond cores to typical mantle values of ~-5‰ in the rims, there is a sympathetic increase in $\delta^{13}C$ from core to rim. In the peridotites the $\delta^{15}N$ signature is mostly compatible with a mantle nitrogen reservoir (-3 to -5‰) although in some RV180 low-N diamonds the $\delta^{15}N$ signature is close to 0‰. Except for RV167, nitrogen contents measured by mass spectrometry are in good agreement with the IR spectroscopic results.

Discussion: Diamonds from both peridotitic and eclogitic parageneses may show multistage growth histories. For the diamonds studied, such growth appears to have occurred under conditions of falling temperature perhaps coinciding with periods of thermal perturbation of the lithosphere. Our data for the lherzolitic diamonds is compatible with the suggestion of Richardson et al. (1993) of a link between lherzolitic diamond formation and craton-scale Bushveld magmatism. The carbon and nitrogen isotopic composition of the diamonds are generally compatible with a mantle source for these components (Boyd and Pillinger, 1994), however, it appears that heavy nitrogen was ?locally scavenged during the early stages of growth of the eclogitic diamonds.

Acknowledgements: Dorrit Jacob (Göttingen University), Fanus Vijoen (DRL, Johannesburg), and Graham Pearson (Durham University) kindly supplied diamond samples from RV124, the RV peridotites, and FRB866, respectively.

FIG.1 Nitrogen aggregation plot for diamonds from peridotite and eclogite xenoliths: Roberts Victor (RV) and Finsch (FRB)



Shaded envelopes show T(NA) values for t(MR) ranging between 1.0 and 3.0 Ga. Data points not affected by mixing plot parallel to T(NA) isotherms.

References:

Boyd S.R. and Pillinger, C.T. (1994) A preliminary study of $^{15}N/^{14}N$ in octahedral growth form diamonds. Chemical Geology, 116, 43-59

Jacob, D. and Jagoutz, E. (1994) A diamond-graphite bearing eclogitic xenolith from Roberts Victor (South Africa): indications for petrogenesis from Pb-, Nd- and Sr-isotopes. Proceedings of the 5th IKC, Volume 1, 304-317.

Mendelssohn M.J. and Milledge H.J. (1995) Recent developments in the interpretation of IR spectra of diamonds. 6th IKC abstracts (this volume).

Richardson, S.H., Harris, J.W., and Gurney, J.J. (1993) Three generations of diamonds from old continental mantle. Nature, 366, 256-258.

Viljoen, K.S., Robinson, D.N., Swash, P.M., Griffin, W.L., Otter, M.L., Ryan C.G. and Win, T.T. (1994) Diamond and graphite-bearing peridotite xenoliths from the Roberts Victor Kimberlite, South Africa. Proceedings of the 5th IKC, Volume 1, 285-303.

TABLE 1

A. Specimen details

Sample No.	Xenolith Type	Diamond Form/Col.	Age Est. (Ga)	T xenolith (°C)	Therm-ometer	Ref.
RV124	ECL	octa(agg) CL,PB	2.7#	1097	gnt-cpx	JJ94
RV161	LHZ	macle PB	1.9-2.0†	1071±31	Ni-gnt	V94
RV167	LHZ	octa(sc) CL	1.9-2.0†	913±33 1016	Ni-gnt gnt-cpx	V94
RV175	HRZ	pca(rou) PB, GY	3.0-3.2†	996±19 1024§	Ni-gnt olv-sp	V94
RV180	HRZ	octa(agg) CL,PB	3.0-3.2†	966§	olv-sp	V94
FRB866	HRZ	octa(sc) CL,PB	2.9*	1102	olv-gnt	

JJ94: Jacob & Jagoutz (1994), V94: Viljoen et al. (1994)
octa(agg, sc) = octahedral aggregate (agg) or single crystal (sc);
pca(rou) = polycrystalline aggregate (rounded); CL = colourless;
PB = pale brown; GY = grey (due to fine graphite inclusions).
#Sm-Nd model age; * Re-Os depletion age (D.G. Pearson)
† estimated from Richardson et al. (1993)
§ calculated assuming Fo93 olivine

C. Carbon and nitrogen isotopic composition

No. of points		Nitrogen (at.ppm)	1σ	Av. ∂15N (‰)	1σ	Av. ∂13C (‰)	1σ
2	C	1893	95	+1.1	3.1	-6.3	0.7
3	C	1393	294	+0.3	0.6	-5.4	0.1
4	R	745	163	-4.7	0.9	-5.2	0.7
1	U	216	-	-5.6	-	-6.2	-
1	R	1089	-	-2.8	-	-5.0	-
3	U	170	15	-4.7	0.3	-5.0	0.9
2	U	355	39	-5.7	2.3	-4.7	0.4
3	U	80	14	+0.1	0.5	-4.9	0.3
1	U	476	-	-3.0	-	-4.3	-

Typical precisions: Nitrogen ±6% relative
∂15N ±1.4‰
∂13C <0.1‰

C = core
R = rim
U = undifferentiated

B. IR spectroscopic results (nitrogen aggregation characteristics)

Sample No.	No. of spectra	Pos-ition	Spectral type	Platelet Index (PI)	1σ	tMR (Ga)	T(NA) (°C)	1σ	Nitrogen range (atomic ppm)
RV124	21	core	IaAB	27	3	2.6	1117	1	1026 - 2317
	13	rim	IaAB	29	4	2.6	1092	3	624 - 984
RV161	2	core	IaAB	12	6	1.85	1166	1	76-121
	11	rim	IaAB	22	5	1.85	1147	9	81-228
RV167	8	core	IaAB	19	2	1.85	1110	1	1521 - 1960
	3	rim	IaAB	25	2	1.85	1099	1	1373 - 1562
RV175	7	-	IaA	-		3.0	1036	2	103 - 379
RV180	11	-	IaAB	36	6	3.0	1083	1	99 - 930
FRB866	5	core	IaAB	30	1	2.8	1116	2	502 - 557
	3	rim	IaAB	33	1	2.8	1109	1	445 - 477

Platelet Index (PI) = I(B')/[μT(1282).x(B)]
PI is based on the integrated area of the platelet peak normalized to be independent of aggregation state and nitrogen content. PI is an indicator of the T conditions that prevailed at the time when most aggregation took place. PI>35 indicates T<1100°C, PI 35-25 indicates T ~1100-1150°C, PI 25-10 indicates T~1150-1200°C and PI <10 indicates T>1200°C and/or siginificant plastic deformation.

tMR = mantle residence time of the diamond in the lithosphere from its time of growth until the time of eruption.

T(NA) = nitrogen aggregation temperature = time-averaged temperature reflecting the cumulative upper mantle thermal history of a diamond.