

# A COMPARATIVE TRACE ELEMENT STUDY OF DIAMONDS FROM PREMIER, FINSCH AND JAGERSFONTEIN MINES, SOUTH AFRICA

H.W. Fesq, D.M. Bibby, C.S. Erasmus, E.J.D. Kable and J.P.F. Sellschop  
NIM-WITS A.A.R.G., N.P.R.U., Univ. of the Witwatersrand, Johannesburg

Natural diamonds, the high pressure polymorph of primary carbon, are generally believed to have formed under stable, equilibrium conditions at depths of 100 km or greater in the upper mantle (1). They are found as phenocrysts in some kimberlites and less commonly in related upper mantle derived rocks e.g. eclogites.

The present hypotheses of diamond genesis favour their crystallisation from igneous melts (1). Inclusions found in diamonds are either minerals which formed in equilibrium with diamonds or the liquid from which these phases crystallised. The impermeable and inert nature of diamonds prevents any mineral, or fluid inclusions from re-equilibrating with the magma transporting the diamonds to the earth's surface. Important information on the geochemistry of the upper mantle and the genesis of igneous rocks can therefore be gained from a study of diamonds and their syngenetic inclusions.

The predominant mineral inclusions reported in diamonds are forsterite and pyrope garnet; less common are enstatite, diopside, chromite, rutile, the sulphides and coesite (1, 2). The chemistries of these inclusions resemble those of minerals found in cognate peridotite, eclogite, and xenocrysts/phenocrysts present in the host kimberlites (3).

In order to study the trace element geochemistry of natural diamond, and by inference their syngenetic inclusions, a total of 520 carats of diamonds from South African sources were analysed by instrumental neutron activation analysis (INAA). Details of the analytical technique and the standardisation procedure followed are reported elsewhere (4).

Diamonds were obtained from three regionally well-separated kimberlites: Premier, Finsch and Jagersfontein. The former is of Precambrian age (5) whilst the latter two are probably Cretaceous.

Representative 1 gram samples consisting on the average of 15 individual stones were selected from one month's production of each mine. Samples were sorted on the basis of four main colour categories (colourless, yellow, green and brown); and the presence of visible inclusions, or their absence at 50x magnification under a polarizing microscope. No distinction was made between coated (6) or clean inclusions but diamonds with fractures were avoided with the exception of the boart samples. Prior to analysis great care was taken in the cleaning of the diamonds. Quantitative results for 16 elements in "inclusion free" diamonds (Table 1) and 26 elements in diamonds with inclusions (Table 2) are presented. Differences greater than two orders of magnitude in the abundance of some elements can be observed. This is a function of the dominant mineral inclusions. An indication of the predominant minerals present in diamonds can be obtained by comparing the chemistry of inclusions contained in diamonds with both the major element chemistry of individual mineral inclusions found in diamonds (1), and the trace element content of kimberlite minerals (7).

Correlation matrices based on the 26 elements analysed were computed for each of the three sources investigated. Significant correlations for the following elements indicate the type of mineral inclusion present:

FIG. 1

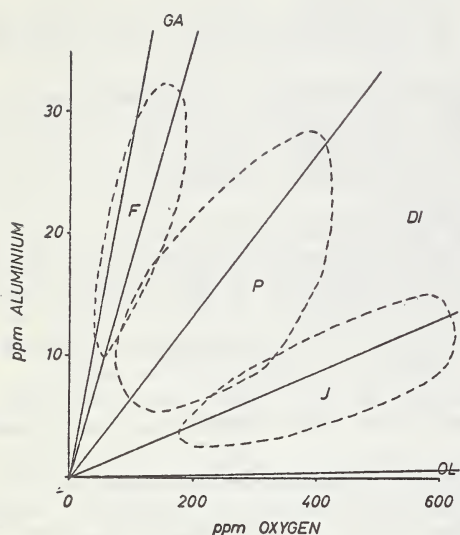


FIG. 2

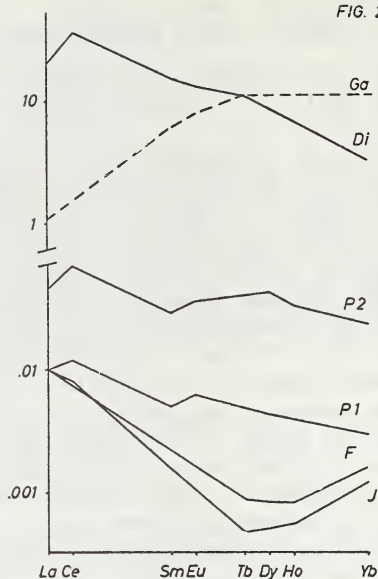


TABLE 2

ELEMENT CONCENTRATIONS IN DIAMONDS WITH VISIBLE INCLUSIONS FROM THREE SOUTH AFRICAN SOURCES

Source:	Premier	(19)		Finsch	(18)		Jagersfontein	(17)
Element	Ave.	Range		Ave.	Range		Ave.	Range
ppm Oxygen	179	35 - 420		65	23 - 103		302	79 - 1620
Mg	52	14 - 128		23	1 - 83		52	5.5 - 372
Fe	24	2.6 - 71		16	5.4 - 34.5		42	3.6 - 141
Ca	16.8	2.2 - 57		2.7	0.3 - 10.5		45	1.5 - 231
Al	11.8	1.3 - 39		6.2	0.44- 28		9.7	0.22- 69
Na	2.42	0.68 - 9.9		3.14	0.75- 19.1		1.97	0.12- 9.91
Ti	1.15	0.14 - 2.95		0.26	LD - 1.88		4.1	0.05- 28.7
Mg/(Mg+Fe)	82.9	67.6 - 92.9		66.3	26.6 - 94.6		68.5	27.3 - 89.2
ppb								
V	39.4	5.4 - 152		16.2	1.5 - 51		61.3	1.5 - 262
Sc	3.84	1.71 - 14.9		2.2	0.17- 12.2		4.4	0.07- 17.2
Cr	166	LD - 518		1450	LD - 5960		374	12 - 1650
Mn	422	82 - 1280		305	11 - 2270		784	26 - 5440
Co	142	14 - 1540		92	21 - 245		196	21 - 1080
Ni	10000	LD - 34000		5460	LD - 14600		8070	LD -24600
Cu	1190	LD - 9320		672	LD - 2060		2679	LD -14600
Sr	180	LD - 360		240	LD - 2240		630	LD - 2430
Ba	550	LD - 2160		11300	60 - 23600		2690	60 -18600
La	4.86	0.5 - 17.5		16.8	0.07- 96.4		32.2	0.98- 161.2
Ce	14.2	2.8 - 52.0		57.8	LD - 136.0		62.6	LD - 234.0
Sm	3.32	LD - 4.76		2.15	LD - 11.9		4.53	LD - 25.0
Eu	0.34	LD - 0.84		0.37	LD - 1.87		1.08	LD - 3.8
Dy	0.58	LD - 2.19		1.57	LD - 4.93		2.22	LD - 3.9
Ho	0.16	LD - 0.83		0.25	LD - 0.78		0.49	LD - 1.02
Yb	0.36	LD - 0.63		1.49	LD - 1.98		1.07	LD - 3.00
Lu	0.08	LD - 0.10		0.38	LD - 0.56		0.28	LD - 0.65

INCLUSIONS: Di&gt;Ga±Ol, S, Sp?

Ga&gt;S±Di

Di&gt;S±Ga±(En, Ol, Sp?)

Numbers in brackets refer to the number of 1 gram samples in the average

LD = Limit of Detection

Ga - Cr-rich Pyrope Garnet, Di - Diopside, En - Enstatite, Ol - Olivine, Sp - Cr-rich Spinel, S - Fe, Cu, Ni, Co Sulphides (Pyrrhotite, Pentlandite)

Diopside	-	O, Ca, Na, Mg, Ti, Al, (Sr), light REE
Garnet	-	O, Al, Sc, Mn, Cr, Mg, heavy REE
Olivine )	-	O, Mg, Ni, Co, low Al
Enstatite )		
Chromite	-	O, Cr, Mg, Co, low Sc, Al, Na
Sulphides	-	Fe, Cu, Ni, Co, low O, Mg

The inferred mineral assemblages in diamonds from the sources we investigated were generally dominated by either garnets (Finsch) or diopside (Premier and Jagersfontein) (Table 2). This statistical analysis was confirmed by plotting the measured Al against oxygen content in all the diamonds analysed (Fig. 1). Superimposed on this diagram are the extreme limits for garnets, diopsides and olivines reported by Meyer and Boyd (1). Generally, the inclusion chemistry is dominated by a diopside-garnet assemblage, for which further evidence is provided by the REE contents in these diamonds relative to that of the average REE in chondrites (8) (Fig. 2). Patterns for average South African kimberlite garnets (GA) and Cr-diopside (DI) are included for comparison. The primitive REE pattern of Premier Cr-diopside ( $P_1$ ) inclusions is in accordance with the relatively primitive pattern of the Premier kimberlites and minerals (9). This may be a function of the Pre-cambrian age of kimberlite (5) and/or derivation from a relatively undepleted mantle.

In the absence of sulphides the Mg/(Mg+Fe) approaches the ratio for olivines, enstatites and pyrope garnets: 92-96 (1). The deviation of this ratio from ~90 could be interpreted as function of the amount of sulphides present (Table 2). Pyrrhotite and/or pentlandite were inferred to be present in nearly all the inclusion containing samples, confirming the observations of Harris (6).

The data obtained for 'inclusion free' samples (all stones; the light coloured ones of gem quality) were analysed statistically for a possible correlation of colour with chemistry. This analysis gave significant correlations between elements found in garnet (Mg, Fe, Al, Sc, Cr, Mn and O) and Cr-diopside (Ca, Al, Na and O) (Table 1).

It is concluded that these elements are present as micro-aggregates - generally amorphous, (10, 11) and represent droplets of trapped liquid which may be expected to be found in diamonds that crystallised from a liquid (1). This conclusion finds further support from the observed excess of oxygen relative to Al, which could indicate the presence of volatiles, e.g. CO<sub>2</sub>, H<sub>2</sub>O. The presence of CO<sub>2</sub> on the crystal boundaries of syngenetic mineral inclusions would provide the mechanism for graphitisation on the inclusion - diamond interfaces described by Harris (6).

In this context it is interesting to note that not only do diamonds from Premier contain a fair number of graphite coated inclusions, but they also have an average of ten times higher trace element content when compared to the other two sources investigated. Premier diamonds should therefore contain more 'liquid' inclusions, which may result from a faster crystallisation rate for diamonds from this pipe when compared to diamonds from Finsch and Jagersfontein.

The very primitive but enriched REE pattern  $P_2$  (Fig. 2) may reflect that of the liquid from which Premier diamonds crystallised. From data obtained so far (Table 1) these 'liquid' inclusions appear to have a Ga>Di±Ol chemistry relatively rich in sulphur.

TABLE 1  
AVERAGE 'TRACE' ELEMENT IMPURITIES IN SOME "INCLUSION FREE"  
SOUTH AFRICAN DIAMONDS

Description	O ppm	Mg ppm	Fe ppm	Ca ppm	Al ppm	Na ppm	Ti ppm	V ppb	Sc ppb	Cr ppb	Mn ppb	Co ppb	Ni ppm	Cu ppb	Sr ppm	Ba ppm
Colourless:	P (3)* 34	6.10	2.70	0.66	0.380	0.173	0.060	2.90	0.731	35.03	46.0	8.0	-	21	-	0.060
	F (3) 32	0.27	0.28	<0.20	0.033	0.022	0.050	0.10	0.007	3.58	0.8	0.5	0.25	8	-	-
	J (3) 39	0.23	0.58	0.16	0.068	0.038	0.021	0.19	0.014	1.08	1.7	6.0	0.27	64	0.007	0.019
Yellow:	P (4) 34	0.80	1.39	0.29	0.310	0.090	0.040	1.90	0.063	11.98	6.8	5.0	1.0	15	-	0.030
	F (3) 45	<0.10	0.64	<0.20	0.050	0.023	0.030	2.00	0.004	0.90	0.4	10.0	0.30	9	-	-
	J (4) 37	0.15	0.47	0.14	0.127	0.043	0.016	0.49	0.090	1.41	2.4	2.0	0.14	-	-	1.12
Brown:	P (6) 75	7.1	8.16	4.20	10.0	0.640	0.090	8.00	2.865	67.78	122.0	17.0	-	57	-	0.100
	F (3) 39	3.7	2.15	0.23	0.270	0.057	0.050	1.00	0.118	95.50	18.0	5.0	<0.20	<10	-	0.040
	J (3) 42	1.4	1.01	0.35	0.280	0.032	0.032	1.18	0.163	93.07	8.7	5.1	0.28	60	-	0.091
Green:	P (2) 181	25.0	16.47	15.2	15.0	3.00	1.00	25.0	4.515	133.25	305.0	50.0	0.60	-	0.4	1.40
	F (5) 31	0.5	1.57	0.25	0.369	0.047	0.20	0.80	0.211	6.93	11.0	4.0	1.0	30	-	0.070
F-test value (35 degrees of freedom)	2.1	4.36	3.71	2.38	3.57	1.46	1.14	3.92	4.57	4.44	3.73	2.57	0.68	0.11	1.30	0.82
Significance (%) <sup>a</sup>	95	95	95	95	95	95	95	95	99	99	95					

<sup>a</sup> 95% significance  $2.88 < F < 4.40$

\* The figures quoted in parenthesis indicate the number of 1 gram samples analysed. P = Premier, F = Finsch, J = Jagerfontein.

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