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

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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 pyropic 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:



TABLE 2

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

Source: Element	Premi Ave.	er (19 Ran) ige		Finsc Ave.	h (1	8) Rai	nge	Jagersfo Ave.	ntein (17 Rang) e
Oxygen	179	35	-	420	65	23		103	302	79 - 1	620
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
A1	11.8	1.3	-	39	6.2	0.4	4-	28	9.7	0.22-	69
Na	2.42	0.68	-	9.9	3.14	0.7	5-	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
Ng/(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	0.1	7 -	12.2	4.4	0.07-	17.2
Cr	166	LD	-	518	1450	LD	-	5960	374	12 - 1	650
Mn	422	82	-	1280	305	11	-	2270	784	26 - 5	440
Co	142	14	-	1540	92	21	-	245	196	21 - 1	080
Ni	10000	LD	-	34000	5460	LD	-	14600	8070	I.D -24	600
Cu	1190	LD	-	9320	672	LD	-	2060	2579	LD -14	600
Sr	180	LD	-	360	240	LD	-	2240	630	LD - 2	430
Ba	550	LD	-	2160	11300	60	-	23600	2690	60 -18	600
La	4.86	0.5	-	17.5	16.8	0.0	7-	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	LÐ	-	1.87	1.08	LD -	3.8
Dy	0.58	LD	-	2.19	1.57	LD	-	4.93	2.22	LD -	3.9
Но	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	C.28	LD -	0.65

Di>Ga±01, S, Sp? INCLUSIONS:

Ga>>S>Di

Di>StGat(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, Pent≹andite)

Diopside		-	0,	Ca,	Na,	Mg,	Τí,	A1,	(Sr)	, light	REE
Garnet		-	0,	A1,	Sc,	Mn,	Cr,	Mg,	heav	y REE	
Olivine Enstatite))	-	0,	Mg,	Ni,	Co,	low	A1			
Chromite		-	0,	Cr,	Mg,	Co,	low	Sc,	A1,	Na	
Sulphides		-	Fe	, Cu	, Ni	, Co	, 101	v 0,	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 diopsidegarnet 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 pyropic garnets: 92-96 (1). The deviation of this ratio from \sim 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 A1, which could indicate the presence of volatiles, e.g. CO_2 , H_2O . The presence of CO_2 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.

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TABLE 1 Description 0 lourless: P (3)* 34 J (3) 59 J (3) 59 J (3) 59 J (4) 37 J (4) 37 J (4) 37 J (4) 37 J (4) 37 J (5) 75 J (4) 37 J (5) 75 d (5)	TARLE 1 Description 0 Description 7 Colouriess: P (3)* 34 F (3) 35 Yellow: P (4) 37 F (3) 37 Brown: P (4) 37 G (5) 75 F (3) 37 G (5) 75 F (3) 31 F (5) 31 F-test value (35 degrees of 2,1 Freedom) 55 significance (1)*			mg M	6.10 0.27 0.23	0.80 <0.10 0.15	7.1 3.7 1.4	25.0	4.36	95	e 2.88						
TABLE 1 Description Lescription J (3) J (3) J (4) Own: P (4) J (4) J (4) Own: P (6) J (4) Comn: P (6) J (3) een: P (5) degrees of cedom) enificance (4)*	TABLE 1 Description Description Colouriess: P (3)° F (3) 7 (3) 7 (4) 7 (3) 7 (4) 7 (3) 7 (3) 7 (5) 7 (ndd 0	34 32 39	34 45 37	75 39 42	181 31	2.1		ficanc						
	Sist Ke	TABLE 1		Description	lourless: P (3)* F (3) J (3)	:llow: P (4) F (3) J (4)	own: P (6) F (3) J (3)	reen: P (2) F (5)	-test value 35 degrees of reedom)	ignificance (%)*	95% sign:						

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