

# MINERAL INCLUSIONS IN DIAMONDS FROM KOFFIEFONTEIN MINE.

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The composition of 78 mineral inclusions recovered from 54 Koffiefontein diamonds have been determined by electron microprobe. Based on these analyses and observations on 938 diamonds with mineral inclusions it is clear that sulphides are most common and that peridotitic minerals are much more abundant than their eclogitic counterparts. (see Table 1.) (This study does not deal with the sulphides any further).

The peridotitic and eclogitic inclusions at Koffiefontein have compositions which cover almost the full range found in inclusions world-wide. (Meyer H.O.A. 1986).

The peridotitic garnets (n=14) have a range in Mg/Mg+Fe from 84.0 to 92.6, in CaO from 3.5 to 8.7 wt%. The latter is rather lower than average. Four garnets plot on the hercynite trend. The olivines (n=15) have the normal Mg-rich compositions (Fo 91.6 - Fo 95.4). The Cr<sub>2</sub>O<sub>3</sub> contents range up to a value of 0.15 wt%. CaO can also be high for a mantle olivine but both the inclusions with the highest CaO (0.13 and 0.16 wt%) occurred in diamonds with black fracture flaws so this could be related to secondary processes. The orthopyroxenes (n=12) are enstatites (En 92.6 - En 95.8) with a low CaO content (0.13 - 0.78 wt%) which decreases with increasing Mg/Mg+Fe ratio. Al<sub>2</sub>O<sub>3</sub> ranges from 0.30 to 0.90 wt% with a single exception which co-exists with ferro-periclase and has an Al<sub>2</sub>O<sub>3</sub> of 1.16 wt%. Cr<sub>2</sub>O<sub>3</sub> ranges from 0.07 to 0.57 wt%. In the majority of cases (n=7) [Al+Cr-Na] at. prop. is restricted to the narrow range of 0.030 - 0.037 suggesting a limited amount of variation in garnet s.s. and therefore a modest crystallisation pressure interval. The single chromite has 63.3 wt% Cr<sub>2</sub>O<sub>3</sub> and 0.1 wt% TiO<sub>2</sub>. The chromiferous peridotitic clinopyroxenes have very high K<sub>2</sub>O contents. (see Table 2). The assigned peridotitic paragenesis is strengthened by the presence of two inclusions of K-rich pyroxene with olivine in one diamond (K-18). The only other apparently peridotitic inclusions found in this study are four ferro-periclases which have been confirmed by X-ray diffraction and are described in detail elsewhere in this volume. (Moore et al.)

The eclogitic garnet inclusions have a wide range in CaO, MgO and particularly FeO. They are characterised by low Cr<sub>2</sub>O<sub>3</sub> (nd - 0.85 wt%), minor TiO<sub>2</sub> (0.07 - 0.76 wt%) and Na<sub>2</sub>O (up to 0.34 wt%), all of which are typical of diamond inclusions and Type I eclogite garnets. The eclogitic clinopyroxenes also show a wide range in compositions. They all have minor TiO<sub>2</sub> (0.13 - 0.42 wt%). Na<sub>2</sub>O (1.4 - 4.6 wt%) and Al<sub>2</sub>O<sub>3</sub> (2.7 - 7.9 wt%) are in a few cases low for eclogitic clinopyroxene diamond inclusions. (cf Meyer H.O.A. 1986). K<sub>2</sub>O contents range up to 0.23 wt%.

In contrast to many other diamond inclusion suites the Koffiefontein mineral inclusions provide a number of examples of disequilibrium assemblages in single diamonds. In all three cases where two inclusions of the same mineral were recovered from one diamond the individual grains had different compositions. (see Table 3). In one case (K-37) two radically different garnets coexist with the same clinopyroxene generating tie lines with very different slopes. Since one more gar-cpx pair (K-16) generates a similar cross-cutting tie line it may be yet another instance of disequilibrium between co-existing phases.

Calculated equilibration conditions for co-existing mineral pairs are given in Table 4. Obviously diamonds with disequilibrium assemblages do not give valid answers. They are included in the Table to show the magnitude of the errors which can result from

this source. The minerals found, their relative abundances, and their compositions suggest garnet hartzburgite (gar,opx,olv), garnet lherzolite (gar,cpx,opx,olv) and eclogite parageneses for the diamonds with a very minor chromite hartzburgite field. The peridotitic parageneses predominate. This is a common association. The high K<sub>2</sub>O contents of the peridotitic clinopyroxenes have never previously been reported. The presence of ferro-periclasite is also unusual and noteworthy because this mineral is stable at very high pressures, and may be an important phase in the lower mantle. Calculated equilibration temperatures for both peridotitic and eclogitic mineral pairs are so low that they are close to or below current estimates of the mantle solidus. Since crystallographic evidence strongly argues against a metamorphic origin for diamonds volatile induced small volume partial melting and/or metasomatic processes must be invoked.

Table 1. (A) Relative diamond inclusion abundances based on observations and analytical determinations from the Koffiefontein Mine.

<u>Sulphides</u>	<u>Perid.</u>	<u>Ecl.</u>	<u>graph.</u>	<u>Clouds</u>	<u>(Ec/Ec+Perid.)%</u>
397	277	22	66	176	7

(B) Relative proportions of peridotite silicate minerals in Koffiefontein diamonds.

<u>Observed Abundances</u>				<u>Calculated Proportions</u>			
<u>gar.</u>	<u>cpx.</u>	<u>colourless</u>	<u>ratio</u> *	<u>gar.</u>	<u>cpx.</u>	<u>opx.</u>	<u>olv.</u>
		<u>opx + olv</u>	<u>opx/olv</u>				
47	5	222	10:12	17.2	1.8	36.8	44.2

\* Determined from 22 diamonds and 27 inclusions.

Table 2. Peridotitic clinopyroxenes in Koffiefontein diamonds.

	<u>K13</u>	<u>K14</u>	<u>K15</u>	<u>K18a</u>	<u>K18b</u>
SiO <sub>2</sub>	55.00	54.70	55.10	54.30	54.80
TiO <sub>2</sub>	.07	n.d.	n.d.	n.d.	n.d.
Al <sub>2</sub> O <sub>3</sub>	2.14	1.55	1.37	.68	.72
Cr <sub>2</sub> O <sub>3</sub>	3.66	.89	.75	2.44	2.34
FeO	1.75	2.40	2.69	1.91	2.28
MnO	.08	.09	.09	.08	.11
MgO	16.60	18.50	18.30	17.50	19.10
CaO	18.30	20.10	19.20	20.30	17.90
Na <sub>2</sub> O	2.35	.45	1.22	.33	.30
K <sub>2</sub> O	.04	.79	.31	1.57	1.68
Total	99.99	99.50	99.04	99.11	99.26

Table 3. Disequilibrium in Koffiefontein diamond inclusions.

	<u>K18a.</u>	<u>K18b.</u>	<u>K19a.</u>	<u>K19b.</u>	<u>K37a.</u>	<u>K37b.</u>
SiO <sub>2</sub>	54.30	54.80	38.70	39.20	40.70	38.00
TiO <sub>2</sub>	n.d.	n.d.	.07	.07	.38	.13
Al <sub>2</sub> O <sub>3</sub>	.68	.72	22.40	22.40	22.40	21.60
Cr <sub>2</sub> O <sub>3</sub>	2.44	2.34	n.d.	n.d.	.20	.04
FeO	1.91	2.28	24.00	21.30	16.20	22.90
MnO	.08	.11	.61	.38	.25	.42
MgO	17.50	19.10	9.63	10.60	15.40	7.36
CaO	20.30	17.90	4.13	5.45	4.05	8.00
Na <sub>2</sub> O	.33	.30	.08	.20	.18	.07
K <sub>2</sub> O	1.57	1.68				
Total	99.11	99.26	99.63	99.60	99.76	98.57

n.d. = not detected

Table 4.

Calculated conditions of equilibration for Koffiefontein  
diamond inclusions.

<u>Diamond Number</u>	<u>Mineral Pair</u>	<u>T<sup>o</sup>C</u>	<u>Method</u>	<u>Pkb.</u>	<u>Method</u>	<u>Probable paragenesis</u>
K10	Gar-Olv	940	OW 79	50	Assumed	Gar-Harz
K11	Gar-Olv	1180	OW 79	50	Assumed	Gar-Harz
K48	Gar-Olv	1157	OW 79	50	Assumed	Gar-Harz
K47	Gar-Opx	1086	MG 78	50	NG 85	Gar-Harz
K2	Gar-Opx	1156	MG 78	57	NG 85	Gar-Lherz
K9	Gar-Opx	1116	MG 78	49	NG 85	Gar-Lherz
K46	Gar-Opx	1014	MG 78	45	NG 85	Gar-Lherz
K13	Cpx only	1094	LD 76	-	None	Gar-Lherz
K14	Cpx only	1109	LD 76	-	None	Gar-Lherz
K15	Cpx only	1143	LD 76	-	None	Gar-Lherz
K8	Gar-Cpx	1016	EG 79	50	Assumed	Eclogite
K16*	Gar-Cpx	895	EG 79	50	Assumed	Eclogite
K41	Gar-Cpx	1221	EG 79	50	Assumed	Eclogite
K42	Gar-Cpx	1220	EG 79	50	Assumed	Eclogite
K43	Gar-Cpx	1231	EG 79	50	Assumed	Eclogite
K56	Gar-Cpx	1160	EG 79	50	Assumed	Eclogite

Disequilibrium Assemblages.

K18	Olv-Cpx	1033	LD 76	-	None	Gar-Lherz
K18	Olv-Cpx	1233	LD 76	-	None	Gar-Lherz
K37	Gar-Cpx	1189	EG 79	50	Assumed	Eclogite
K37	Gar-Cpx	860	EG 79	50	Assumed	Eclogite

\* K16 tie line parallels K37 disequilibrium tie line, which cross cuts other tie lines. Possibly K16 gar-cpx pair are not in equilibrium either, providing an explanation for the very low calculated T.

EG 79 = Ellis and Green 1979

OW 79 = O'Neill and Wood 1979

LD 76 = Lindsley and Dixon 1976

MG 78 = Mori and Green 1978

NG 85 = Nickel and Green 1985

REFERENCES

- ELLIS D.J. and GREEN D.H. 1979. An experimental study of the effect of Ca upon garnet-clinopyroxene Fe-Mg exchange equilibria. *Contributions to Mineralogy & Petrology*, 71, 13-22.
- LINDSLEY D.H. and DIXON S.A. 1976. Diopside-enstatite equilibria at 850-1400°C, 5-35 kb. *American Journal of Science* 276, 1285-1301.
- MEYER H.O.A. 1986. (in press) Inclusions in diamond. *Mantle Xenoliths.* (ed. P.H. NIXON.) Wiley & Son.
- MORI T. and GREEN D.H. 1978. Laboratory duplication of phase equilibria observed in natural garnet lherzolites. *Journal Geology* 86, 83-97.
- NICKEL K.G. and GREEN D.H. 1985. Empirical geothermobarometry for garnet peridotites and implications for the nature of the lithosphere, kimberlites and diamonds. *Earth and Planetary Science Letters* 73, 158-170.
- O'NEILL H.S.C. and WOOD B.J. 1979. An experimental study of Fe-Mg partitioning between garnet and olivine and its calibration as a geothermometer. *Contributions to Mineralogy & Petrology* 70, 59-70.