THE OCCURRENCE OF MOISSANITE AND FERRO-PERICLASE AS INCLUSIONS IN DIAMOND

R.O. MOORE; M.L. OTTER; R.S. RICKARD; J.W. HARRIS*; J.J. GURNEY

Department of Geochemistry, University of Cape Town, South Africa.
*Department of Applied Geology, University of Strathclyde, Glasgow.

MOISSANITE

Moissanite (SiC) has been reported from a wide variety of geological environments, including a number Soviet kimberlites (e.g. Marshintsev et al., 1984). However, the validity of the numerous documentations of "natural" SiC have been seriously questioned by a number of authors. Milton and Vitaliano (1984) believe that not a single report convincingly proves its existence in nature and that contamination from industrial sources represents the real source.

Moissanite has been found for the first time as a primary inclusion in diamonds from the Monastery kimberlite in South Africa and the Sloan diatremes in the U.S.A. A total of six inclusions of this phase (three from each of the above localities) were observed to be primary within their host before the diamond was broken for inclusion recovery. It is emphasised that the moissanite inclusions reported here were mounted directly in epoxy resin without coming into contact with carborundum abrasives.

The inclusions range in size from 40 to 125 um and are a pale green translucent colour. Their morphologies were not well characterised, but curved, possible cubo-octahedral, crystal faces are evident on one inclusion from Sloan (A90), whilst one of the Monastery inclusions (C16-01) has a distinctive flattened disc shape. This inclusion was analysed by X-ray diffraction (XRD) techniques using a 57.4mm Gandolfi camera, and the results are tabulated in Table 1. Only the largest inclusion has been analysed. The remaining inclusions were identified by semi-quantitative microprobe techniques which together with careful qualitative scans over the full spectrum of elements detectable on the microprobe indicated them to be pure SiC (~67%Si; ~33%C).

Although the general structure of silicon carbide is relatively simple (essentially long chains of SiC tetrahedra), detailed structures may be extremely complex due to one dimensional disorder or polytypism (Shaffer, 1969). Over 75 polymorphs have been identified in the literature. The XRD analysis of the moissanite inclusion does not perfectly match any of the nine polymorphs for which detailed XRD data was available to the authors (Shaffer, 1969). However, specific peaks from the 2H and 6H polymorphs correspond with a large number of the inclusion reflections. It is possible that the moissanite inclusion represents a mixture of more than one SiC polymorph, or more likely, that it represents a polymorph for which XRD data was not available to the authors.

Mineral associations were observed at both localities. At Monastery, two of the moissanite inclusions were liberated from diamonds hosting eclogitic garnets showing the effects of pyroxene solid-solution in garnet (Moore and Gurney, 1985; Moore and Gurney, this volume), whilst the third occurred as a discrete monomineralic inclusion. At Sloan, however, one moissanite inclusion was liberated from a diamond hosting a diopside of peridotitic affinity, while another formed the crystalline eye to a sulphide (?) rosette feature. The third occurred as a single inclusion within its host diamond. Table 2 lists microprobe analyses of mineral inclusion phases found in association with moissanite.

Some interesting observations can be made from the associated mineral inclusions. At Monastery, the two garnet inclusions imply a high pressure origin for their host diamonds. Crude estimates evaluated from the experimental data of Akaogi and Akimoto, (1979) are 110 and 140 kbars for diamonds A4-03 and A1-15 respectively. These pressures represent absolute maxima, as a combination of bulk compositional effects as well as the reported overestimate of pressure calibrations in the experimental data (Irifune et al., 1986) will lower these estimates by approximately 40 kbars to 70 and 100 kbars respectively. At Sloan, where moissanite is found in association with the peridotitic paragenesis, high temperatures and pressures of formation are again implied. However, it is emphasised that equilibration conditions are not tightly constrained due to the rarity of coexisting mineral pairs (see Otter and Gurney, this volume). A single garnet-olivine pair yields an O'Neill and Wood (1979) temperature of 1370°C (50 kbars assumed). Furthermore, the single diopside found in association with moissanite yields a Lindsley and Dixon (1976) (20kbars) temperature of 1224°C. Pressure estimates following Nickel and Green (1985) for four orthopyroxenes range between 58 and 73 kbars if one assumes a temperature of 1370°C and/or between 52 and 65 kbars if one adopts the lower temperature option of 1224°C.

The common factor which has emerged between the Monastery and Sloan moissanite occurrences is the high temperatures and pressures of equilibration. Furthermore, our observations indicate that moissanite is not restricted to either peridotitic or eclogitic paragenesis diamonds (the same is observed for sulphide inclusions). Data on the physical (P,T, fO_2) and chemical conditions favoured by moissanite is insufficient to justify speculation as to its significance to diamond formation and mantle petrology. However, the occurrence of moissanite as a primary inclusion in diamond implies an extremely reducing environment for diamond growth. This is consistent with the common occurrence of sulphide inclusions as well as the rare reports of metallic iron in diamonds (Meyer, 1986).

FERRO-PERICLASE AND MAGNESIO-WUSTITE

Two types of Fe-Mg oxide minerals have been found as inclusions in diamond. The first, which is represented by a single inclusion from a Monastery diamond has been termed magnesio-wustite (FeO = 93.01 wt.% and MgO = 7.29 wt.%, Table 3). The second type represented by 5 inclusions (4 from Koffiefontein; 1 from Sloan) have been called ferro-periclase. The latter have MgO contents which range between 76.04 and 78.74 wt.% and FeO between 19.41 and 21.55 wt.% (Table 3). The terminology adopted in this report differs from that used by Scott Smith et al. (1984) who report the occurrence of two magnesio-wustites (ferro-periclase in our terminology) as inclusions in diamonds from kimberlites near Orroroo.

The inclusions are all in the region of 70 um in maximum dimension with ferro-periclase being dark orange to brown in colour, translucent and isotropic. The magnesio-wustite is black and opaque. One of the four ferro-periclase inclusions from Koffiefontein coexists with an enstatite (Table 3), implying a peridotitic association.

Periclase in association with magnetite has been reported from an Arkansas diamond (Newton et al., 1977), who suggested that it represents an original magnesite inclusion which decomposed upon diamond combustion in the inclusion recovery process. The inclusions discussed here have all been liberated by mechanical breakage, which renders this potential origin inappropriate. The association of a ferro-periclase inclusion with orthopyroxene raises the possibility that it may be formed by the desilicification of enstatite. Scott Smith et al. (1984) reject such a mechanism since enstatites of typical mantle compostions (Mg/Mg+Fe ~0.94) would be unlikely to produce the ferro-periclase compositions (Mg/Mg+Fe ~0.86) observed both at Koffiefontein and Orroroo by this simple reaction.

Indications are therefore that these oxide phases represent primary inclusions. Experimental work by Liu (1975) suggests that at 250 kbars Mg_2SiO_4 (olivine with a spinel structure) transforms to pyroxene with a perovskite structure plus MgO with a cubic structure. Scott Smith et al. (op cit) point out that if the enstatite and ferro-periclase found in the Koffiefontein diamond crystallised in equilibrium at 1000°C, pressures in excess of 200 kbars are implied by the experimental data of Yagi et al. (1979). Another consideration is that these oxide phases would require extremely reducing conditions of formation which are not readily apparent in the well documented regions of the upper mantle. It is therefore possible that the ferro-periclase and magnesio-wustite inclusions in fact represent ultra-high pressure phases. Le Roex (Nature, submitted) has recently demonstrated chemical correlations between southern African kimberlites and South Atlantic hotspots. Moore and Gurney (this volume) drew attention to the possibility that a rising diapir(s) related to hot-spot activity could serve as a potential mechanism fo the sampling of diamonds from extreme depths in the mantle. This suggestion could also be applied to the ferro-periclase, magnesio-wustite and even the moissanite inclusions described here.

REFERENCES

AKAOGI M. and AKIMOTO S. 1979. High pressure phase equilibria in a garnet lherzolite, with special references to Mg^{2+}-Fe^{2+} partitioning among constituent minerals. **Physics of the Earth and Planetary Interiors** 19, 31-51.

IRIFUNE T., SEKINE T., RINGWOOD A.E. AND HIBBERSON W.O. 1986. The eclogite-garnetite transformation at high pressure and some geophysical implications. **Earth and Planetary Science Letters** 77, 245-256.

le ROEX A.P. 1986. A geochemical correlation between source region signatures of southern African kimberlites and South Atlantic hotspots. submitted to **Nature**.

LINDSLEY D.H. and DIXON S.A. 1979. Diopside-enstatite equilibria at 850-1400°C, 5-35 kb. **American Journal of Science** 276, 1285-1301.

LUI L. 1975. Post-oxide phases of olivine and pyroxene and the mineralogy of the mantle. **Nature** 258, 510-512.

MARSHINTSEV V.K., SHCHELCHKOVA S.G., ZOL´NIKOV G.V. and VOSKRESENSKAYA V.B. 1967. New data on moissanite from kimberlites in Yakutia. **Geologiya Geofizika** 12, 22-31.

MEYER H.O.A. 1986. Inclusions in diamond. In Nixon P.H. ed, **Mantle Xenoliths**, Wiley & Son, in press.

MILTON C. and VITALIANO D. 1984. Moissanite, SiC, a non-existent mineral. XXVII International Geological Congress, Moscow.

MOORE R.O. and GURNEY J.J. 1985. Pyroxene solid solution in garnets included in diamond. **Nature** 318, 553-555.

NEWTON M.G., MELTON C.E. and GIARDINI A.A. 1977. Mineral Inclusions in an Arkansas diamond. **American Mineralogist** 62, 583-586.

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 and Petrology** 70, 59-70.

SCOTT SMITH B.H., DANCHIN R.V., HARRIS J.W. and STRACKE K.J. 1984. Kimberlites near Orroroo, South Australia. In Kornprobst J. ed, **Kimberlites I: Kimberlites and Related Rocks**, pp.121-142. Elsevier, Amsterdam.

SHAFFER P. 1969. A Review of the structure of silicon carbide. **Acta Crystallographica** B25, 477-488.

YAGI T., BELL P.M. and MAO H.K. 1979. Phase relations in the system MgO-FeO-SiO_2 between 150 and 700 kbar at 1000°C. **Carnegie Institute of Washington Yearbook** 78, 614-618.

TABLE 1

XRD Analysis of Moissanite C16-01

(d-spacings/intensity)

4.01/5	2.54/5	2.37/5	2.08/2	1.58/1	1.44/3	1.11/1	1.00/2	.986/1	.955/2	.900/3
2.60/8	2.49/10	2.30/5	1.69/1	1.53/6	1.39/3	1.05/1	.992/1	.976/2	.933/2	

TABLE 2

Phases coexisting w/ Moissanite

	Monastery		Sloan
	A4-03	A1-15	A78
	GAR	GAR	CPX
SiO_2	42.1	46.3	54.7
TiO_2	1.21	1.05	0.05
Al_2O_3	18.3	13.6	0.99
Cr_2O_3	0.02	1.20	1.29
FeO	14.7	9.07	2.72
MnO	0.27	0.23	0.11
MgO	10.3	23.6	19.9
CaO	11.9	5.16	18.9
Na_2O	1.08	0.14	0.65
K_2O	-	-	0.20
NiO	-	-	-
Total	99.88	100.35	99.51

TABLE 3

Magnesio-Wustite,Ferro-Periclase & Coexisting Phases

	Monastery	Sloan	Koffiefontein				
	A1-40	A100	K30	K33	K34	A262	A262
	MG-WUS	FE-PER	FE-PER	FE-PER	FE-PER	FE-PER	OPX
SiO_2	ND	ND	0.08	0.09	0.13	ND	57.1
TiO_2	0.17	ND	ND	ND	ND	ND	0.03
Al_2O_3	0.17	0.10	ND	ND	0.07	ND	1.16
Cr_2O_3	ND	0.84	0.49	0.52	0.67	0.57	0.36
FeO	93.0	19.4	21.7	20.5	20.3	19.8	3.33
MnO	0.32	0.32	0.15	0.16	0.17	0.19	0.11
MgO	7.29	78.7	77.3	76.8	76.9	78.1	36.9
CaO	ND	0.04	ND	0.05	0.03	ND	0.12
Na_2O	-	0.07	0.29	0.25	0.20	0.30	ND
K_2O	-	ND	ND	0.06	ND	-	ND
NiO	-	-	-	-	-	1.41	-
Total	100.95	99.47	100.01	98.40	98.40	100.37	99.11

ND = not detected; - = not analysed .