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Iron carbide and metallic inclusions in diamonds from Jagersfontein

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Introduction

Diamonds from Jagersfontein kimberlite with isotopically light carbon include majoritic garnets and associated minerals that may be superdeep, perhaps from the asthenosphere or transition zone (Tappert et al, 2005). Metals and carbides are very rare in natural diamonds but have been reported in pyroxenitic garnet inclusions within polycrystalline diamond from Venetia kimberlite (Jacob et al, 2003; Fe_3C "cohenite"). We describe the occurrence of metallic and carbide inclusions together with their host diamonds from Jagersfontein.

Inclusion suite

A suite of >50 diamonds collected during kimberlite mining at Jagersfontein, are characterised by a variety of dark metallic incusions which we have analysed by electron microprobes. Of 35 irregular stones with exposed surface and subsurface inclusions, 19 contain carbides (Fe-carbide, CrFeNi-carbide, and "Cr-cohenite"), just 6 contain sulphides (Fe-S, FeNi-S, Ni-S), and various other inclusions recognised comprise Fe-oxides, ilmenite, SiO2, opx, cpx, mica and MgF. Candidate higher pressure minerals we have observed within this suite, include occasional grains of ?ferropericlase and an Mg-Si-O phase. The metallic carbides are Ni-poor but often contain Cr and have no natural counterparts from the literature that we are aware of (Fig 1). Cr is not in itself a discriminating feature of the Jagersfontein carbides, since one polished specimen also contains Cr-free carbide similar to presumably Cr-free cohenite in the Venetia spherules (Cr not reported, see Table 1).

Carbides

Iron carbide was also found in polished sections of two of these diamonds, and occurs in vein-like fractures or as large platelets with preferred orientations relative to the diamond host (Fig. 2). The metallic phase intergrown within one diamond shows limited compositional variation according to petrographic texture and is compositionally close to Fe_3C with minor but consistent Si and O.

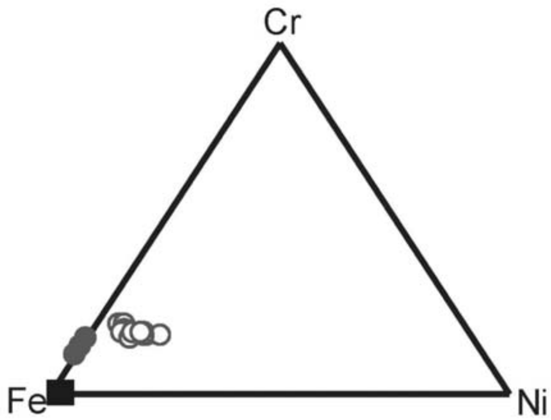

Fig 1 Indicative compositional summary of metallic carbides from Jagersfontein (circles; solid and open represent two different diamond samples) compared with "cohenite" from Venetia (solid square, range up to 1-3% Ni, Jacob et al., 2004).

X-ray diffraction patterns of one of the polished specimens containing substantial Fe-carbide, surprisingly did not positively confirm cohenite, but shows some similarities with other reported synthetic metallic compounds (not from diamond); this X-ray work is continuing.

Si in Carbides: Geobarometer versus oxidation

We are currently exploring the hypothesis that the presence of Si in the metallic inclusions can be used to constrain pressure estimates, and is consistent with an

	Jag b20	Jag b26	Jag 5	Jag 10	Venetia (Av)	*cohenite*	*cementite*	*Disko cohenite*
Fe	65.43	80.92	88.42	90.28	90.41	*54.92*	*94.73*	*(94.73)*
Cr	15.07	8.99	2.04	0.02	n.a.			*n.a.*
Ni	9.32	0.4	0.33	0.10	1.61	*28.86*		*0.6-3.1*
Si	0.78	0.55	1.65	0.78	0.03			*n.a.*
S	0.14	0.06	0.02	0.07	0.21			*n.a.*
Al	0.43	0.02	0.15	0.07	n.a.			*n.a.*
O	2.08	1.55	0.97	3.99	n.a.			*n.a.*
C	5.32	6.21	5.86	4.51	6.53	*6.56*	*5.27*	*(5.27)*
Co			0.21	0.18	0.37	*9.66*		*0.4-0.6*
	98.57	98.7	99.44	100*		*100**	*100**	**100*

Table 1 Representative probe analyses of metallic inclusions in 4 Jagersfontein diamonds compared with carbides from Venetia (Jacob et al, 2004: average of 14 analyses in metallic spherules) and "meteoritic" cohenite, cementite and Disko cohenite from Uivfaq assumed to be stoichiometric Fe_3C (Goodrich and Bird, 1985). n.a.= not analysed, *normalised total. Jag samples b20 and b26 are for exposed carbides, and Jag 5 and Jag 10 are polished specimens

unusually high pressure origin. The possible contribution of Si as the light alloying component in the Earth's core has recently been explored theoretically and experimentally, with estimates in the range 4-7 wt% (Alfe et al, 2007), athough experiments with additional oxygen, suggest more complex iron-silica interactions at the core-mantle boundary (Dubrovinsky et al, 2003). An indirect but major finding of the experimental work has been to establish that for less extreme pressures throughout the mantle (to about 25 GPa; Malavergne et al., 2004), the amount of Si (and O) in native iron is expected to correlate with P, T and fO_2 (oxygen fugacity). Si solubility in iron metal correlates with oxygen substitution and has been verified experimentally at pressures up to 25 GPa (Dobson unpublished). In other words, native iron can be expected as a minor constituent throughout the lower mantle, according to more than one process and may equally exist as carbide depending on local conditions and abundance of carbon (Oganov and Zhang, 2008). It is possible therefore, that the metallic and carbide inclusions in diamonds from Jagersfontein were trapped in the lower mantle, which could make these materials the deepest known terrestrial samples.

Deep carbon

A major question relevant to the Earth's deep carbon cycle (eg: Jones, 2008), concerns potential isotopic fractionation between these two coexisting carbon reservoirs (diamond, carbide). As a first step, we have performed detailed high precision step-heating (combustion) isotopic analyses for simultaneous carbon and nitrogen isotopes in a few of these inclusion-bearing diamonds at PSSRI (Verchovsky, unpublished). These results are so far ambiguous. It should be mentioned that nitrogen contents are low and the total combustion took up to 3 days to complete due to the relatively large sample size (few mm size). In one sample (N5), $\delta^{13}C$ was rather constant (-13.2, total range -15.0 to -11.7), but $\delta^{15}N$ varied repeatedly downwards between +7 and -1.0. Another sample (N6) showed "normal mantle" carbon isotope ratios ($\delta^{13}C$ range -5.4 to -3.2; mean -4.3) which is rare for Jagersfontein, and wide variations in $\delta^{15}N$ from +15.3 to +5.8. To what extent these stable isotope variations for C and N correlate with cathodoluminescence zoning and heterogeneity of inclusions remains to be determined in polished sections. We are currently engaged in a systematic calibration for stable isotope analysis of carbides using the ion probe, as the next stage in this investigation.

References

Alfe, D., Price, G. D., and Gillan, M. J., (2007). Temperature and composition of the Earth's core. *Contemporary Physics* **48**, 63-80

Dubrovinsky, L., Dubrovinsky, N., Langenhorst, F., Dobson, D., Gessmann, C., Abrikosov, A. A., Johansson, B., Baykov, W. I., Vitos, L., Bihan, T. L., Crichton, W. A., Dimitriev, V., and Weber, H. P., 2003. Iron-silica interaction at extreme conditions and the electrically conducting layer at the base of the Earth's mantle. *Nature* **422**, 58-61.

Goodrich C.A. and Bird, J.M (1985) Formation of iron-carbon alloys in basaltic magma at Uifvaq, Disko Island: the role of carbon in mafic magmas. *Journa l of Geology*, **93**, 475-492

Jacob, D.E., Kronz, A. and Viljoen, K.S. (2004) Cohenite, native iron and troilite inclusions in garnets from polycrystalline diamond aggregates. *Contributions to Mineralogy and Petrology*, **146**, 566-576

Jones A.P., (2008) Earth's deep carbon cycle; from geodynamics to climate. *Geophysical Research Abstracts*, Vol. **10**, EGU2008-A-05046, 2008

Malavergne, V. r., Siebert, J., Guyot, F. o., Gautron, L., Combes, R., Hammouda, T., Borensztajn, S., Frost, D., and Martinez, I., 2004. Si in the core? New high-pressure and high-temperature experimental data *Geochimica et Cosmochimica Acta* **68**, 4201-4211.

Oganov, A. R. and Zhang, F. (2008) New ideas on the behaviour of minerals in Earth's mantle and core. *Geophysical Research Abstracts*, Vol. **10**, EGU2008-A-01068

Tappert, R., Stachel, T., Harris, J.W., Muehlenbachs, K., Ludwig, T., and Brey, G.P. (2005): Diamonds from Jagersfontein (South Africa): Messengers from the sublithospheric mantle. *Contributions to Mineralogy and Petrology*, **150**, 505–522.

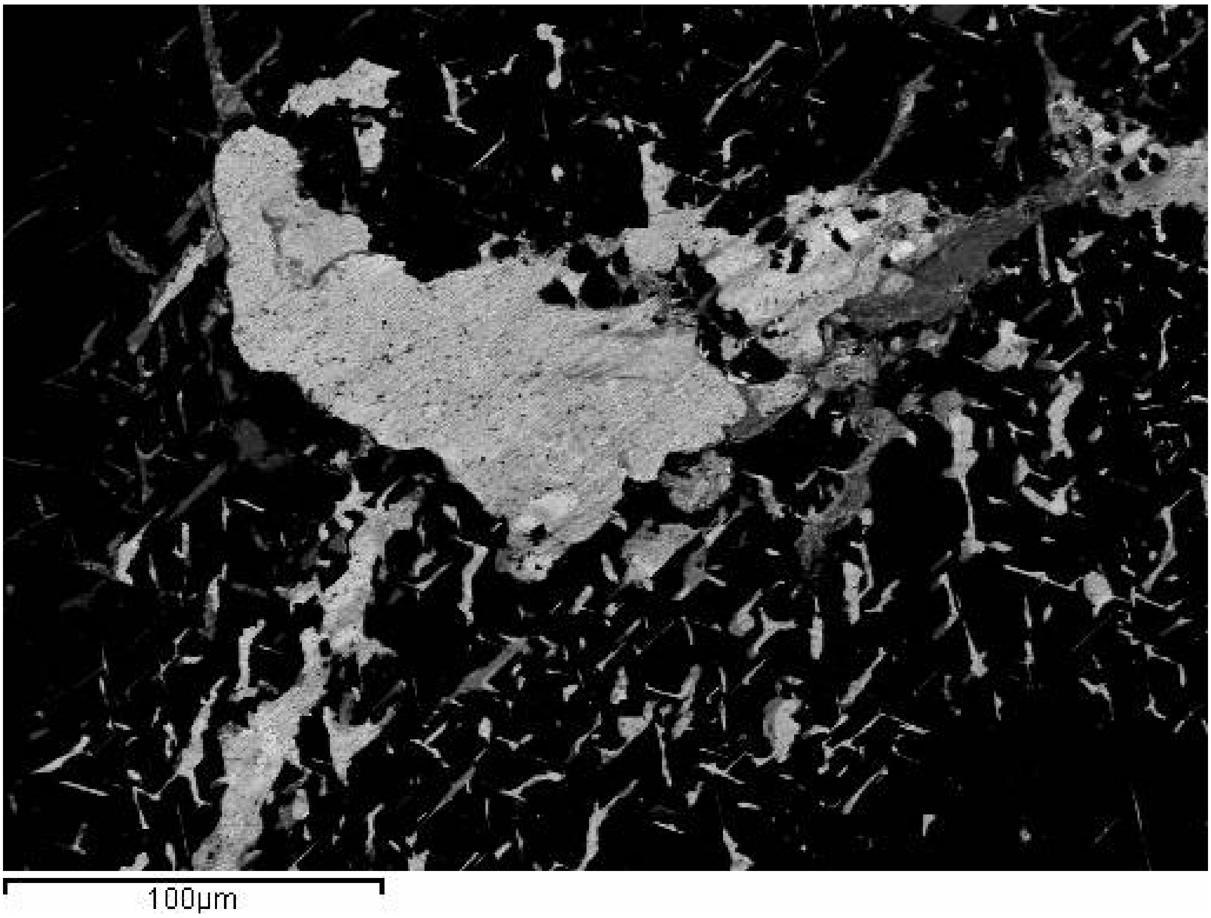

Fig. 2 Polished Jagersfontein (Jag 5) diamond specimen (backscatter electron image: JEOL electron microprobe) showing substantial metallic carbide (light colours), including preferred crystallographic orientations reminiscent of platelets in diamond host. All dark/black material is diamond