

Nature of eclogitic diamonds from Yakutian kimberlites: evidence from isotopic composition and sulphide inclusion chemistry

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Introduction.

Previous workers have suggested alternative parageneses for diamondiferous eclogites, either originating from primary mantle melts (eg. Smyth et al., 1989) or from subduction and high pressure-temperature melting of crustal material (Helmstaedt and Doig, 1975). The paragenesis of diamonds with abundant sulphide inclusions has long been the subject of controversy. Meyer (1987) and Deines and Harris (1995) have suggested that many diamonds belong to a discrete sulphide paragenesis, unrelated to either the peridotitic or eclogitic parageneses generally advocated for the origin of diamonds with silicate inclusions. In this paper we present new data on Yakutian eclogitic diamonds which reveal their nature, origin, and genetic groupings.

Samples and analytical methods.

Twenty eclogitic diamonds from kimberlitic pipes Mir and 23d Party Congress (Malo-Botuobinsky kimberlitic field) were studied, seven containing sulphides. Information obtained about syngenetic inclusions and diamonds has been linked to their growth history. Internal structure was examined by cathodoluminescence (CL) and birefringence imaging of central diamond plates, sawn and polished on the {110} plane. For some diamonds hydrogen (H) and nitrogen (N) contents and aggregation state were identified by FTIR. The chemistry of inclusions was studied by electron microprobe, proton microprobe and ion microprobe (IMP). Carbon (C) and N isotopic composition was analysed by mass-spectrometry, mainly on fragments of diamond off-cuts, with some in-situ analyses on diamond plates. Sulphur (S) isotopic composition of sulphide inclusions was determined by IMP.

Results and discussion

Deines and Harris (1995) showed that for stones from many locations in Africa, sulphide inclusions with low Ni concentrations can occur in diamonds of low as well as high $\delta^{13}\text{C}$ content. From the calculated lack of equilibrium of sulphides with mantle olivine these authors concluded also that a particular group of sulphide inclusions (80%) with low Ni/Fe ratio could not be ascribed to either peridotitic or eclogitic parageneses and should be recognised as a third "sulphide" paragenesis.

Using their and other published data plus our own results we are able to classify the sulphide-bearing diamonds into peridotitic and eclogitic parageneses, each subdivided in turn into further genetic groups. Our identification of genetic groups of eclogitic diamonds was based on correlation of their internal structure, history of growth, presence of coesite inclusions, chemistry and S isotopic composition of sulphide inclusions, and C and N isotopic composition of diamonds (Table 1).

Table 1. Quantitative characteristics of Sf-bearing eclogitic diamonds.

Group	Cs	$\delta^{13}\text{C}$ ‰	$\delta^{15}\text{N}$ ‰	$\delta^{34}\text{S}$ of Sf ‰	Ni in Sf wt %	Cu in Sf wt %	Mo in Sf ppm	
1	a	no	-16 to -12	-1.3 to +3.5	+2 to +4	0.7 to 3	0.7 to 1.4	<8 to 66
	b	no data	-20 to -12	no data	-3 to +14	4.5 to 12	0.06 to 2	no data
2	a	no data	-9 to -2.8	no data	-7 to +5	0.2 to 3	0.05 to 1	no data
	b	yes	-7 to -4	-2 to -0.2	-1 to +2	3 to 12	3 to 4	60 to 300

To date we have such data for only a small collection of diamonds, but we believe the use of such complete associated information is instructive and may be more meaningful than an abundance of stand-alone analyses, taking into account the complex history of growth of diamonds and the inhomogeneous composition of sulphides. The two main groups of eclogitic diamonds are called Light $\delta^{13}\text{C}$ (group1) and Heavy $\delta^{13}\text{C}$ (group 2). These groups were then further subdivided into Low-Ni (a) and High-Ni (b), according to the Ni content in sulphide inclusions (Table 1, Fig. 1).

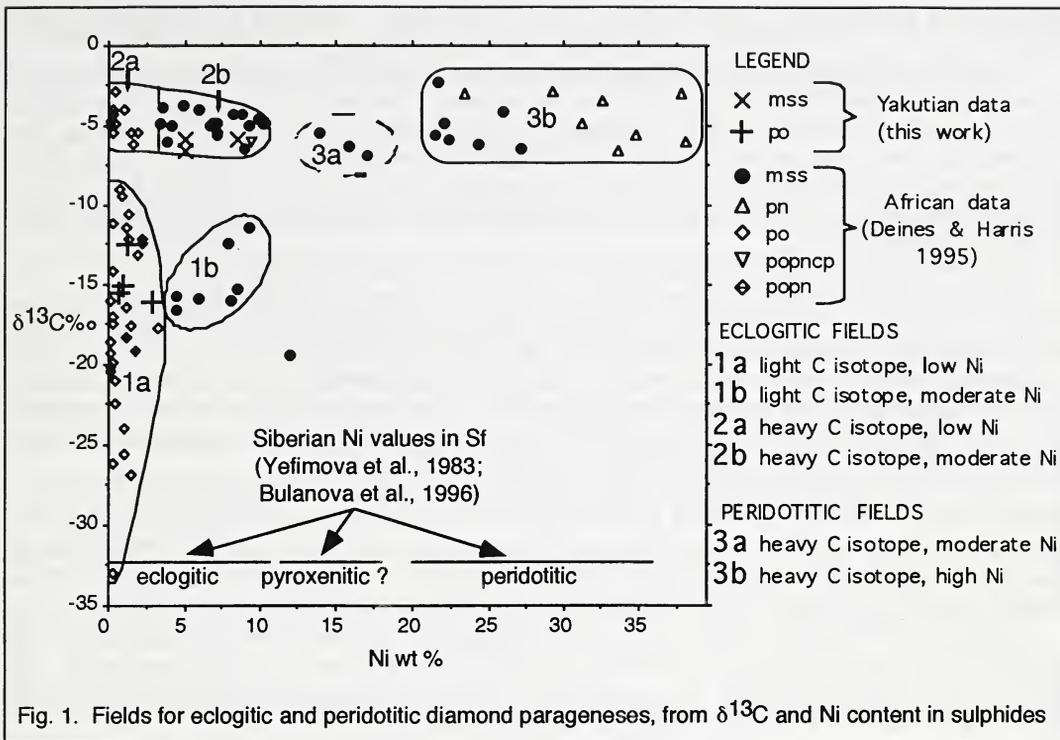


Fig. 1. Fields for eclogitic and peridotitic diamond parageneses, from $\delta^{13}\text{C}$ and Ni content in sulphides

Light $\delta^{13}\text{C}$, low Ni-Sf (Group 1a) are represented by rough-layered octahedrons having simple octahedral zonation and one stage of growth. They have homogeneous blue CL colour and were grown by tangential mechanism of growth. The diamonds show low content of N, very low N aggregation (type 1aA mainly) and no H. The diamonds do not contain Cs inclusions, have light C isotopic composition and N isotopes ranging from negative to positive values (Table 1). Numerous Sf inclusions in the diamonds are represented by pyrrhotite with low contents of Ni, Cu and Mo, and positive S isotope values (Table 1).

The majority of eclogitic diamonds and their sulphide inclusions analysed by Deines and Harris (28 from 37 with light carbon isotope composition) appear to belong to genetic Group 1a (Fig. 1). The remaining nine are richer in Ni, 5-12 wt %, and belong to Group 1b (Fig. 1). Other published data (Eldridge et al, 1991) also show predomination of the Group 1a chemistry of sulphide inclusions for eclogitic African diamonds (21 from 26). Their $\delta^{34}\text{S}$ values lie in a wider range, from -10 to +13 ‰, which is a characteristic feature of crustal sulphur, implying origin by subduction of crustal material, which is supported by the light carbon isotope composition obtained for Group 1 stones by other workers. Eldridge et al (1991) themselves did not analyse C isotopes for their diamonds.

Heavy $\delta^{13}\text{C}$, moderate Ni-Sf (Group 2b) are represented by thin layered and slightly stepped octahedrons, with complicated internal structure giving evidence of two or more stages of diamond formation. Their cores have cubic, rounded or more complex shape (intergrowths or aggregates). During late stages the growth shape changes to rough-layered and then to the thin layered octahedron. Core zones have yellow or yellow-green CL colour followed by blue CL colour for the octahedral zones. The change of CL colour and shape of growth correspond with fibrous, hummocky or mixed mechanism of growth for the seed zones and a layer by layer mechanism for the rim zones. FTIR spectroscopy shows a high or medium degree of N aggregation and presence of H in the central rounded zones, and a low content and degree of aggregation of N in the rim zones. Inclusions of Cs and K-Al-Si-phase (partly crystallised melt?) are a characteristic feature of the diamonds, providing evidence of the presence of melt (fluid) during their growth. C isotopic composition of the stones lies within the field of isotopically heavy peridotitic and eclogitic diamonds (Table 1, Fig. 1). N isotopic composition of the diamonds shows negative values. Sulphide inclusions in the diamonds are

represented by monosulphide solid solution (Mss) with moderate content of Ni, Cu and Mo, and S isotopic composition within the range from +2 to -1 $\delta^{34}\text{S}$ ‰ (Table 1).

The majority of sulphide inclusions from isotopically heavy eclogitic African diamonds analysed by Deines and Harris (1995) (18 from 30) show Ni contents in sulphides comparable to our eclogitic Group 2b (Fig 1). Nevertheless eleven of them are low Ni sulphides, which we call Group 2a. Five sulphide inclusions from data of Eldridge et al. (1993) might also belong to group 2b, because of a similar range of Ni content (3-9 wt. %) and the narrow range of $\delta^{34}\text{S}$ (from -1 till +3 ‰). These S isotope values and the heavy C isotopic composition of the diamonds suggest a mantle source, without crustal input.

Fig 1 also shows peridotitic diamond data for comparison with the eclogitic results.

Field 3b corresponds to high Ni peridotitic sulphide inclusions (22-36.6% Ni), (Bulanova et al, 1996). Field 3a represents peridotitic sulphide inclusions with medium (12-19%) Ni content, probably belonging to the pyroxenitic paragenesis (Bulanova et al, 1996).

The fields shown are in a good agreement with all previous data about C isotope composition of the two main parageneses of diamonds from kimberlites. Thus, peridotitic diamonds are isotopically heavy, and contain high-Ni sulphide inclusions having a restricted sulphur isotopic composition. There is no doubt about their mantle origin and source of C, N and S.

Eclogitic diamonds lie within the two fields of composition. Isotopically heavy eclogitic diamonds (field 2) should also have a mantle origin. The majority of sulphide inclusions in these diamonds have high content of Ni and restricted composition of $\delta^{34}\text{S}$, (Group 2b). They probably represent a paragenesis of coesite eclogites of magmatic origin. Isotopically heavy diamonds with low Ni sulphide inclusions (Group 2a) might belong to other varieties of mantle eclogites.

A mantle metamorphic process with an input of crustal material more likely formed the isotopically light diamonds (field 1) which have a wide $\delta^{34}\text{S}$ composition of sulphide inclusions. The minority of them might belong to the paragenesis of coesite eclogites (Group 1b), but most of them represent other varieties of diamondiferous eclogites (Group 1a).

Conclusions

There is a correlation of isotopic composition of diamonds with chemistry and S isotopic composition of associated sulphides. The data for Yakutian and African diamonds lie within similar compositional fields, implying similar diamond formation processes.

Sulphide inclusions in diamonds from kimberlites belong to the peridotitic or eclogitic paragenesis; there is no separate third sulphide paragenesis of diamonds.

Eclogitic diamonds in kimberlites can arise from subducted crustal material subjected to metamorphic events within the upper mantle (Group 1), or directly by igneous processes within the mantle (Group 2).

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