THE SEQUENCE OF CRYSTALLIZATION OF DIFFERENT TYPES OF BORT FROM YAKUTIAN KIMBERLITES AND THE CONDITIONS OF THEIR FORMATION

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Introduction. Polycrystalline aggregates are the assemblage of many crystals of one or a few minerals, which have been formed simultaneously or consecutively. Thus, the study of the morphology of diamond crystals forming the aggregates and their relationships with each other is a key to understanding the history and conditions of their growth. 86 samples of bort were studied: 51 from Aichal pipe, 29 from Udachnaya pipe and 6 from Mir pipe. 41 samples of diamond intergrowths have been investigated also for comparison: 20 from Aichal pipe, 19 from Udachnaya pipe and 2 from Mir pipe. The structure of aggregates, the shape of the syngenetic inclusions, their location in the volume of the aggregates were studied in the specially prepared polished sections and plates of diamond by optical methods and photoluminescence imaging. The chemistry of inclusions from different parts of the samples have been identified by electron-microprobe.

Morphology of aggregates. Bort was classified on the two main varieties: fine-grained (FGB) and coarse-grained (CGB), in dependence from the size of forming its individual diamond crystals (Smelova, 1991). FGB is formed by diamond grains of uncertain shape having the size up to 0.2 mm. The color of FGB is variable from grey to black. CGB almost always is formed by a well-shaped transparent diamond crystals (laminar octahedrons or more rare trigon-trioctahedrons, cubes and cubooctahedrons) varying in the size from 0.2 up to 2 mm. Intergrowths of diamonds (DI) are formed by octahedrons and cubes having the size up to 4 mm.

The identified order of crystallization of bort varieties is as follows: FGB→CGB forming by uncertain shape grains, sometimes containing the diamond druses→CGB forming by well-shaped diamond crystals. Aggregates of CGB usually are presented by compact drusy samples of rounded shape. Their surfaces is formed by well-shaped corners of diamond crystals. Our study of the samples consisting of the intergrowths of bort and diamond monocrystal exhibited that there are two orders of their crystallization: monocrystal→bort (Orlov, 1973), and bort→ monocrystal also (Smelova, 1994).

The different abundance of types of aggregates described above have been identified: 1) ID and CGB formed by cubes are spread in Aichal pipe only; 2) the order of formation: monocrystal→ CGB was found in the samples from Aichal also; 3) the opposite sequence of crystallization CGB→monocrystal was revealed in the samples from Udachnaya pipe.

Based on the morphological features of CGB described above, one can assume that its formation as well as monocrystals of diamonds took place in a free environment (Natural diamond..., 1993). It is confirmed by the abundance of diamond aggregates in the kimberlites. The conditions for a moving, meeting and sticking together of growing seeds are provided only in a free environment like flowing solution is, unlike the metasomatic conditions. The origin of aggregates took place in more viscosious environment, compare to the monocrystals, because the high energy of crystallization of diamond and low viscosity of environment will be the reason of the more fast migration of carbon to the more large seeds, which caused the preferable growth of monocrystals rather, then origin of the new seeds.

Compositions of the inclusions. The following minerals were identified as syngenetic inclusions in the bort and DI: peridotitic assemblage: pyrope, olivine, Cr-diopside, enstatite, magnesite,

phlogopite, chromite, magnetite, Mss, richterite, sanidine (?); eclogitic assemblage: omphacite, pyrope-almandine, rutile.

The chemistry of inclusions from bort and DI generally is the same as for the ones from diamond monocrystals, but the first have more high Fe/(Fe+Mg). Inclusions of harzburgite-dunitic paragenesis predominate in the DI, but those of lherzolitic affinity are more abundant in bort.

The abundance of two mineral assemblages in different kimberlitic pipes have been studied. All samples from Udachnaya (bort and DI) belong to peridotitic paragenesis, but those from Aichal and Mir pipes revealed an eclogitic paragenesis more often. Thus, our data are in agreement with the ones about abundance of diamond monocrystals paragenesis in the Yakutian kimberlitic pipes (Natural diamond..., 1993), which is evidence of the common origin of monocrystals and aggregates of diamonds.

Conditions of formation.
Temperature. Nontouching syngenetic inclusions from the same variety of bort or from the same individs of DI have been used for calculations. The equilibrium T° of formation of Ol-Sp mineral pairs using O'Neil-Wall geothermometer (1987) for peridotitic paragenesis is 1045°C. The same estimation for eclogitic paragenesis using the Gar-Cpx mineral inclusions (Ellis-Green,1979) is 1220-1275°C.

Besides the evolution of the T° during the time of peridotitic aggregates formation have been identified using the change of composition of sulfide inclusions (Mss) located in the different varieties of bort.. It was found that during the time of diamond aggregates growth the content of Cu in the associated inclusions of Mss from FGB is going up and those from CGB is going down. The Fe content changes in the opposite direction in agreement with isomorphic scheme: $Cu^{2+} \leftrightarrow Fe^{2+}$. According to experimental results the sulfide melt enriches by Ni and Cu and becomes more poor by Fe in the process of its crystallization. Thus the identified trend of the change of sulfide compositions may be considered as evidence of the pulsational character of T° during the formation of bort.

Pressure. The mineral pair Mag-Cpx from bort indicates the high P of its formation in the peridotitic environment, because the magnesite is a stable phase at the P=60 kbar, T=1700 K and low content of hydrogen in the system (Saxena, 1988).
The qualitative estimation of a P for eclogitic paragenesis have been done, using the dependence of pressure and the content of Ca-molecule of Escola ($Ca_{0,5}AlSi_2O_6$) in the omphacites. Its content in the omphacites from aggregates is 2,30-9,86 mol% corresponding to 60-65 kbar.

Oxygen fugacity. The presence of the syngenetic inclusions of the magnesite in the bort and diamond monocrystals as well (Natural diamond..., 1993) and the identified syngenetic inclusions of magnetite in the bort (Smelova, 1991) showing the possibility of the crystallization of diamond monocrystals and their aggregates at the QFM buffer. The association mentioned above Cpx+Mag may exist at 45 kbar and 1100°C and f_{O_2} also corresponding to QFM buffer ($\lg f_{O_2}$=-8,5) (Ryabchikov et al; 1981).
Conclusions. The summary of the above data shows the following conclusions:

1) Bort, DI and diamond monocrystals from the same kimberlitic pipes are characterized by the similar morphological features: octahedral shape is more abundant in Udachnaya and Mir samples, but cubic shape is more widely spread in Aichal ones.

2) The same range of composition is determined for associated with bort, DI and diamond monocrystals minerals.
3) The identical abundance of different paragenesis of bort, DI and diamond monocrystals in the different kimberlitic pipes is shown: The content of eclogitic paragenesis increases generally in the direction: Udachnaya - Mir - Aichal.
4) Similar range of PT conditions do exist for bort, DI and diamond monocrystals formation.

The bort, DI and diamond monocrystals were formed in the common geochemical systems and PT conditions, and the order of their origin and growth depends mainly from the degree of carbon supersaturation. The predomination of the lherzolitic paragenesis in the bort and of the harzburgite-dunitic ones in the DI indicates the preferable crystallization of diamond monocrystals and DI during the formation of mantle dunites and harzburgites, and the growth of bort in the lherzolites.

The morphology of bort is exhibited their crystallization in the free environment. It may be the silicate-sulfide melt where the diamond aggregates were grown under more high carbon supersaturation than monocrystals.

The comparison of the dunitic, harzburgitic and garnet lherzolitic melt shows the enrichment of the last by SiO_2 and Al_2O_3, testifying the high viscosity of lerzolitic melt and the low possibility of diffusion in it, which is the reason of the formation of the numerous centers of diamond nucleation and the formation of aggregates. Thus the properties of lerzolitic melt promotes the preferable origin of bort in it, and the properties of harzburgite-dunitic ones provide the condition of diamond monocrystals and DI growth.

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