IMPACT DIAMONDS: THEIR FEATURES, ORIGIN AND SIGNIFICANCE

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1. The impact diamonds have been discovered in various natural objects either of parental (meteorites and rocks of astroblems) or secondary collector (various sedimentary rocks) type. The first find of the diamonds (its origin was established later) was made by Profs. M.V.Erofeev and P.A. Lachinov in 1888 [3]. Then the diamonds were found both in another carbonaceous chondrites-ureilites and Fe meteorites. The first occurrence of the diamonds from the terrestrial astroblems was discovered in the Popigai crater in 1971 [11]; then they were found in the Ries [13] and Kara craters [4] and in some other impact sites [14]. Re-deposited impact diamonds are known from sedimentary rocks in various Regions [12 and others]. The finds in metamorphic rocks [8] seem to be the old re-deposited diamonds. The diamonds in globally-dispersed material derived from the large impact craters [15] can be selected as a special type re-deposited by impact. The so-called "colloidal" diamonds found in meteorites [9] are hardly impact ones.

2. The diamonds described (mainly 0.1-0.5 mm in size; rarely up to 1-5 mm) are colored differently: colorless, white, yellow, gray and dark-gray to black grains; yellow and dark ones are the most widespread. The yellow coloration is supposed to be connected with the lonsdaleite impurity whereas the dark one - with the impurity of graphite. The transparent and translucent grains are often anysotropic pleochroic uniaxial positive ones with the birefringence from 0.005 to 0.020, depending on the lonsdaleite impurity [14].
There are 2 main morphological types of the impact diamonds in rocks of the astroblems: (a) scaly or angular flattened (up to sheet-like) grains: (b) volume-xenomorphic grains. More rare type - in case of paramorphs along the well-crystallized parental graphite - is represented by fully or partially-outlined single lamellae hexagons or its regular accretions. In last case, hexagons are concentric to each other (twinning of parental graphite crystals along pinakoid, (0001)) or axially-turned about each other (twinning of parental graphite crystals according V.S.Veselovsky). Much more rare type is represented by diamond paramorphs along the complex graphite twinning [14]: along $(10\bar{1}0)$ and (0001) II $(10\bar{1}0)$. Togorites (diamond paramorphs on coal) have no or rarely exhibited layered or lamellae forms [4]. The diamonds.from meteorites show the irregular forms also. Sculptural elements are broadly widespread on the surface of diamond grains, being represented by various thin (down to 5-7 mkm or smaller) hatching, such as: direct parallel lines, of one to several systems; systems of curved lines; fun hatching. This hatching is well-expressed in color, luster or relief. Part of them is considered to be connected with the cracks of parental graphite; another ones are the graphite lamellae inclusions; another ones are the result of natural etching of diamonds. The diamonds from the impact crater formations exhibit the traces of etching in form of superfine surface corrosion provided by cell comb-like microrelief. Sometimes, the local seats of more intensive etching (groups of relatively large cavities and deep complex cross-cutting penetrations) are added to this surface corrosion. The etching is provided by action of alkalies in high-temperature parental impact melt.

3. By the X-ray data, the impact diamonds are polycrystalline fine-grained (crystallites of 1 - 0.1 mkm or smaller) aggregates. In common, diamond paramorphs on the graphite, found in astroblems and placers, are made up of mixture of cubic and hexagonal phases [12,14], cubic one do-

minating up to 100%, whereas hexagonal one forming an impurity (0-25%), rarely growing in content up to 50-70%. Lonsdaleite impurity is established to be greater in diamonds from small craters rather then from large astroblems, i.e., the duration of shock loading is important for the origin of this phase. The lonsdaleite impurity in togorites is low and is observed rarely. The similar low content of lonsdaleite (0-10%) is found in ureilite diamonds, originated from poorly-crystallized graphite or non-crystallized forms of carbon. On the contrary, the lonsdaleite content in diamonds from Fe meteorites (crystallized parental graphite) is more higher, up to 30%. The impurity of chaoite, a high-temperature polymorph of carbon, is established in some grains of complex (graphite + cubic diamond + lonsdaleite) composition found in astroblems [17].
All the diamonds originated from the parental graphite, exhibit the various degree of preferred orientation of crystallites, up to the degree of "monocrystal" [11,12,14 and others]. As it was first shown by [14], the new high-pressure carbon phases have the preferred orientation in respect to the parental graphite crystals, for example: $(10\bar{1}0)$ of lonsdaleite is parallel to (111) of diamond and is parallel to (0001) of graphite; etc. The preferred orientation of crystallites in togorites [4] and diamonds from some ureilites [10] is weakly-expressed or is absent at all.
The isotope composition of carbon for the diamonds from astroblems is "lightened", with $\delta^{13}C_{,PDB}$ ranging from - 0.99 % to - 2.457% [5,6,15,16], and the carbon isotopic compositions for co-existing diamonds and parental graphite grains are sometimes similar to each other. Depending on the source of carbon (graphite or coal) the terrestrial impact diamonds differ from each other not only in morphology and phase composition but also in another characteristics, such as: density (3.44 - 3.55 g/cm^3 for "graphite" diamond against 2.5 - 3.1, rarely up to 3.3 g/cm^3 for togorites), color of photoluminescence (yellow-orange or brick-red against the yellow-green or light-blue, correspondingly), impurity of paramagnetic N ($<10^{15}$ against $n10^{15}$ - 10^{20} C-centers/cm^3, correspondingly), start of combustion (580-760°C against 520-650°C, correspondingly), $\delta^{13}C_{,PDB}$ (- 0.99 - - 2.01% against - 2.275 - - 2.457%, correspondingly).

4. The preferred orientation of crystallites together with the impurity of lonsdaleite is considered to be the reliable evidence of the impact origin of the diamonds [7,10]. The transformation of parental graphite to diamond is supposed to be both by the martensitic and the diffusion way. Undoubtedly, the transition to diamond had taken place by the martensitic way for paramorphs with crystallites of preferred orientation in respect to the parental graphite. Both martensitic and diffusion ways of transformation are possible for mainly cubic diamond paramorphs without preferred orientation of crystallites. At that, the hexagonal phase should be originated first but then partially or completely annealed to cubic phase still at the shock-loaded state. For togorithes transition had probably taken place by the diffusion way at high residual temperatures. According to the pressure-release adiabats, the graphite transformation to the mixture of cubic diamond + lonsdaleite should be realized at shock pressures from 40-60 GPa (mixed-phase regime, partial transition) to more then 60 GPa (complete transition). At the usual laboratory shock-loading experiments with the duration of impulse $\sim 10^{-6}$ s the transformation of graphite to the cubic diamond has taken place since the pressures ~ 30 GPa and more [2], whereas the same transition to the cubic diamond + lonsdaleite mixture is under the pressures of more then 70 GPa [7]. At the Popigai crater (duration of shock impulse was ~ 1 s) the partial cubic + hexagonal diamond paramorphs begun to originate since the pressures of 45-50 GPa [17]. At the usual shock-loading experimental conditions (P ~ 20-100 GPa, residual temperature up to 2500°K, time $\sim 10^{-6}$ s) the impact diamonds do not originate along the non-crystallized forms of carbon, and additional pre-experiment heating is required to stimulate such a transition at the residual temperatures up to 3500°K. At the Kara crater (duration of shock impulse was ~ 0.5-0.8 s) the high-pressure poly-

morphs of carbon were possibly originated along the coal at the pressures > 60 GPa and residual temperatures < 3000°K [4,5]. At similar conditions (a long enough compression stage) the diamonds in some ureilites were possibly formed along the non-crystalline forms of carbon.The angular forms of diamond grains as well as their characteristic size (< 1 mm) should be provided by the fragmentation of source graphite due to volume decreasing at the polymorph transition. The chaoite impurity in the diamonds shows the high, > 2600°K, residual temperatures in shocked material.

5. The impact diamonds are of great petrologic, geologic and general cognitive interest. They are the evidence of shock stage of meteoritic material formation for the ureilites and a part of Fe meteorites. This stage was happened in the Universe after the silicate and metal-sulphide ones. In the Canyon-Diablo Fe meteorite the diamonds were formed by the collision of this meteorite with the Earth. In the rocks of the terrestrial astroblems the diamonds are, the important mineralogical criterion of the shock; then they are fruitfully-used for various petrologic reconstructions.
The distal ejecta deposits can be clearly revealed by the presence of impact diamonds. For example, it was made for the Popigai astroblema, whose distal ejecta were recently traced at the distance up to 500 km [15]. Such traces of globally-dispersed material from the large craters are important for the hypothesis of impact extinctions by W.Alvarez [1]. The whole rank of Phanerozoic extinctions is known represented in the Earth's sedimentary sequence by the global boundary layers of specific deposits, which are related to impacts and expressed by Ir anomalies, microtektites, grains of shocked quartz, etc. We consider, the impact diamonds are also common for these boundary layers, such as: Czech tektites-moldavites (Ries ~ 14 Ma-age event); Eocene/Oligocene Ir anomaly in Massignano cross-section, Italy (Popigai ~35 ? Ma-age event); K/T ash-layers of the Northern and Central America (Chuxulub 65 Ma-age event).
The quest for impact diamonds in West (Talitsa and Tavda serieses) and East (Lena-R. mouth and other points) Siberian Paleogenic deposits seems to be important for the next tracing of distal ejecta from the Popigai, with the perspective of reliable geological dating of this impact event in the marine continuous sedimentary sequences. Owing to their resistance, the impact diamonds can be the only evidence of the Pre-Cambrian astroblems and their distal ejecta, when all another features of shock metamorphism are completely eliminated.

REFERENCES: - 1. ALVAREZ L.W., et.al. (1980), Science, 208, 4448, 1095-1108; - 2. DE CARLI P.S., JAMIESON J.C. (1961), Science, 133, 3467, 1821; - 3. EROFEEV M.V., LACHINOV P.A. (1888), Zhurnal of Russian Phys.-Chem. Soc., 20, 3, 185-213 (in Russian); - 4. EZERSKY V.A. (1982), Meteoritika, 41, 134-140 (in Russian); - 5. EZERSKY V.A. (1987), PHD-Thesis, VSEGEI, Leningrad, 16 p. (in Russian); - 6. GALIMOV E.M. (1984), Geochimia i Cosmochimia, 27 Int. Geol. Congr., Reports, vol. 11, 110-123 (in Russian); - 7. HANNEMANN R.J., et.al. (1967), Science, 155, 3765, 995-997; - 8. HOLOVNYA S.V., et.al. (1977), Geochimia, 5, 790-793 (in Russian); - 9. LEWIS R.S., et.al. (1987), Nature, 326, 6109, 160-162; - 10. LIPSCHUTZ M.E. (1964), Science, 143, 3613, 1431-1434; - 11. MASAITIS V.L., et.al. (1972), Zapiski Vses. Mineral. Ob., 101, 1, 108-113 (in Russian); - 12. POLKANOV Ju.A., et.al. (1973), Dokladi AN Ukrainian SSR, B, 11, 989-990 (in Russian); - 13. ROST R., et.al. (1978), Dokladi AN SSSR, 241, 3, 695-698 (in Russian); - 14. VAL'TER A.A., ER'OMENKO G.K., KVASNITSA V.N., POLKANOV Ju.A. (1992), Shock-metamorphic minerals of carbon, Kiev, 172 p. (in Russian); -.15. VISHNEVSKY S.A., et.al. (1995), Abstr. to 4-th Int. Workshop IV, Ancona, May 12-18, 1995, Italy (in Press); - 16. VISHNEVSKY S.A., et.al. (1974), Abstr. submitted to the V Vses. Symp. on stable isotopes, Moscow, part 2, 160-162 (in Russian); - 17. VISHNEVSKY S.A., PAL'CHIK N.A. (1975), Geologia i Geophizika, 1, 67-75 (in Russian).