IMPACT ORIGIN of the DIAMOND-BEARING KUMDY–KOL DEPOSIT (N. KAZAKHSTAN)

#6156

L.I. Tretiakova - *St. Petersburg Branch Russian Mineralogical Society, St. Petersburg, Russia (ltretia@gmail.com)*

A.M. Lyukhin - *Institute of Remote Forecasting of Ores, LLC, Moscow, Russia (alex.lyukhin@gmail.com)*

Introduction: Any collisions of extraterrestrial bodies with the Earth leave "signatures" on the Earth surface. There are also a large number of "signatures" of the impact event, along which it is possible to trace the history of the Kumdy-Kol diamond deposit formation. The impact event was followed by prograde, retrograde metamorphism and metasomatic changes in target rocks, that became the causes of the nucleation, growth and conservation of diamonds [Tretiakova, Lyukhn, 2017a, 2017b].

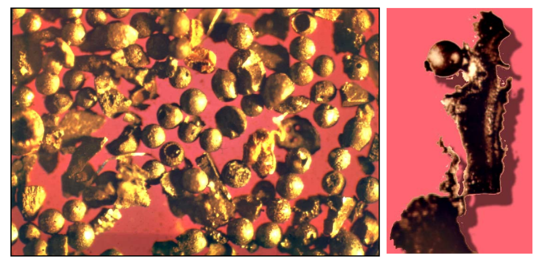


Fig. 2. Metallic spherules from the Kumdy-Kol deposit. [Zeilik, 1997]

Signatures of impact event: The main signature is **ring structure** with a diameter of ~ 3 km (**Fig. 1**), in shape and size comparable to a small impact crater [Melosh, 1989; Koeberl, 2002]. In various metamorphic rocks of the Kumdy-Kol diamond occurrence, have been identified numerous inclusions of meteoritic substance represented by **spherules**, small dump-bells, drop-like formations, flat casts, small snakes, wires and other fanciful forms brought about during the injection of melted substance of a comet into the fractures of a target's rocks (**Fig. 2**). The composition of these particles presented of a magnetite, hematite, iocite, troilite, α-iron, plessite [Zeilik, 1997].

Fig. 1. The space image of the Kumdy-Kol occurrence area. (✧ - occurrence emplacement)

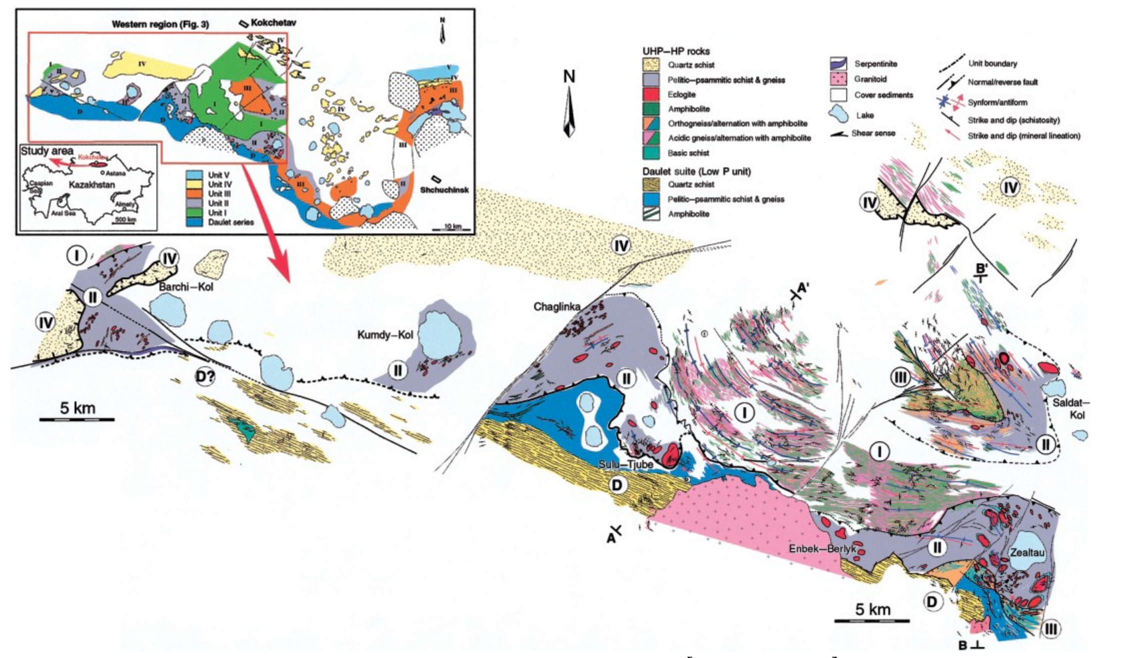


Fig. 3. Simplified geological map of Kokchetav metamorphic belt. [Kaneko, 2000]

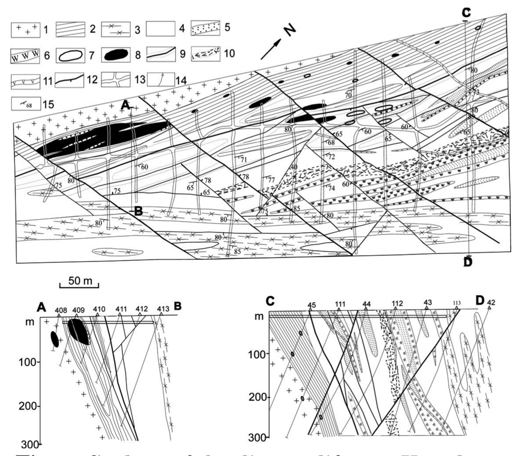


Fig. 4. Geology of the diamondiferous Kumdy-Kol zone. 1 – Granite; 2 – "Tranzition zone"; 3 – Migmatite; 4 – Biotite gneiss; 5 – Quartzose rock; 6 – Siliceous-carbonate rock; 7 – Eclogite; 8 – Garnet-pyroxene rock. 9 – related to NE-trending zones, 10 – related to the fissure zones. 11 – Dykes; 12 – Minor faults; 13 – Adit horizon; 14 – Drill holes; 15 – Strike and dip (foliation). [Pechnikov, Kaminsky. 2008b]

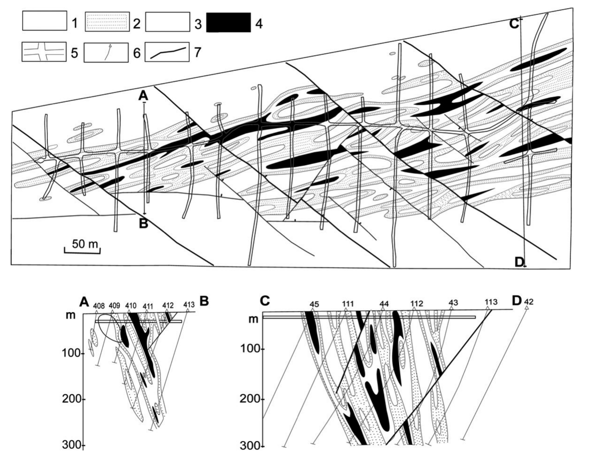


Fig. 5. Distribution of diamond content in the diamondiferous zone of the Kumdy-Kol deposit. Diamond grade (carat/ton): 1 – from 0 to 5; 2 – from 5 to 20; 3 – from 20 to 50; 4 – more than 50. 5 – Adit horizon; 6 – Drill hole; 7 – Fault. [Pechnikov, Kaminsky. 2008b]

Geological features of deposit: Features of the geological structure of the Kumdy-Kol deposit are given according to sources [Kaneko, 2000, Lavrova et al, 1999, Pechnikov, Kaminsky, 2008a, Pechnikov, Kaminsky, 2008b, Vishnevsky, 2011, Lavrova et al., 1997] (**Fig. 3 -5**).

The Precambrian basement (containing rocks of the deposit) is composed of garnet-biotite and two-mica gneisses of the Proterozoic age (~ 1900-2600 Ma) [Lavrova et al., 1997, Lavrova et al, 1999]; the age of the UHP metamorphic event, which was the cause of the changes in the rocks of diamond containing and diamond formation after impact – the Cambrian (~ 517–527 Ma), and the age of the lenses of leucocratic granites is the late Cambrian–Ordovician [Katayama, Maruyama. 2009]. **This means that gneisses were formed as a result of regional metamorphism ~ on 2 billion years earlier, and granites several million years after the formation of the ore zone of the deposit.**

Rocks of ore zone (**Fig. 4**) are represented diamondiferous metasomatically modified metamorphic rocks enriched Au, U, Ti, mainly introduced by garnet-biotite and biotite gneisses (containing graphite, sulfides, water, oxides of iron, REE) and lenses of quartz, carbonate, garnet–pyroxene rocks, altered eclogites. Diamondiferous rocks interlayered with barren, without graphite, rocks previously regionally metamorphosed to garnet-biotite gneisses or granite injectable lenses.

The diamond-bearing zone (**Fig. 4, 5**) has a complex lenticular-block structure, blocks with different rock compositions stand out overlapping, steeply dipping (angle of dip 60-80^0), a stratified body of NE strike, represented by an irregular alternation of ore (with different content of diamonds) and non-ore zones, extending in the form of a strip extending to the surface at a distance of ~ 1300 m at width ~ 40 m on the SW flank and up to ~ 250 m on the NE flank (expanding towards the Kumdy-Kol lake) and wedged out at a depth of ~ 300 m (**Fig. 4-5**) It is confined to faults NE, NNE and latitudinal strike, forming a single tectonic zone of crushing and fracturing, filled with breccia cemented by enclosing rocks with a fine-grained mass, and having blastomylonite and blastocataclasite structures [Pechnikov, Kaminsky, 2008a, b, Vishnevsky, 2011]. These metasomatic host rock zones developed at the expense of all varieties of regionally metamorphosed (amphibolite-facies) rocks with relics of UHPM mineralization, with the strongest contrast revealed in a gneissose substrate [Pechnikov, Kaminsky 2008a, b]. **The distribution of diamonds (size 10-50 μm) in rocks of the ore zone does not have clear lithological and spatial boundaries**.

The criterion for the diamondiferous of the deposit rocks is their intensive metasomatism, diamonds are found in all types of metasomatic altered rocks in the form of phenocrysts in all minerals and interstitial space of rocks. Diamonds are always confined to cracks in rocks and minerals and do not replace the previously existing mineral, but fill the voids in the microcracks of rock-forming minerals, including their epigenetic (later) varieties (**Fig. 6-9**).

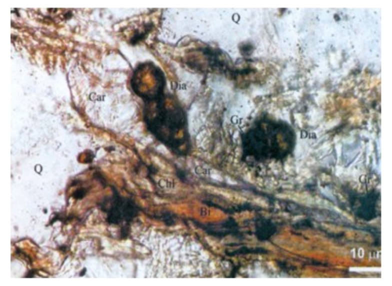
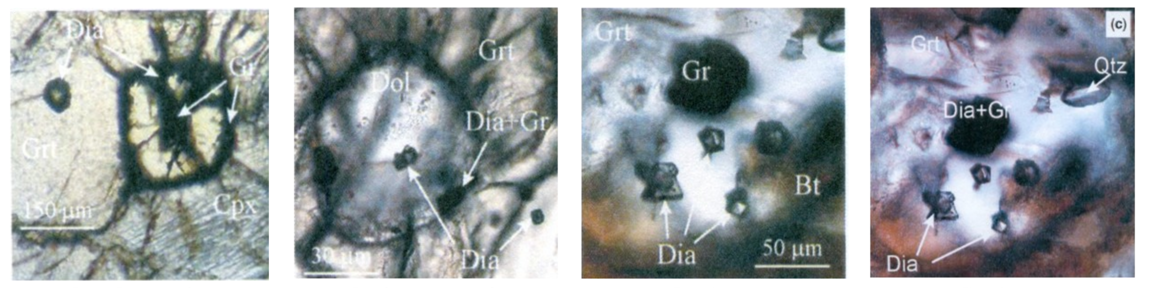


Fig. 6. Altered garnet-biotite gneiss rich in graphite and sulphide: diamond inclusion in carbonate and chlorite-sericite aggregate. [Pechnikov, Kaminsky, 2008 b]



Grt-Cpx rocks | Carbonate rock | Gneisses | Gneisses

Fig. 7. Diamonds from different lithology. [Korsakov et al., 2010]

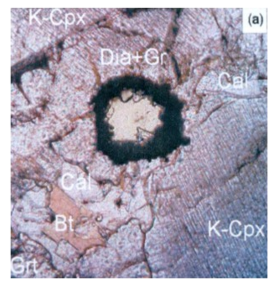


Fig. 8. Intergranular graphite-coated diamond [Korsakov et al., 2010]

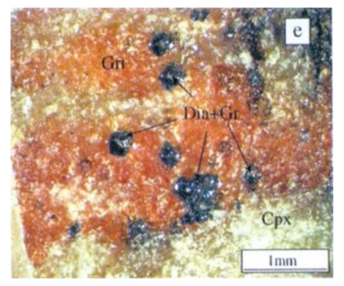


Fig. 9. Graphite-coated diamonds included in Crt-Cpx rock. [Korsakov et al., 2010]

Signatures of impact metamorphism: Collision of huge velocity comet and the Earth had been caused of rapid shock wave compression (peak of pressure > 50 GPa) and multiple complex mineral transformation, among them:

1. Presence of UHP minerals: diamond↔lonsdaleite (**Fig 10**), coesite (**Fig.11, 12**), omphacite. Microdiamond (~10-50 μm size), graphite and coesite crystals distributed within the grains of all rock-forming minerals, fractures in rocks and minerals;
2. Delivering moissanite (SiC) and graphite spheruls (**Fig.13**) (Korsakov et al., 2010), meteoritic matter: magnetite, iocite (FeO), troilite (FeS), ∝-Fe, Ni-Fe by comet;
3. Dislocation and birefringence in diamonds, planar structure in quartz, inclusions UHP minerals in rock-forming minerals (**Fig. 7, 12**).

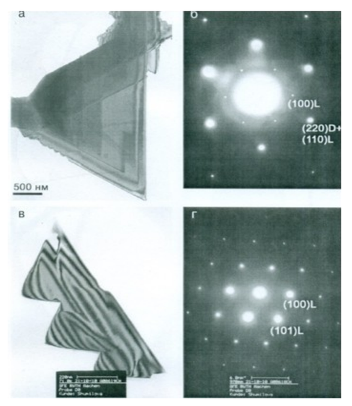


Fig. 10. Data of transmission electron microscopy of lonsdaleite from Kumdy-Kol deposit: (a) a section of a microcrystal of cubic diamond with monocrystalline lonsdaleite and a picture of its electron diffraction (б); (в) isolated monocrystalline lonsdaleite and a picture of its electron diffraction (г). [Shumilova et al., 2012]

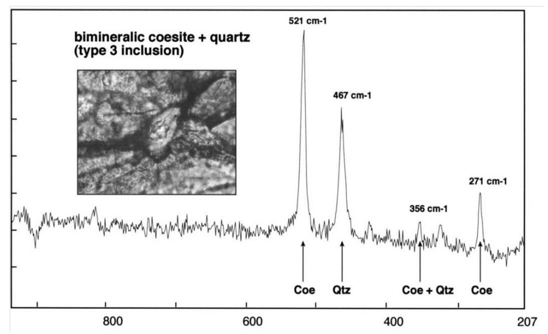


Fig 11. RS of coesite. [Parkinson, 2000]

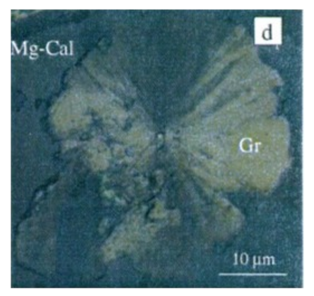


Fig. 13. Graphite spherule. [Korsakov et al., 2010]

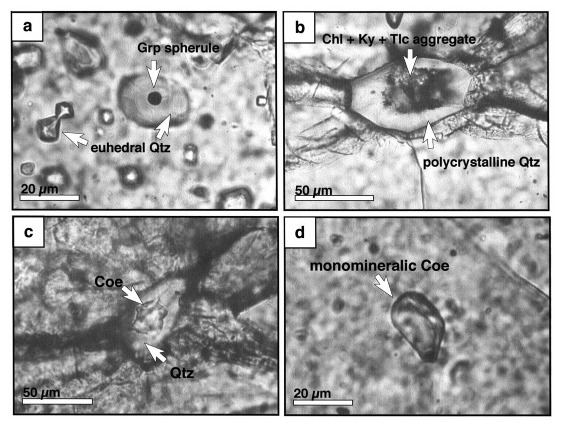


Fig. 12. Diamond and silica types (coesite and palisade, euhedral, polycrystalline quartz) inclusions in garnet. [Parkinson, 2000]

Feasible scenario of impact event: *Diamond-bearing deposit started to form on the peak of UHP metamorphism provoked by comet impact under oblique angle on the Earth surface. Comet core was consisted from chondritic matter with abundance of carbon and possible nano-diamonds, having abnormal value of noble gases (He, Ne, Ar, Xe) + IDPs (SiC, graphite and diamonds with high contents of noble gases) + carbonaceous matter presolar grains, including diamond and graphite, SiC, Si_3N_4, Al_2O_3, $MgA_{l2}O_4$, $CaAl_{12}O_{19}$, TiO_2, $Mg(Cr,Al)_2O_4$, silicates, TiC, Fe-Ni metal, noble gases and trace elements. These evaporated comet substance under high pressure was injected into previously metamorphic host rocks appeared to be impact-cosmogenic source of diamond seeds and/or nanodiamonds. Water-vapor comet cloud with H_2O, C, CH, CH_4, CN, HCN gases and fine dispersed comet core, survived during comet passing through Earth dense atmosphere, mixed with vapor and melting target rocks and produced complicated carbon saturated vapor-fluid–melt that was a source of diamond growth on carbonaceous matter seeds imported by a comet (likewise plasma-assisted CVD growth technique).*

Petrologic signatures of prograde metamorphism:

1. Specific rock minerals associations: dolomite + diopside + garnet +(aragonite) ± diamond in dolomite marble [Ogasawara et al, 2000];
2. High concentrations: Na, Ti in garnets, K, Na in clinopyroxenes, K in amphiboles, Al, Si in titanite, Al in phengite [Shatsky et al., 1995; Zhang et al., 1997];
3. Cation's exchange in shock-activated phases $2Al^{3+} \rightarrow [(Mg, Fe)^{2+}+Ti]$ or $(Ca+Al) \rightarrow (Na+Ti)$ in garnets, $Si \rightarrow (Mg^{2+} + Na + Al^{3+})$ in clinopyroxenes [Zhang & Liou, 2001];
4. Solid phase transformations in host rock minerals: lamella K-feldspar [Shertl et al., 2004] and phengite needles in diopside [Fukasawa et al., 2001, Katayama, Maruyama, 2009], quarts lamella in clinopyroxene from eclogites [Katayama et al., 2000, Katayama, Maruyama, 2009];
5. Intensive metasomatic alteration of diamond-bearing rocks. Inclusion compositions in diamonds have similarity to extraterrestrial matter. High and low pressure mineral inclusions in zoned garnets and zircons from rock-forming minerals are present [Tretiakova, Lyukhin, 2017a, 2017b].

Signatures of retrograde metamorphism: Conditions of retrograde metamorphism were created with a sharp drop in pressure and a slow rocks cooling after impact. Under these conditions, the fluid/melt supported to metasomatic alteration in target host rocks: the formation of symplectitic plagioclase+amphibole after clinopyroxene, and replacement of garnet by biotite, amphibole or plagioclase mark retrograde amphibolite facies recrystallization at 650–680°C and pressure <10 kbar; the exsolution of calcite from dolomite, and development of matrix chlorite and actinolite imply an even lower grade greenschist facies overprint at ~ 420°C and 2–3 kbar [Zhang et al., 1997]. Presence epigenetic inclusions (represented secondary minerals) in diamonds. And much more…

Carbon in the deposit ore zone: Carbon is represented by diamond, graphite, transitional forms with diamond structure, lonsdaleite, chaoit, α- and β-carbines and X-ray amorphous skeletal forms [Shumilova et al., 2001]. Morphological types of diamonds are cubes, combined forms of skeletal, rosette, spheroidal crystals, twins, aggregates consisting of idiomorphic crystals, less often octahedral. Microdiamonds are zonal (**Fig. 14**) [Korsakov et al., 2005] with narrow bands are characterized by different of N aggregation state [Nadolinny et al., 2006], cores and rims differ in morphology, C, N isotopic compositions, and have dislocations and anomalous birefringence.

Graphite is represented by single crystals, grains in diamond seeds, and replaces diamond at the final stage of diamond formation, diamonds in "shirts" of graphite (**Fig. 16-18**) [Korsakov et al., 2010], inclusions and intergrowths with diamond, sulphides and other minerals, spherules (**Fig. 2, 13**), aggregates, flakes in matrix [Shumilova et al., 2001], develops along cracks in strongly modified rocks.

Diamonds and graphite do not replace the previously existing minerals, but fill the voids and microcracks in the minerals and their interstices (**Fig. 5, 15**). Inclusions of microdiamonds in minerals and rocks are represented by single crystals, intergrowths with all rock-forming minerals, the most often formed aggregates are diamond ± graphite; diamond + apatite + Cpx; diamond + hydrated phases - phlogopite and fengite; coesite coalescence with diamond. Impurity elements in diamonds are Na, Mg, Al, Si, Sc, Ti, V, Cr, Mn, Co, Ni (**Fig. 19**), As, Sb, La, Ce, Sm, Eu, Hf, Au, To, S, H, Zn, and high concentration of nitrogen and hydrogen [Lavrova et al., 1999].

Values of diamond carbon isotope composition of $\delta^{13}C$ (–8.9 to –27‰) compare with $\delta^{13}C$ (–5 to –31‰) in meteoritic diamonds. Diamonds from various rocks are differentiated on their carbon isotopic pattern: diamonds from gneisses have lighter isotopic compositions relatively to those of pyroxene-carbonate and garnet-pyroxene rocks. Varieties of carbon modifications and its isotopic compositions suggest to discrete carbon sources. Values of graphite carbon isotope composition of $\delta^{13}C$ are lighter than those in diamonds [Pechnikov et al., 1993] that do not supported the hypothesis of transformation graphite to diamond for this deposit. **The composition of carbon matter of ore zone is comparable to that of presolar nano-diamonds** [Huss, 2005].

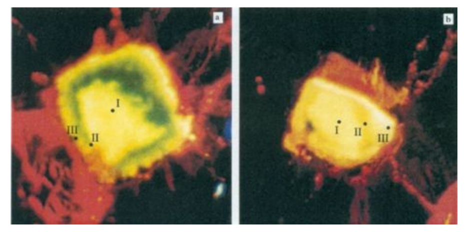


Fig. 14. Cathodeluminescence image of diamond. [Korsakov et al., 2005]

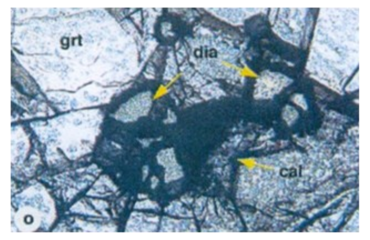


Fig. 15. Diamonds and graphite filled the voids and microcracks in the minerals and their interstices [Korsakov et al.,2010]

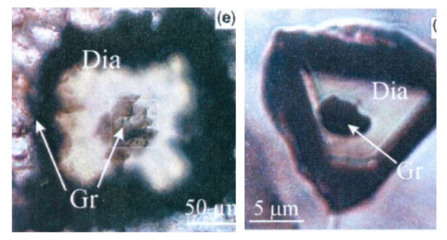


Fig. 16. Diamonds in "shirts" of graphite [Korsakov et al., 2010]

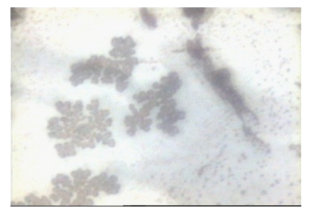


Fig.17. Graphite inclusions in diamonds .

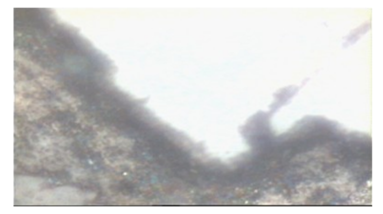


Fig.18. Core of a diamond (white) and its rim (black)

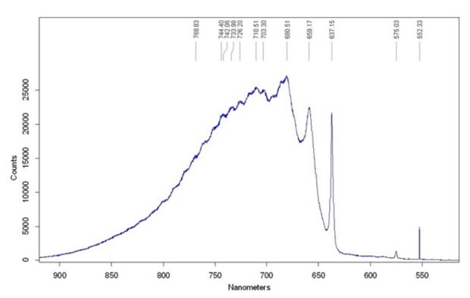


Fig.19. Ni in diamond (PLS).

Noble gases in diamonds: $^3He/^4He$ isotopic ratio ($7x10^{-1}$ до $8x10^{-9}$) of Kumdy-Kol diamonds [Shukolukov et al., 1993, 1996] is significantly higher than $^3He/^4He$ ratio of IDPs ($>10^{-4}$), Earth's atmosphere ($1.4x10^{-6}$), solar wind ($4.3x10^{-4}$), MORB-source mantle ($1.1x10^{-5}$). ^3He occurs in diamond lattice and inclusions (more abundance, then in the lattice) in diamonds [Shukolukov et al., 1996, Sumino et al., 2011], it means that ^3He was trapped by diamonds during its formation outside Solar System [Huss, 2005], presuming that ^3He more likely primordial galactic component. Ne, Ar, Xe also present in these diamonds.

Nitrogen, Hydrogen, Nickel in diamonds: Microdiamonds have high N concentration (up to 10000 ppm by mass-spectrometry data and up to 3300 ppm by IRS data) and N aggregation state Ib+IaA (Ib > IaA) [Nadolinny et al., 2006], high enriched $\delta^{15}N$ (+5.3 to + 25 ‰), high H concentration in diamonds compare with value H in coma comet gases (CN, HCN), diamonds from chondrites and presolar diamond grains. Presence of Ni-N centers in diamonds identified by PLS (**Fig. 19**). Photoluminescence spectrum (PLS) (Ar laser λ 514.5 nm) (**Fig. 19**) from section of cuboid diamond close to the cube face registered intense bands of 694, 700 and 710 nm, observed in diamond core (**Fig.17**) and rim parts (**Fig. 18**) identified as Ni-N and/or Ni-N-H defects (temperature range of these defects ~1300–2200°C) [Tretiakova, 2010]. The band 637 nm ($(NV)^-$ defect) is very strong in diamond outer zone and weak in the core, the weak band 575 nm ((NV)O defect) observed in diamond rim, both defects are characteristic of irradiated and annealed type 1b diamonds. PLS data confirm the data obtained by IRS.

Inclusions in diamonds: Protogenetic inclusions of carbon in cores of microdiamonds are represented by various carbon phases and graphite (**Fig. 16**), they are also the substance of the comet injected into the target rocks during the impact event and appear to be the seeds of diamonds. Another inclusions in diamonds are represented by oxides of Si, Ti, Fe, Cr with impurities of the trace elements: Mg, Ca, Al, K, Na, S, P, Pb, Nb, Cl, Zn, Ni, and minerals Ca-Ti-zircons, ThxOy, $BaSO_4$ [Dobrzhinetskaya et al, 2003], carbonates, silicates (**Fig. 20**) [Hwang et al., 2005, 2006], inclusions of melted glass and K-C-OH fluid with various contents of trace elements Si, Fe, Ni, Ti, Cr, Zr, Ba, Mg, Th, Na, P, S, Pb, Zn, Nb, Al, Ca, Cl. [Hwang et al. 2005], and inclusions consisting of fluid + nanodiamonds + sulfides of Fe, Co, Ni, Zn + of various rock-forming minerals, [Hwang et al. 2006, Dobrzhinetskaya et al, 2003]. All components of inclusions and trace elements are present in a carbon-rich fluid-melt.

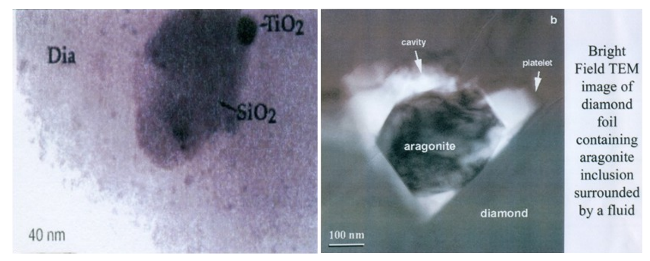


Fig. 20. Inclusions in diamonds. [Hwang et al. 2005, 2006]

So, diamond crystallization was occurred likewise plasma-assisted CVD growth technique on carbonaceous matter seeds from over saturated carbon fluid/melt. Small diamond sizes, low N aggregation state and diamond preservations suggest to short-term diamond grown process.

References: Dobrzhinetskaya et al., 2003, J.Met.Geol. 21, 5, 425-437; Fukasawa, 2001, Eleventh Annual Goldschmidt Conf. 3549 pdf; Hwang, 2005. Earth Planet Sc.Let. 231 (2005) 295–306; Hwang et al., 2006, EPSL, 231, 295-306; Huss, 2005, Element, 1, 97-100; Kaneko, 2000, Island Ark, 9, 264-283; Katayama et al., 2000, Island Arc, 9, 3, 417 – 427; Katayama, Maruyama, 2009, J. Geol. Society, 166, 783-796; Koeberl C. 1998, Mineral. Mag. 66 (5), 745-768; : Korsakov et al., 2005. Spectrochim. Acta Part A, 61, 2378 – 2385; Korsakov et al. 2010, J. Petrol., 51, 3, 763-783; Lavrova et al., 1999, Moscow, Naychnii Mir, 228 pp (in Russian); Lavrova et al., 1997, Geokhimia, 7, 675-682 (in Russian); Melosh, 1989, Impact cratering: a geological process, 245 pp; Nadolinny et al, 2006, Eur. J. Miner., 18, 738-743; Ogasawara, 2000, Island Arc, 9, 3, 400–416; Pechnikov et al., 1993, Geokhimiya, 1, 150-154 (in Russian); Pechnikov, Kaminsky, 2008a, 9IKC Ext.Abstract A-00006-2008; Pechnikov, Kaminsky, 2008b, Eur. J. Miner. 20, 395-413; Pleshakov, Shukolyukov, 1994, Noble gas Geoch.& Cosmochem., Tokyo, 1994, 229-243; Shatsky et al, 1995, In UHP metamorphism , Ed. R.G Colemann. & Xiaomin Wang. Stanford Univ., Cambridge Univ. Press. pp. 427-455; Shertl et al., 2004, Eur. J. Miner., 16, 49-57; Shukolyukov et al., 1993, Petrologia, 1, 110-119 (in Russian); Shukolyukov et al., 1996, Geokhimia, 1, 22-35 (in Russian); Sumino, 2011, EPSL, 307, 439-449; Shumilova et al., 2001, Dokladi Akad. Nauk, 378, 3, 390-393 (in Russian); Shumilova et al., 2012. Vestnic, 2, 11-13 (in Russian); Tretiakova, 2010, Acta mineral.-petrograph. abstract ser 6, 20-th General Meeting. IMA, Hungary, Abstract: 3; Tretiakova, Lyukhin, 2017a, Ural Geology J., 3 (117), 43-74 (in Russian); Tretiakova, Lyukhin, 2017b, 11IKC, Ext. Abstract, No 11IKC-4506; Vishnevsky, 2011, http://www.proza.ru/2011/12/28/522 (in Russian); Zeilik B.S., 1997, Geologia i razvedka nedr Kazakhstana, 3, 2-8 (in Russian); Zhang et al., 1997, J. Metam Geol., 15, 4, 479 – 496; Zhang, Liou, 2001, 11 Gold. Conf. 3108.