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Magmatism of the Earth and related strategic metal deposits

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The mineral deposits of strategic metals are vulnerable to political and economic changes, and their availability is essential for high-technology, green energy, and other applications. The most of they are related to the deep-seated alkaline magmas. This book offers a collection of papers presented at the 36th International Conference on “Magmatism of the Earth and Related Strategic Metal Deposits” held from May 23th to 26th 2019 in Saint Petersburg State University, Saint Petersburg, Russia. The conference articles are focused on the understanding of the geological processes that produce high concentrations of critical metals in geological systems such as the metal transport in the mantle and crust and enrichment processes, hydrothermal and metasomatic processes leading to the formation of such significant deposits. Papers in this book give a representative overview including mineralogy, geochemistry and origin of strategic metals deposits.

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The cover pictures – View down the Neva to the river between the Winter house of its Imperial Majesty and Academy of Sciences. G.A. Kachalov's engraving according to M.I. Makhayev's drawing (approx. 1750-1752).

GENESIS OF DIAMOND-BEARING ROCKS FROM THE UPPER MANTLE XENOLITHIC ASSOCIATIONS IN KIMBERLITES (BY MINERALOGIC AND EXPERIMENTAL EVIDENCE)

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Diamond-bearing peridotites, pyroxenites, eclogites and grospydites, being well-stirred with similar diamond-free bedrocks, have been revealed among the upper-mantle xenoliths in kimberlites. Nevertheless, the unaltered rock-forming minerals in the diamond-bearing and diamond-free xenoliths exhibit dissimilar compositions. On the contrary, the major minerals of the diamond-bearing rocks are of identical composition over the analogous phases included into their diamonds what is illustrated in the Table. The compositional identity for the mineral phases of diamond-hosted inclusions and rock-forming minerals of diamond-bearing xenoliths may be evaluated as the key evidence of the fact that diamonds, mineral inclusions therein, and rock-forming minerals of diamond-bearing rocks represent products of the unitary diamond-producing processes within the chamber-reservoirs of their common parental melts. The genetic scenario is in excellent agreement with the requirements of the experimentally justified syngenesis criterion regarding the compositions and physicochemical properties of the natural parental media for diamonds and their minerals included (Litvin, 2007). The syngenesis criterion provides the basis for the mantle-carbonatite theory of genesis of diamonds and associated phases (Litvin et al., 2016; Litvin, 2017). A distinguishing feature of this theory is the concordance of mineralogical analytical data and experimental physicochemical results for the multicomponent systems with nature-like boundary compositions.

The mantle-carbonatite theory substantiates that diamond-bearing ultrabasic peridotite-pyroxenite and basic eclogite-grospydite rocks have principally originated in a common parental media together with individual diamonds and their primary inclusions. The parental media represent completely miscible multicomponent silicate-(±oxide)-carbonate melts with dissolved carbon. On evidence derived from the mineralogical data (Sobolev, 1977), the natural silicate-carbonate parental melts of diamonds and their primary inclusions as well as of diamond-bearing rocks are changeable within the ultrabasic-basic compositions. By petrological information (Marakushev, 1984) and ^{13}C-isotope geochemical data (Galimov, 1991), the effect of compositional changeableness is also a characteristic feature of the upper mantle silicate magmas and diamond-free rocks. The physicochemically agreed processes of crystallization of natural diamonds and diamond-hosted mineral inclusions as well as rock-forming minerals of diamond-bearing rocks proceeded simultaneously within the upper-mantle chamber-reservoirs of the diamond-producing silicate-carbonate-carbon melts. The diamond-free bedrocks of the differentiated mantle material are the enclosing upper mantle rocks for the chambers. Hence the physicochemical conditions of petrogenesis of the diamond-bearing and diamond-free rocks with similar rock-forming minerals are different. Their combination within the upper mantle xenoliths in kimberlites has been in progress due to their transportation by kimberlitic magmas from the mantle to the Earth‘s crust depths.

Experimental study at 6 GPa of melting relations on the olivine (Ol) – diopside (Di) – jadeite (Jd) – garnet (Grt) system has revealed the peritectic reaction of olivine and jadeite-enriched melt with formation of garnet. The reaction position is schematically demonstrated as point P in the boundary Ol – Di – Jd join of the development of the Ol-Di-Jd-Grt system at the Fig. It is possible to see that the univariant curves Ol+Grt+L and Ol+Cpx+L can join together with temperature lowering in the quasi peritectic point P at 1380-1420^{o}C. During reaction in the peritectic association Ol+(Cpx/Omph)+Grt+L the Ol phase has to be disappeared and the univariant curve Omph+Grt+L, controlling formation of the basic eclogites, is formed. In the regime of fractional crystallization, these processes provide a transition from the olivine-normative compositions of the residual melts to the silica-normative ones and, correspondingly, from formation of the ultrabasic materials of the upper mantle garnet-peridotitic facies to the basic materials.

Table. Examples of the identity of mineral compositions for the diamond-hosted inclusions and diamond-bearing eclogites.

	Mir, Yakutia (Sobolev et. al., 1972)				Udachnaya, Yakutia (Shatsky et al., 2008)			
	Grt		Omph		Grt		Omph	
Oxide	Inclus	Rock	Inclus	Rock	Inclus	Rock	Inclus	Rock
SiO_2	40.00	39.70	54.80	55.50	42.35	42.40	56.27	56.40
TiO_2	0.46	0.43	0.48	0.56	0.08	0.12	0.33	0.19
Al_2O_3	22.00	21.50	9.79	9.39	23.20	23.30	4.84	4.91
Cr_2O_3	0.04	0.07	0.05	0.06	0.09	0.10	0.07	0.11
MgO	9.02	9.79	8.97	8.96	19.72	20.50	15.30	14.60
FeO	20.90	18.20	4.94	4.48	9.76	10.20	3.17	2.64
MnO	0.52	0.39	0.07	0.04	0.16	0.53	0.11	0.13
CaO	8.18	8.53	13.10	12.70	4.01	3.18	16.42	17.60
Na_2O	0.17	0.17	6.70	6.82	0.02	0.10	2.61	2.68
K_2O	-	-	0.30	0.08	-	-	0.54	0.60
Total	101.29	99.28	99.20	98.59	99.40	100.43	99.65	99.86

Comment. Inclus. – inclusion in diamond, Rock – diamond-bearing rock, Grt – garnet, Omph – omphacite.

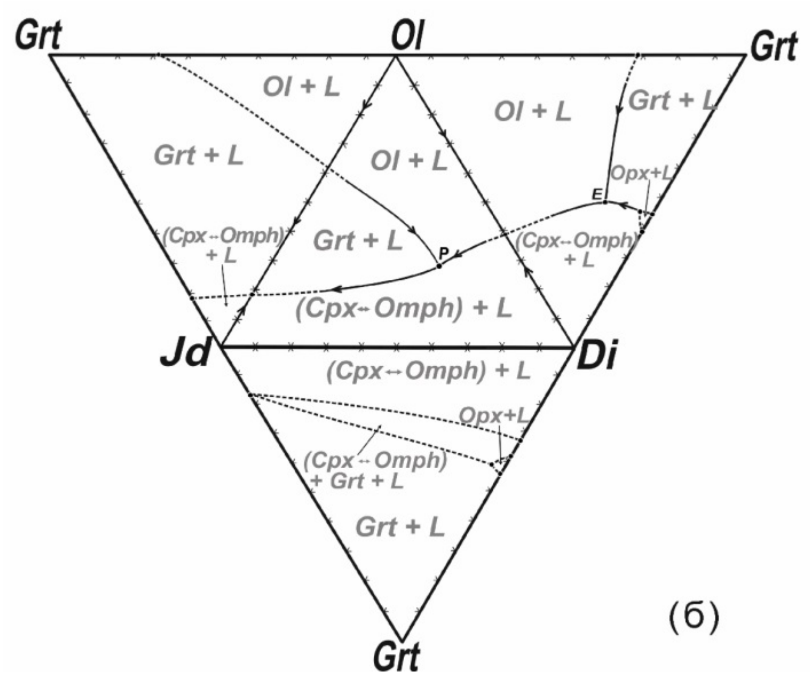

Fig. Melting relation for the boundary joins of the Ol-Di-Jd-Grt system by the relevant experimental data.

Genesis of the continuous ultrabasic-basic series of the diamond-bearing peridotite-pyroxenite-eclogite rocks contemporaneously with the diamond-hosted inclusions of peridotitic and eclogitic paragenesises has to be under control of fractional crystallization of their parental melts. The ultrabasic-basic evolution of the diamond-producing melts occurrs with elimination of olivine and orthopyroxene as the result of their peritectic reactions with melts that is revealed in physicochemical experiments. The peritectic reaction of orthopyroxene and melt is resulted in formation of clinopyroxene (Litvin, 1991). The major product of the peritectic reaction between olivine and jadeite-enriched melt is garnet. It should be pointed out that this process is well correlating with reactionary formation of pyrope in the forsterite-jadeite system above 4.5 GPa (Gasparik, Litvin, 1997).

The mechanical stirring of the diamond-bearing peridotites, pyroxenites, eclogites and grospydites with similar diamond-free bedrocks has been in progress within the streams of kimberlitic magma and locked in the crust cumulative cameras during the process of kimberlite magma solidification in them. Under this scenario, the ascending streams of kimberlite magma has destroyed the parental chambers and, inside of them, captured individual diamond crystals with primary inclusions, as well as diamond-bearing rocks, separate minerals and their intergrowths. Therewith, the kimberlite magmas have also captured the upper mantle diamond-free enclosing rocks at the magmas destructive entrance into and egress from the parental chambers. The chamber-extracted and enclosing upper mantle materials, being permanently intermixing, were transferred by kimberlitic magma to the crust cumulative cameras where the mix of genetically different diamond-bearing and diamond-free rocks were locked due to hardening of the kimberlite magma. Under the hardening processes within the cumulative cameras, the kimberlitic magmas liberate a strongly compressed fluid phase. At critical high pressure the fluid stream must force its way up through the cumulative camera roof for formation of explosive kimberlitic pipes. In the process the mechanically stirred diamond-bearing and diamond-free xenolith together with containing them kimberlite were transferred into the pipes.

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