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The Problems Revealed on a Basis of the Mantle-Carbonatite Theory of Diamond Genesis

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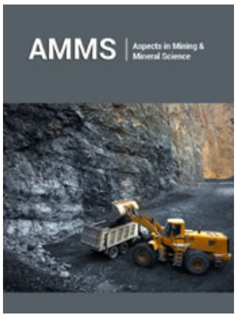

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Abstract

High-pressure experimental studies make it possible to determine the completely miscible silicate-carbonate melts with dissolved carbon as the parental media for diamonds. Physico-chemically the genesis of diamonds and associated phases is unraveled in the mantle-carbonatite theory. Its effectivity is illustrated with the experimental study at 6GPa of the diamond-forming system peridotite/eclogite-carbonate-(C-O-H-fluid). This research has resulted in the discovery of the peritectic reaction of olivine and jadeite-bearing melts with formation of garnet. Only this reaction provides an ultrabasic-basic evolution of the melts with transfer from the diamond-bearing peridotites to eclogites (in conditions of the melts fractional crystallization under the Earth's gravitation field). The mantle-carbonatite theory will also allow an understanding of the genesis of the unique Matryoshka-type diamond that is of interest as the diamond-host having a closed empty cavity inside of which the movable diamond-inclusion is revealed.

Keywords: Diamond origin; Mantle-carbonatite theory; Ultrabasic-basic evolution; Olivine peritectic reaction; Metastable graphite; Origin on unique Matryoshka-type diamond

Introduction

The mantle-carbonatite theory is substantiated with mineralogical and experimental data and reveals the physico-chemical mechanisms of genesis of diamonds and associated mineral phases at the Earth's mantle conditions [1]. Diamonds of kimberlite and lamproite deposits have been formed under PT-conditions of the upper mantle in chambers of the peridotite-carbonate and eclogite-carbonate melts-solutions of carbon with the admixture components of the (C-O-H)-fluid. The metasomatic carbonatization of the mantle minerals by CO_2-component of the ascending streams of the supercritical C-O-H-fluids is of significance in the initiation of the diamond-forming systems and their chambers (Figure 1). As a result, the carbonate melts which are dissolved the mantle silicates and generate the completely miscible silicate-carbonate melts. This carbonate and silicate-carbonate melts are very effective solvents of the mantle metastable graphite. With graphite dissolution the silicate-carbonate melts, oversaturated to diamond with carbon, are created. The melt-solution are capable of mass nucleation and crystal growth of diamonds. The ultrabasic and basic compositions of these melts-solutions of carbon must correspond to the criterium of the diamonds and inclusions syngenesis [2]: to be capable to a growth capturing by diamonds both the paragenetic and xenogenetic minerals which are detected in the natural diamonds. The main stages in the formation of diamond deposits [3-5]: [1] origin of the upper mantle chambers of silicate-carbonate-carbon melts (150-250km, 4.5-7.5GPa); [2] mass growth of diamonds with the capture of syngenetic minerals; [3] transport by kimberlite magmas of the diamonds and associated phases with formation of the cumulative chambers at the Earth's crust; [4] generating of a highly compressed gas-fluid C-O-H phase at solidification of kimberlite melts in cumulative chambers and "fluid drilling" of the solid roof; [5] formation of diamond deposits in the kimberlite explosive pipes. Here it is given a brief overview of the progress in development and application of the mantle-carbonatite theory of genesis of diamonds and associated mineral phases.

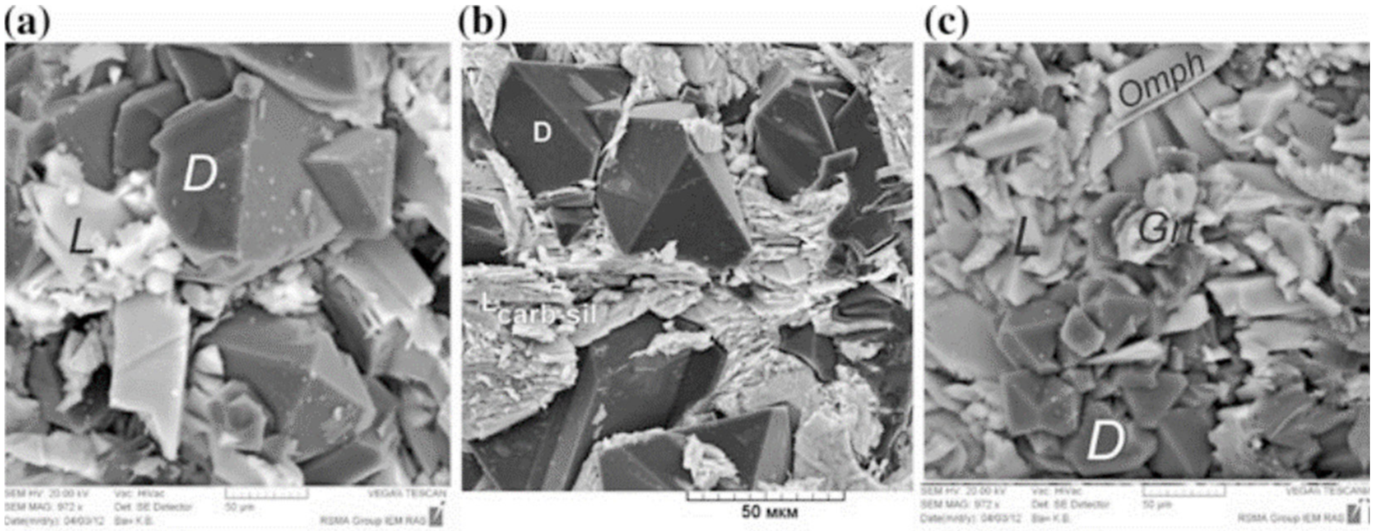

Figure 1: Experimental samples of the eclogite-carbonate system ($Ecl_{40}Carb_{60}$-C) after quenching: (a,b)- liquidus crystallization of diamond (D) where L for completely miscible clogite-carbonate melt; (c)-paragenetic crystallization of diamond with omphacite (Omph) and garnet (Grt) [1].

Garnet-Forming Olivine Peritectic Reaction

Melting relations of the diamond-forming olivine–jadeite–diopside–carbonates–(C-O-H-fluid) system are studied in experiments at 6.0GPa in the polythermal $Ol_{74}Carb_{18.5}(C\text{-}O\text{-}H)_{7.5}$-$Omp_{74}Carb_{18.5}(C\text{-}O\text{-}H)_{7.5}$ section, where $Ol=Fo_{80}Fa_{20}$, $Omp=Jd_{62}Di_{38}$ and $Carb=(MgCO_3)_{25}(FeCO_3)_{25}(CaCO_3)_{25}(Na_2CO_3)_{25}$ [3]. The peritectic reaction of olivine and jadeite-bearing melts with formation of garnet has been determined as a physico-chemical mechanism of the ultrabasic–basic evolution of the diamond-forming system [4]. During the process, the CO_2 component of the supercritical C-O-H-fluid can react with silicate components to form additional carbonates of Mg, Fe, Ca and Na (Figure 2a). The solidus temperature of the diamond-forming system is lowered to 1000–1020 °C by the joint effect of the H_2O fluid and its carbonate constituents. The experimentally recognized peritectic mechanism of the ultrabasic–basic evolution of the diamond-forming system explains the origin of associated paragenetic inclusions of peridotite and eclogite minerals in diamonds, as well as the xenoliths of diamond-bearing peridotites and eclogites of kimberlitic deposits of diamond. Diamond-forming systems have formed with the use of material from upper mantle native peridotite rocks. In this case, the capacity of the rocks to initiate the peritectic reaction of olivine was transmitted with silicate components to diamond-forming systems (Figure 2b).

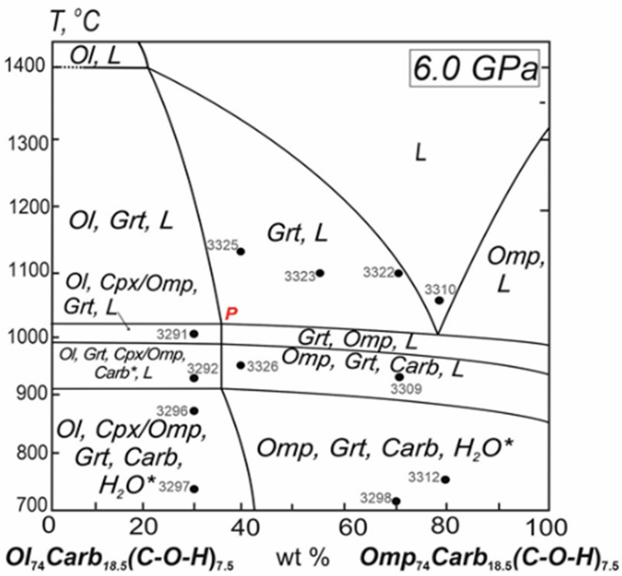

Figure 2a: Melting relations of the ultrabasic–basic diamond-forming Ol-Jd–Di–Carb–(C-O-H-fluid) system in its $Ol_{74}Carb_{18.5}(C\text{-}O\text{-}H)_{7.5}$–$Omp_{74}Carb_{18.5}(C\text{-}O\text{-}H)_{7.5}$ polythermal section at 6.0GPa. Symbols: P, peritectic point, L, melt; Ol, olivine; Fo, forsterite; Fa, fayalite; Omp, omphacite; Grt, garnet; carb, carbonates; H_2O*, supercritical water. Numbered points correspond to experimental compositions (in the table of [4]).

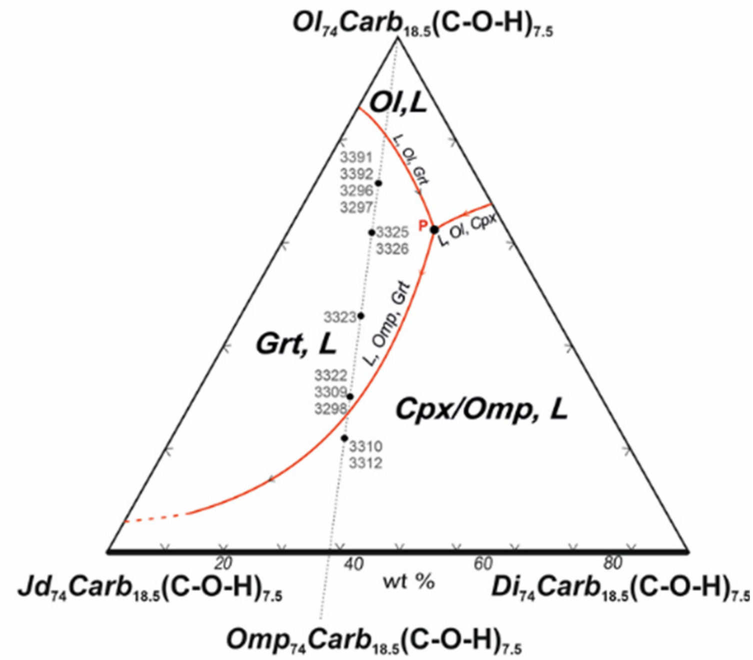

Figure 2b: The peritectic point P of the ultrabasic–basic diamond-forming olivine (Ol)–jadeite (Jd)– diopside (Di)–carbonates (Carb)-(C-O-H-fluid) system at 6GPa. The position of the polythermal section $Ol_{74}Carb_{18.5}(C\text{-}O\text{-}H)_{7.5}$ – $Omp_{74}Carb_{18.5}(C\text{-}O\text{-}H)_{7.5}$ is shown by the dotted line (symbols: L, melt; Ol, olivine; Cpx, clinopyroxene; Omp, omphacite; Grt, garnet; Carb, Mg-Fe-Ca-Na-carbonate mix. Numbered black points are experimental compositions) in the table of [4].

How Matryoska-Type Diamond is Formed

A physicochemical analysis of the genesis of a unique Matryoshka-type diamond from the Nyurbinskaya kimberlite pipe of Yakutia, Russia, was performed [5]. The specimen consists of a host diamond with a cavity containing a loose diamond inclusion; two through holes with a width of 0.1-0.4mm emerge from the cavity. As a result, the crystallization of the host diamond with a cavity and diamond inclusion under the conditions of mass genesis of diamonds in completely miscible eclogite-carbonate-carbon melts of the upper-mantle diamond-forming chamber are substantiated. The initially closed cavity was filled with a diamond-forming eclogite-carbonate melt with dissolved carbon, and, after its solidification, with Mg, Fe, Ca and Na carbonates, omphacite, garnet and coesite, as well as metastable microgranular graphite and sulfides. After millions of years, a rather rapid kimberlite capture took place in a consolidated diamond-forming chamber and the carbonate-containing substance with diamonds was transported to the Earth's crust (Figure 3). The diamond-forming substance in the cavity melted. This process was accompanied by partial dissolution of diamonds, including the host diamond and inclusions. The decrease in pressure upon the transportation resulted in the incongruent decomposition of Mg- and Fe-carbonates into oxides and CO_2 with C-O-H fluidization of kimberlite magma and assimilated matter. Two through holes were formed explosively under the conditions of significant pressure difference between the cavity of the host diamond and its surface. This was accompanied by the ejection of the parental melt from the cavity into which the C-O-H fluid-bearing kimberlite melt penetrated. The final episodes of partial dissolution of diamonds from the Matryoshka sample by kimberlite and assimilated melts continued during the formation of a cumulative chamber in the Earth's crust and its solidification with the release of a highly compressed C–O–H fluid. "Fluid drilling" of the top of the cumulative chamber stimulated the explosive formation of the Nyurbinskaya pipe and its filling with kimberlite and assimilated diamondiferous matter. With prolonged compaction of this substance, the Matryoshka diamond was subjected to atmospheric and hydrothermal factors, as is evidenced by fine-grained sedimentary barite, a mineral of barium sulphate $BaSO_4$ found in the through holes of the host diamond.

Figure 3: General view of the Matryoshka diamond sample containing a diamond inclusion with visible boundaries. Video filming by JSC ALROSA (Siberian Times 2019. Matryoshka diamond. YouTube).

Conclusion

The origin of the parental silicate-carbonate-(C-O-H)-C melts for the diamond-bearing peridotites and eclogites as well as the main stages in the formation of diamond deposits in kimberlite pipes are presented. The peritectic reaction of olivine and jadeite-bearing melts with formation of garnet has been experimentally determined at 6GPa as a physico-chemical mechanism of the fractional ultrabasic-basic evolution of the diamond-forming systems. The mechanism is responsible for the consecutive genesis of diamond-bearing peridotites and eclogites as well as of the paragenic ultrabasic and basic mineral inclusions in diamonds. The origin of the Matryoshka diamond sample is interpreted on the basis of the mantle-carbonatite theory of the formation of natural diamonds and associated paragenic and xenogenic mineral phases.

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