

Chapter 2

Mantle Rocks and Diamond-Associated Phases: Role in Diamond Origin

The components of rock-forming and accessory minerals of the upper mantle, transition zone and lower mantle rocks have been involved into the processes of diamond genesis. Through their dissolving in primary carbonate melts, the mantle minerals have turned into components of the parental silicate-(\pm oxide)-carbonate-carbon melts-solutions for diamonds and co-crystallized paragenetic minerals. The minerals newly crystallized from the melts-solutions have been fragmentarily included into diamonds commonly growing with them. Xenogenetic accessory solid and liquid phases of the mantle rocks easily penetrating into the low-viscous diamond-parental melts can also be trapped by the growing diamonds. So, the mantle petrological processes are marked by the diamond-forming episodes that is of significant importance for solution of the diamond genesis problem. Therewith, the crucial information is directly related to the origin of primary mineral inclusions in natural diamonds of the deep Earth's interiors. Realization of new lines of attack to the problem of genesis of not numerous diamond-bearing peridotites and eclogites, which were discovered together with the upper-mantle diamond-free xenoliths in kimberlites, has been made possible in the context of the mantle-carbonatite conception of genesis of diamonds and associated phases. All the above will allow an understanding of the role of minerals and rocks associated with diamonds in resolution of the principal problems of the genetic mineralogy of diamond. In the current comprehension, genesis of diamonds and associated phases have been proceeded within the detached reservoirs-chambers of diamond-parental melts inside of the enclosing them upper mantle, transition zone and lower mantle rocks.

2.1 Xenoliths of Native Upper-Mantle Rocks in Kimberlites

The mineralogical, petrological and geochemical features of differentiated rocks of the upper-mantle at the depths, where diamond is a thermodynamically stable phase, are of great concern in an investigation of genesis of diamonds and associated phases. The components of major and accessory minerals of the mantle rocks had been involved into diamond genesis through their dissolution in primary carbonate melts of metasomatic origin. The native upper-mantle rocks serve also as an enclosing matrix for the upper-mantle reservoirs-chambers of parental melts for diamonds and their syngenetic mineral inclusions. Garnet-bearing peridotites, pyroxenites, eclogites, and grospsydites, which are presented as xenoliths in kimberlites, belong to the upper-mantle garnet-peridotite facies. The upper-mantle rocks have been withdrawn by the ascending kimberlitic magmas along with products of physico-chemical activity of the diamond-producing systems in the detached reservoirs-chambers (Litvin et al. 2014) and were carried out from the depths of 150–250 km (Ringwood 1975; Sobolev 1977; Dawson 1980). The peridotitic rocks at kimberlitic pipes of South Africa (Mathias et al. 1970) are represented as garnet dunites and garnet werhlites as well as most widespread garnet lherzolites (43%), garnet harzburgites (18%), harzburgites (16%) and lherzolites (14%). The modal mineral contents for garnet lherzolites are changeable and comprise for olivine 50–75%, orthopyroxene 12–34%, clinopyroxene 1–17%, garnet 1–15% at medium compositions $Ol_{64}Opx_{27}Cpx_3Grt_6$. About the same modal mineral relations are found for the xenoliths of garnet lherzolites from kimberlitic pipes of Yakutia ($Ol_{66}Opx_{25}Cpx_3Grt_6$) (Ringwood 1975) and Lesotho ($Ol_{65}Opx_{25}Cpx_4Grt_6$) (Dawson 1980). Pyroxenitic rocks of the garnet-peridotite facies are presented by garnet- and garnet-olivine orthopyroxenites, clinopyroxenites and websterites. Among eclogites there are predominantly biminerale omphacite-garnet rocks and relatively few in number corundum-, kyanite-, coesite/quartz-, and orthopyroxene-eclogites.

Composition diagram for isoconcentric ternary section (Ol, Grt)–(Opx, Grt)–(Cpx, Grt) of the upper-mantle peridotite-pyroxenite system olivine Ol–orthopyroxene Opx–clinopyroxene Cpx–garnet Grt is shown in Fig. 2.1 as a basis for classification of ultrabasic rocks of the upper-mantle garnet-peridotite facies. The garnet-free ultrabasic peridotites and pyroxenites were classified using the ternary boundary join Ol–Opx–Cpx earlier (Streckeisen 1976).

Schematic composition diagram-complex for the upper-mantle peridotite-pyroxenite-eclogite system olivine Ol–(clinopyroxene Cpx/omphacite Omph)–corundum Crn–coesite Coe (Fig. 2.2) combines all the representative ultrabasic and basic rocks (Litvin 1991; Litvin et al. 2016). Ultrabasic and basic compositions are separated by the inner Opx–Cpx/Omph–Crn boundary plane between two ultrabasic (A, B) and three basic (C, D, E) diagrams-simplexes. The ultrabasic compositions consolidate the conjugate garnet-peridotite-pyroxenite Ol–Opx–Cpx–Grt (A) and olivine-eclogite Ol–Cpx–Grt–Crn (B) simplexes. The eclogitic simplexes

Fig. 2.1 Schematic classification for ultrabasic rocks of the garnet-peridotite facies, correspondingly, peridotites: 1 Grt-dunite, 2 Grt-harzburgite, 3 Grt-lherzolite, 4 wherlite; and pyroxenites: 5 Grt-Ol-orthopyroxene, 6 Grt-Ol-websterite, 7 Grt-Ol-clinopyroxene, 8 Grt-orthopyroxene, 9 Grt-websterite, 10 Grt-clinopyroxene. The composition boundaries are marked by ciphers in vol%

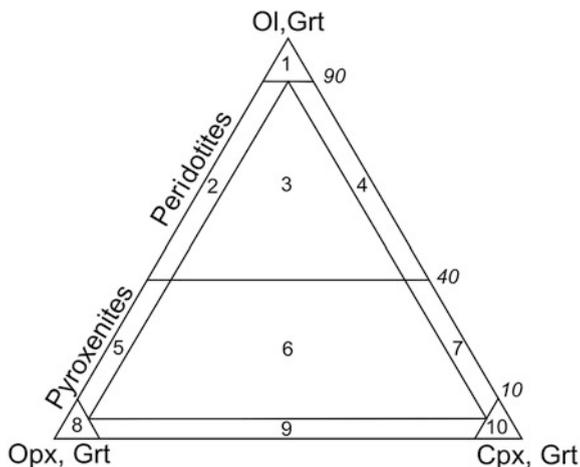
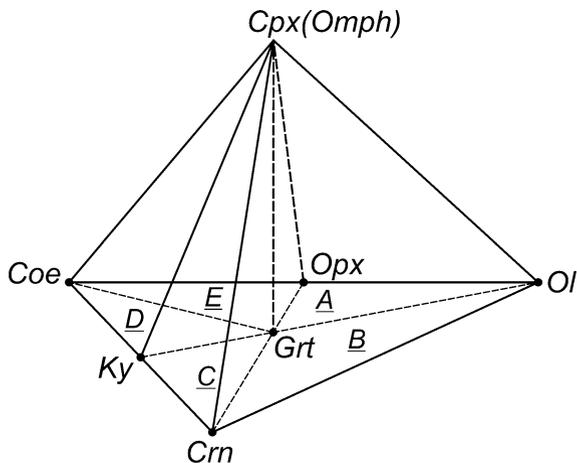


Fig. 2.2 The complex coordinate framework for ultrabasic and basic rocks of the garnet-peridotite facies, correspondingly, ultrabasic rocks: (A) peridotitic Ol-Opx-Cpx-Grt, (B) Ol-Crn-eclogitic Ol-Crn-Cpx-Grt; and basic rocks: (C) Crn-Ky-eclogitic Cr-Ky-Omph-Grt, (D) Ky-Coe-eclogitic Ky-Coe-Omph-Grt, (E) Coe-Opx-eclogitic Coe-Opx-Omph-Grt



Crn-Omph-Grt-Ky (C), Ky-Omph-Grt-Coe (D) and Coe-Omph-Grt-Opx (E) belong to the basic compositions. It should be remarked, that xenoliths of ultrabasic olivine eclogites are exceptionally rare (Dawson 1980) or missed in kimberlites (Mathias et al. 1970). At the same time, the olivine eclogites are reasonably representative for xenoliths of the less deep upper-mantle spinel-peridotite facies.

The upper-mantle peridotitic rocks have been to a variable degree differentiated and depleted with alkaline, ferriferous and other low-melting components. This was bound up with partial melting of hypothetical primary rock and redistribution of the low-melting components into the melts. As a consequence, relatively refractory restitic peridotitic rocks were occurred and carried out by kimberlitic magmas as xenoliths to the Earth's crust. This consideration was taken into account at elaboration of a pyrolite model of the undepleted chemical composition of the upper

mantle primary rock (Ringwood 1975). The xenoliths of least depleted garnet lherzolites have been also considered as the natural specimens of the upper-mantle primitive rock (Takahashi 1986).

All of the peridotite-pyroxenite conversions from garnet dunite via garnet harzburgites and lherzolites to garnet websterites, garnet oethopyroxenites and garnet clinopyroxenites are demonstrated by xenoliths of the upper-mantle rocks in kimberlites (Dawson 1980). Complete peridotite-pyroxenite modal transitions as the markers of fractional crystallization have been disclosed in the pipe Matsoku (Harte et al. 1975).

Bimineralic omphacite-garnet varieties comprise 78% and predominate among basic eclogitic rocks of the garnet-peridotite facies (Mathias et al. 1970; Dawson 1980). High aluminous corundum, kyanite and corundum-kyanite eclogites and groszpydites are reasonably representative (18%), but othopyroxene and coesite eclogites are less common (4%). The accessory minerals of the garnet-peridotite facies are Cr-spinel, coesite, sanidine, sillimanite, orthopyroxene, kyanite, corundum, rutile, ilmenite, pyrrhotite, pyrite, chalcopyrite, pentlandite, djerfisherite.

Relative proportions of xenoliths of the ultrabasic and basic upper-mantle-rocks in kimberlites of South Africa and Yakutia make it possible to establish that 95% of them are peridotitic-pyroxenitic and only 5% eclogitic (MacGregor and Carter 1970; Ringwood 1975). Xenoliths of pyroxenites dominate in the pipe Matsoku (Lethoto). The exceptions are represented by the kimberlitic pipes Roberts-Victor (South Africa) with 20% of ultrabasic and 80% of eclogitic xenoliths as well as Bobbeyan and Ritfonstein (South Africa), Orapa (Botswana), Garnet-Ridj and Mozes-Rock (USA), Zagadochnaya (Yakutia) with eclogite xenoliths predominantly or completely (Dawson 1980). The examples of a radical predominance of eclogite xenoliths over peridotite ones in the upper-mantle composition testify that both peridotites so eclogites may be served as the enclosing rocks for the reservoirs-chambers of parental melts for diamonds and associated phases.

At the complex diagram of peridotite-pyroxenite-eclogite system Ol-Cpx/Omph-Crn-Coe (Fig. 2.2), the ultrabasic peridotite-pyroxenite Ol-Opx-Cpx-Grt (A) and eclogite Ol-Cpx-Grt-Crn (B) simplexes are supplemented by the basic simplexes Crn-Omph-Grt-Ky (corundum-kyanite eclogites) (C), Ky-Omph-Grt-Coe (kyanite-coesite eclogites) (D) and Coe-Omph-Grt-Opx (coesite-orthopyroxene eclogites) (E). The high aluminous groszpydites are crucially distinguished from kyanite eclogites for a higher content (more than 50%) of the grossularite component in garnet. Eclogites are comparable with basalts by contents of their major components. On the basis of high-pressure experimental data on subsolidus transformations of basalts into eclogite, it was assumed (Yoder and Tilley 1962) that each of the main basalts type has the chemically equivalent eclogite. However it was pointed out essential difference between basalts and eclogites of the garnet-peridotite facies, which are in a noticeable content of potassium component in basalts with a negligible quantity in eclogites (Forbes 1965). Evidence that the compositions of mantle eclogites and basalts are not equivalent was repeatedly considered (Dawson 1980; Snyder et al. 1997). These features have assumed an obvious significance in the context of the problem of

origin of basic eclogite rocks of the upper mantle during differentiation of primary ultrabasic magmas generated by the primitive garnet lherzolites (pyrolites). The potentialities of these processes in the regime of fractional evolution of ultrabasic-basic magmas are supported by the smooth trends for the change in contents of characteristic components at clinopyroxenes and garnets of peridotites, pyroxenites and eclogites of the garnet peridotite facies (Sobolev 1977; Marakushev 1984). Alternatively, the subduction version of origin for eclogites of the upper mantle and the deeper mantle basic rocks from the oceanic basalts material is substantiated. A certain supporting for the subduction version was arose by idea of “eclogitic thermal barrier” (O’Hara and Yoder 1967; O’Hara 1968) evolved from experimental studies of the upper mantle systems with simplified “model” compositions. The idea is a peculiar kind of physico-chemical blockade to a possibility for ultrabasic-basic evolution of the upper-mantle magmas.

Along with this, an experimental discovery of the effect of olivine garnetization owing to its reaction with jadeite component at pressures of higher 4.5 GPa (Gasparik and Litvin 1997) makes possible to come afresh to solution of the problem of ultrabasic-basic magmatic evolution of the native silicate substance and diamond-producing silicate-(±oxide)-carbonatite melts of the upper mantle (Litvin 2012; Litvin et al. 2016).

2.2 Transition-Zone and Lower-Mantle Petrology from High-Pressure Experiments

The plausible evidence for xenoliths of native lower-mantle rocks which are accessible for analytical investigations remains unknown (Stachel et al. 2005). Discrete mineralogical data for the transition-zone substance have received in studies of chromitites from the peridotite complex Luobusa (Tibet) which had been transferred to the Earth’s surface along the boundary between Indian and Asian blocks. Inside the chromitites the primary inclusions of metamorphic microdiamonds, siliceous rutile and coesite were identified; there was also crystallographic evidence of transition-zone wadsleyite in the form of “retrograde olivine” (Satsukawa et al. 2015). Initially the data of testing experiments on phase transformations of the upper-mantle minerals under high pressure were used for evaluation of a probable lower-mantle mineral assemblage (Ringwood 1975). It has been obtained that the lower-mantle matter can be composed of periclase MgO —29, stishovite SiO_2 —22, $(\text{MgSiO}_3 \cdot \text{Al}_2\text{O}_3)_{\text{ss}}$ of ilmenite structure—24, $(\text{CaSiO}_3 \cdot \text{FeSiO}_3)_{\text{ss}}$ of perovskite structure—23, NaAlSiO_4 —2 (wt%). In this case it was allowed that the chemical composition of the primitive upper-mantle garnet peridotite may be cited as a typical representative of the whole mantle deep-seated material.

The hypothesis for isochemical composition of the primitive mantle at all depths was used as a basis for the experimental testing subsolidus phase transformations of hypothetical garnet pyrolite and natural garnet lherzolites at pressures of

25–45 GPa (Takahashi 1986; Wood 2000; Hirose 2002). It was demonstrated that wadsleyite Wd and ringwoodite Rw (both are Mg_2SiO_4 polymorphs) and majoritic garnet Maj $\text{Mg}_3(\text{Fe,Al,Si})_2(\text{SiO}_4)_3$ represent the most probable ultrabasic rock-forming minerals of the transition-zone with their contents (wt%) ($\text{Wd} \leftrightarrow \text{Rw}$)₅₇Maj₄₃ at 450–550 km depths and, respectively, $\text{Wds}_{57}\text{Maj}_{37}\text{Cpx}_6$ at 410 km border with the upper mantle and $\text{Rw}_{57}\text{Maj}_{36}\text{CaPrv}_7$ at 670 km border with the lower mantle. Therewith ferropericlase FPer (Mg,Fe)O, bridgmanite Brd (Mg,Fe) SiO_3 and Ca-perovskite CaPrv CaSiO_3 may be the rock-forming minerals of lower-mantle ultrabasic rock $\text{FPer}_{17}\text{FBrd}_{70}\text{CaPrv}_{13}$ (Akaogi 2007). Bridgmanite as a high-pressure mineral of the composition (Mg,Fe) SiO_3 takes its name in 2014 from a detection in a shocked meteorite and structural determination (Tschauer et al. 2014). Earlier bridgmanite was named as “Mg-perovskite” for as mineral inclusions inside ultra-deep diamonds so experimentally justified phases of corresponding chemical composition. It turned out that stishovite Sti SiO_2 is absent among subsolidus phases in the testing experiments with the use of ultrabasic garnet lherzolite and pyrolite compositions. This may be considered as evidence that formation in situ of stishovite does not proceed in the lower-mantle ultrabasic material.

A pressure range of the experiments includes the major seismic boundaries “upper mantle–transition zone” (410 km) and “transition zone–lower mantle” (670 km) at pressures 13–14 and 23–24 GPa, respectively. In the experiments with pyrolites it has been found that the upper-mantle rock-forming mineral may be represented by olivine (Mg,Fe) SiO_4 , orthopyroxene (Mg,Fe) SiO_3 , clinopyroxene $\text{Ca}(\text{Mg,Fe,Na})(\text{Si,Al})_2\text{O}_6$ and pyropic garnet (Mg,Fe,Ca) Si_3O_{12} with their proportions in the upper-mantle peridotite $\text{Ol}_{59}\text{Opx}_{19}\text{Cpx}_{10}\text{Grt}_{12}$ (Akaogi 2007). Olivine undergoes a polymorphic transition into the denser wadsleyite that is responsible for formation of the 410 km seismic disruption. The 520 km seismic disruption is created by the polymorphic transition of wadsleyite into ringwoodite inside the transition zone. At higher pressure, ringwoodite Rw (Mg,Fe) SiO_4 must be broken down into the assemblage of ferropericlase FPer (Mg,Fe)O and bridgmanite FBrd (Mg,Fe) SiO_3 that should determine the 670 km seismic disruption. Moreover, the conversion of ringwoodite may be responsible for more than 60 vol% petrological composition of the lower mantle.

Under the transition zone conditions, the crystal chemical reactions of the orthopyroxene and clinopyroxene components are activated during their dissolution in garnet with formation of the majoritic garnets solid solutions with the components as majoritic $\text{MgMaj Mg}_4\text{Si}_4\text{O}_{12}$ (Ringwood and Major 1971) as Na-majoritic $\text{NaMaj Na}_2\text{MgSi}_5\text{O}_{12}$ (Dymshits et al. 2010; Bobrov et al. 2011; Bobrov and Litvin 2011). Majoritic garnet together with wadsleyite \leftrightarrow ringwoodite phases within the pressure 16–17 GPa interval becomes the determining phases of the transition zone ultrabasic rocks. Within 20–26 GPa the majoritic garnet solid solutions have been experienced in phase transformations with formation and liberation of the (Mg,Fe,Al)-bridgmanite and Ca-perovskite. Hence on testing experimental data grounds, mineralogy of the lower mantle upper horizons is mainly determined by ferropericlase, bridgmanite and Ca-perovskite.

The assumed mineralogy of the transition zone and lower mantle material of a subduction origin can be arrived from experimental studies of subsolidus phase relations of the mid-ocean ridge basalts (MORB) at pressures of 25–45 GPa (Irifune and Ringwood 1993; Hirose et al. 1999; Ono et al. 2001; Akaogi 2007). As a result it was established that stishovite, Ca-perovskite, bridgmanite and aluminous phases based on $\text{Mg}_2\text{CaAl}_6\text{O}_{12}$ component (in the absence of the periclase-wustite solid solution phases) are most probable as the rock-forming minerals of the hypothetical transition-zone basic rocks. The experimental data on subsolidus transformations of the MORB basalts have drawn to a substantiation of the version that stishovite represents a subducted mineral of the transition zone and lower mantle but not a mineral capable to be formed in situ from the native material of the lower mantle. Hence the subduction mantle mineralogy is taken as an adjunct to the native in situ mineralogy of the transition zone and lower mantle. Therewith it is allowed that stishovite formation could proceed in association with ultra-deep diamonds and other minerals originated from the oceanic crust while the crust blocks have been subducted to the transition zone and lower mantle depths (Ono et al. 2001; Stachel et al. 2005; Walter et al. 2008). At the same time, it is necessary to point out the essential indicatory importance of the presence of ferropericlase and bridgmanite for the ultrabasic whereas stishovite for the basic rocks of the Earth's lower mantle.

2.3 Primary Mineral Inclusions in Upper-Mantle Diamonds

Analytical mineralogy of heterogeneous inclusions in diamonds has been turned out as the result of intense microprobe investigations (Meyer and Boyd 1972; Sobolev 1977; Navon et al. 1988; Schrauder and Navon 1994; Zedgenizov et al. 2004; Titkov et al. 2006; Logvinova et al. 2008). The generality of the growth melts for diamonds and paragenetic phases-inclusions has substantiated. A paragenetic fixation of the starting positions of diamonds and associated phases is exhibited by the primary inclusions in diamonds, diamond-bearing peridotites and eclogites, and accrete specimens of upper-mantle minerals and diamonds.

High residual pressure inside the hermetic inclusions in diamonds also points to the generality of the parental melts of diamonds and their inclusions as well as to their genesis at PT-conditions of diamond stability. The residual pressure is remained in the hermetic cameras of mineral inclusions in diamonds after their cooling to normal temperature during transportation by kimberlitic magma from the mantle depths to the Earth's crust. Diamond-formation pressures of 5–7 GPa at 1000–1400 °C were calculated from the residual pressures of 1.5–2.5 GPa which have been determined for hardened carbonatite melt multiphase inclusions with solid and liquid phases of volatile compounds (Navon 1991). The pressure of coesite entrapment by growing diamonds is estimated as 5.5 ± 0.5 GPa at 1210 °C from the residual pressure of 3.62 ± 0.18 GPa in the inclusion (Sobolev et al.

2000; Fursenko et al. 2001). Residual pressures were reported for monocrystalline graphite (Glinnemann et al. 2003) and olivine (Nestola et al. 2014; Angel et al. 2015) included in diamonds. The residual pressures within primary inclusions are unambiguously evidenced that the inclusions were trapped from the growth melts for diamonds and associated phases. Nevertheless, a paragenetic or xenogenetic origin of mineral phases inside inclusions is only possible to ascertain with the use of physico-chemical experiments. The residual pressure in inclusions allows to calculate the conditions of their entrapment, which correspond to PT-parameters of thermodynamic stability of diamond.

Chemical compositions of mineral inclusions in the natural upper-mantle diamonds demonstrate that chemically varied minerals and melts with dissolved volatiles have been trapped by the growing diamonds as the primary (syngenetic) inclusions. Among syngenetic inclusions (synchronous caption) there are disclosed as paragenetic (grown with diamond in common parental melts) so xenogenetic (outside newcomers into parental melts) mineral phases belonging to peridotite-pyroxenite and eclogite parageneses. The facts testify that diamond crystal growth have been proceeded in parental melts of extremely changeable ultrabasic and basic compositions.

Mineral inclusions in the upper-mantle diamonds demonstrate that the diamond-parental media are compositionally highly variable, with respect to the major silicate-oxide components especially. Among the basic mineral inclusions, omphacite Omph and garnet Grt of eclogitic paragenesis are most abundant whereas corundum Crn, kyanite Ky, coesite Coe and orthopyroxene Opx are rare in occurrence. Olivine Ol, orthopyroxene Opx, clinopyroxene Cpx, garnet Grt, Cr-spinel CrSpl inclusions belong to peridotitic paragenesis. Accessory assemblages include magnetite Mag, ilmenite Ilm, rutile Rt, zircon Zrn, chromite Chr as well as pseudomorphs of quartz Qtz and phlogopite over coesite and olivine, respectively. Sulfide minerals pyrrhotite Po, pentlandite Pn, pyrite Py, chalcopyrite Cpy, Cu-Fe-Ni-monosulfide solid solutions Mss belong to the abundant inclusions in diamonds whereas djerfisherite Dj is rare. It can be seen that diamond-hosted minerals are analogous to the rock-forming and characteristic accessory mineral phases of the native peridotite-pyroxenite and eclogite rocks of the upper mantle. Carbonate minerals magnesite Mgs, dolomite Dol, siderite Sd, calcite Cal (as a polymorphic product of aragonite Arg) are not common (Schrauder and Navon 1994; Wang et al. 1996; Stachel et al. 1998; Titkov et al. 2006). Native metals iron Fe^0 and alloys of iron with Cr and Ni $FeNi^0$ as well as moissanite Mois SiC are rare in occurrence (Sobolev et al. 1981; Leung et al. 1990, 1996; Mathez et al. 1995).

The multicomponent heterogeneous inclusions in diamonds of silicate-carbonate substance with volatile compounds (Schrauder and Navon 1994; Izraeli et al. 1998, 2001; Logvinova et al. 2003; Navon et al. 2003; Klein-BenDavid et al. 2003, 2006, 2007a, b; Zedgenizov et al. 2004, 2009, 2011) adequately characterize the solidified products of the major components and phases for the diamond-producing parental melts. Investigations of a variety of phases included in diamonds makes it possible to establish that these inclusions represent oxide, silicate, carbonate, phosphate apatite Ap, sulfide, chloride, carbide, native metal micro-minerals and

rarely-occurred silicate-carbonate (carbonatitic) hardened melts. The inclusions occasionally contain the solitary phases of volatile components CO₂, CH₄, H₂O and K-Na-chloride-water brines. The silicate-carbonate substances of inclusions in Botswanian diamonds have approximated by two boundary carbonatic and silicic compositions (Schrauder and Navon 1994). There also were calculated the average compositions of the alkaline-chloride-water brines included into diamonds of the Kofffontein pipe (Izraeli et al. 2001). Compositionally similar inclusions of the hardened melts are occasionally observed in association with the primary inclusions of peridotite and eclogite minerals (Izraeli et al. 1998; Logvinova et al. 2003). It is significant that the hardened melts were turned out to be similar to the inclusions in diamonds together with as the P-type (peridotitic) so the E-type (eclogitic) minerals. Studying the inclusions of the probable hardened silicate-carbonate melts led to a cautious suggestion that the melts were trapped by the growing diamonds and would constitute the carbon-bearing melt-solutions from which diamonds were able to crystallize (Navon 1999). Hardened Fe-Ni-sulfide melts have discovered as inclusions in diamonds together with the hardened carbonatite melts and peridotite minerals (Klein-BenDavid et al. 2003).

Paragenetic with diamond minerals of peridotites and eclogites that crystallized from the growth melts could be trapped together with the completely miscible silicate-carbonate-carbon parental melts (Litvin 2007, 2012). With this the growing diamonds have a chance of trapping xenogenetic sulfide and titaniferous ilmenite Ilm and rutile Rt melts which are completely immiscible with carbonatitic growth melts. The trapping of inclusions has been came to the end by their hermetization with growing layers and subsequent hardening the growth melts under cooling of the diamond-producing mantle reservoirs-chambers. Xenogenetic sulfide melts have also been hardened. Volatile components have been emitted from hardening carbonatite melts and could create the gas phases and alkaline-chloride-water brines. By this means a complete dissoluble state of the volatile components in diamond-parental melts-solutions but existence of own volatile phases inside the hardened parental melts materials in the diamond-hosted inclusions.

Thus, primary mineral inclusions in the upper-mantle diamonds belong to the peridotite-pyroxenite (olivine, orthopyroxene, clinopyroxene, garnet, spinel, Mg-Fe ilmenite, etc.) and eclogite-grospydite (omphacitic clinopyroxene Omph, garnet Grt, chromite Chr, ilmenite Ilm, sanidine Sa, corundum Crn, kyanite Ky, coesite/quartz Coe/Qtz, rutile Rt, etc.) assemblages. In fact, the mineralogical data characterize the bulk composition of the medium parental for diamond and syngenetic inclusions as the multicomponent system MgO-CaO-FeO (Fe, Fe₂O₃)-MnO-NiO (Ni)-Na₂O-K₂O-Al₂O₃-Cr₂O₃-(Cr)-TiO₂-ZrO₂-SiO₂-P₂O₅-CuS (Cu₂S)-FeS (FeS₂)-NiS-KCl-NaCl-SiC-Fe₃C-CO₂ (CO, CH₄)-H₂O-C. Wide variability of chemical and phase compositions of the parental media ranging from peridotite with modal olivine to eclogite with modal coesite, kyanite, and corundum is one of its main features. The carbonatite component of the parental media is also variable, primarily with respect to its alkalinity (Schrauder and Navon 1994). The components and phases of volatile compounds are also diverse (Izraeli et al. 2001). It has been established that the substances of primary inclusions in diamonds are

derivatives of separate mantle media, and this circumstance comes into conflict with the assumption that primary inclusions are products of the direct entrapment of fragments of the upper-mantle peridotites and eclogites by growing diamonds (Sobolev 1977; Taylor and Anand 2004; Spetsius and Taylor 2008). To all appearances, the mantle peridotite is the main source of silicate components of parental media at the initial stage of their formation with participation of alkaline C–O–H-bearing metasomatic agents (Litvin 1998).

Mineralogical methods cannot establish genetic relationships between diamond and mineral phases initially entrapped therein, and thus an unbiased and reliable chemical mode of diamond formation in the natural multicomponent heterogeneous medium cannot be proved. Diamond crystallization in silicate (Williams 1932), metallic (Wentorf and Bovenkerk 1961), carbonate (Von Eckermann 1967), sulfide (Marx 1972), or C–O–H volatile (Haggerty 1986) growth media were suggested, but none of these suggestions deduced from mineralogical evidence has given rise to a reliable solution. Almost all of the substances pertaining to the heterogeneous multicomponent parental medium were assumed to be a possible diamond-bearing media. The diamond-forming capability of mantle melts and genetic relationships between mineral phases of natural diamond-producing systems can only be established by physico-chemical experiments at high pressure and temperature. The testing experiment is the most important at the initial stage of experimental research concerned with diamond origin.

2.4 Primary Mineral Inclusions in Transition-Zone and Lower-Mantle Diamonds

Diagnostics of mineral inclusions for the asthenosphere and transition zone derived diamonds is essentially complicated due to a reversible polymorphism of wadsleyite Wd and ringwoodite Rw, both of $(\text{Mg,Fe})_2\text{SiO}_4$ composition, with the formation of “retrograde” olivine. Also, low-Ca clinopyroxenes transform into orthopyroxenes due to temperature lowering during transportation of diamonds from their mantle reservoirs-chambers to the Earth’s crust. All this is conditioned by the diminution of diamond and inclusion thermal expansion and corresponding pressure reduction within the hermetic cameras with inclusions. At high-pressure experiments with the pyrolytic compositions (Akaogi and Akimoto 1979) it has been determined that the contents of Al_2O_3 higher than 0.3 wt% in wadsleyite and the more in ringwoodite are the indications which allow to bring them in correlation with the transition zone mineralogy. The transition zone majoritic garnets are also disequibrated and partially transformed into the assemblage of garnet and pyroxene under the upper mantle conditions. The exsolution of pyroxene from majoritic garnet has been evidenced in the inclusion in diamond and at the majorite-bearing rock (Bobrov and Litvin 2011). Nevertheless the inclusions of majorite garnets in diamonds may only be operable as acceptable indicators of the genesis of diamond and associated

phases under conditions of the transition zone (Stachel et al. 2000a, b; Stachel 2001). Their compositions are not sufficiently differ from the lithospheric eclogitic and asthenospheric majoritic garnets, with the exception of elevated siliceosity, the tendency for increase at contents of Na and Ti components and decrease at concentration of Fe components.

Identification of the transition zone majoritic garnets from inclusions in the deep mantle derived diamonds has been made possible by the barometric effect which is caused by near-linear increasing of the excess-Si content in garnets within 7–15 GPa interval at 1200 °C. This effect is demonstrated when experimental results (Akaogi and Akimoto 1979; Irifune 1987; Gasparik 2002) and mineralogical data for inclusions in diamonds of the Monastery and Jagersfontein pipes (South Africa), the placers of the regions of Kankan (Guinea) and Juina (Brazil), and some others sources has been composed (Stachel et al. 2005).

Experimental studies at 6–20 GPa and 1800–2100 °C of the system pyrope—Na-majorite (Dymshits et al. 2010; Bobrov and Litvin 2011) made possible to synthesize Na-bearing majoritic garnets which composition is characterized with a regular increase of the Na-majoritic component $\text{Na}_2\text{MgSi}_5\text{O}_{12}$ from 5 mol% at 8 GPa up to 32–38 mol% at 20 GPa. These results are in agreement with the data of experimental investigation of the system forsterite–jadeite up to 22 GPa (Gasparik and Litvin 1997) which allow to reveal the effect of forsterite garnetization during the reaction of forsterite and jadeite components at pressures higher 4.5 GPa. Moreover, the high contents of Na-majorite component up to 40 mol% have determined in the resultant garnets at 22 GPa. The thermobarometric properties of the Na-majoritic garnet solid solutions have made an identification of the transition-zone majoritic garnets by Na_2O contents (Bobrov and Litvin 2011). The majoritic garnets of the transition zone ultrabasic rocks can be distinguishing by a high content of Cr_2O_3 (up to 14 wt%). The concentration of earths in majoritic garnets distinguishes markedly them from the mid-ocean basalts enriched with the light rare elements and C–O–H–N volatile components (Palot et al. 2014).

Determination of mineral inclusions inside the lower mantle ultra-deep diamonds is relatively more simply from the fact that their chemical and structural peculiarities would be basically conserved during transportation to the Earth's crust. Ultrabasic primary inclusions in the lower-mantle diamonds are presented by periclase-wustite solid solution phases FPer $(\text{MgO}\cdot\text{FeO})_{\text{ss}}$, bridgmanite FBrd $(\text{Mg, Fe})\text{SiO}_3$, and Ca-perovskite CaSiO_3 CaPrv (Harte and Harris 1994; Stachel et al. 2000a, b, 2005; Kaminsky et al. 2001; Zedgenizov et al. 2014). The phases included in super-deep diamonds are analogous to the anticipated major rock-forming minerals of the lower-mantle rocks which have justified by experimental transformation of the upper-mantle garnet lherzolites or hypothetic pyrolites (Akaogi 2007). Inclusions of ferropericlase as separate grains less than 1 mm or intergrowths with bridgmanite and Ca-perovskite are the most frequent. An important marker for belonging of other minerals to ultrabasic lower-mantle assemblage is their syngensis with ferropericlase and (Mg, Fe) -bridgmanite in super-deep diamond-hosted inclusions. Among these minerals is tetragonal almandine-pyrope phase $(\text{Mg, Fe})(\text{Al, Cr, Mn})_2(\text{Mg, Fe}^{3+})_2\text{Si}_3\text{O}_{12}$ (TAPP) (Kaminsky

2012). Along with this, it was noticed (Stachel et al. 2005) that the TAPP phases are chemically different as compared with the common peridotitic garnets by the nearly complete absence of Ca-components at their composition (less than 0.1 wt% CaO). Besides, the TAPP density is less than that measured for garnet under the lower mantle conditions. All this permits to suggest that the TAPP mineral is a “retrograde” phase stabilized at influence of the high ratio $\text{Fe}^{3+}/\text{Fe}^{2+}$ during diamonds transfer over the transition zone depths. In this case it may be demonstrative the TAPP samples within inclusions of diamonds from the Kankan alluvial deposits (Guinea). The unit grains of titaniferous Ca-perovskites associated with ilmenite, non-identified Si–Mg-phase and majoritic garnet have discovered as inclusions in diamonds from the Juina placers (Brazil) (Kaminsky et al. 2001). The main admixture in the majoritic garnet composition is presented by Na-component at a typical concentration of 0.27–1.12 wt% Na_2O (Kaminsky 2012). The majoritic garnets may appear among mineral association of most upper horizons of the lower mantle that is well consistent with experimental data on their stability (Irifune and Ringwood 1993). The inclusions with compositions of olivine, magnetite, titanite Ttn, picroilmenite Pilm and manganoilmenite, spinel and Cr-spinel, as well as sulfides bornite Bn, violarite Vio and heazlewoodite Hz, carbides chalipite Chal and cogenite Cog, native iron, nickel and alloy haxonite Hax are also referred to the ultrabasic lower-mantle association.

It is paradoxical that the basic mineral stishovite SiO_2 from inclusions in the lower-mantle diamonds from the kimberlite pipes and ancient placers of Juina (Brazil), Kankan (Guinea), Slave (Canada) and Koffifontein pipe (South Africa) is in an intimate association with the phases of periclase-wustite solid solutions $(\text{MgO}\cdot\text{FeO})_{\text{ss}}$ (Hayman et al. 2005; Harte 2010; Kaminsky 2012). The assemblage of stishovite with ferropericlase and bridgmanite in common inclusion is not infrequent. The complex bimineral inclusions in the forms of intimate paragenetic intergrowths of stishovite and phases of peridotite-wustite solid solutions have been discovered. The paragenetic association of stishovite SiO_2 and ferropericlase $(\text{Mg}, \text{Fe})\text{O}$, which is definitely the lower mantle in situ mineral, is obviously indicative that stishovite is also the lower-mantle in situ phase (as in the case of ultradeep diamonds with inclusions of these minerals).

The paragenetic coexistence of stishovite and mineral phases of periclase-wustite solid solutions $(\text{MgO}\cdot\text{FeO})_{\text{ss}}$ in hermetical inclusions within the lower-mantle diamonds put down to the effect of “stishovite paradox” (Litvin 2014). The major consideration is in that an origination of the paradoxical paragenetic assemblage $\text{SiO}_2 + (\text{MgO}\cdot\text{FeO})_{\text{ss}}$ is inherent of stishovite exclusively. In contradiction to stishovite, the other lower-pressure SiO_2 polymorphs quartz and coesite can react with the MgO and FeO oxides with the formation of stable intermediate compounds —enstatite MgSiO_3 and ferrosilite FeSiO_3 as well as their continuous solid solutions $(\text{MgSiO}_3\cdot\text{FeSiO}_3)_{\text{ss}}$ under PT-conditions of the Earth’s crust, upper mantle and transition zone. For this reason, the association of quartz (coesite) and (Mg, Fe) -oxides is believed to be “under a ban” for the conditions of the Earth’s crust and upper mantle.

A ferriferosity of the periclase-wustite solid solution phases inside inclusions in the lower mantle ultradeep diamonds is variable over a wide range ($fe = 0.10\text{--}0.64$). The ferriferosity values for the lower mantle plausible composition are bound to be within $fe = 0.12\text{--}0.27$ on experimental and rating assessments (Wood 2000; Lee et al. 2004). Inasmuch as it is reasoned that the native lower mantle minerals have been included into diamond, the obvious inconsistency of this sort was explained by the subsolidus reaction of bridgmanite decomposition to ferriferous phase of the periclase-wustite solid solutions $(MgO\cdot FeO)_{ss}$ and SiO_2 (Fei et al. 1996). Most probably, a large ferriferosity change for periclase-wustite mineral inclusions paragenetic to diamond-hosts can result from the fractional ultrabasic-basic evolution of grown melts which are parental for diamonds and associated phases. As this takes place under the lower mantle conditions, a paradoxical assemblage of Mg-Fe-oxides and stishovite SiO_2 is formed as the result of the physico-chemical mechanism of “stishovite paradox” (Litvin 2014). This is agreed with existence of the unlimited periclase-wustite solid solutions in the MgO-FeO system at the lower mantle pressures.

Stishovite together with (Mg,Fe,Al)-bridgmanite and Ca-Na-perovskite should be related to basic inclusions in the lower mantle diamonds taking into account the experimental subsolidus transformations of the mid-oceanic basalts (Akaogi 2007). Their belonging to the basic in situ association of mineral inclusions in the lower-mantle diamonds may be established with the use of the definite typomorphic indicators (apart from their paragenetic association with stishovite). For the basic bridgmanites it may be a relatively higher content of Al_2O_3 which is close to 10 wt % by comparison to the less than 3 wt% Al_2O_3 for the ultrabasic bridgmanites (Stachel et al. 2005), that is commensurable to the real values of 8.3–12.6 wt% Al_2O_3 for the bridgmanite inclusions in diamonds of the Sao-Luis alluvial placers (Brazil) (Harte et al. 1999). The (Mg,Fe,Al)-bridgmanites are characterized by elevated ferriferosity. This is also consistent with the data of experimental studies at 24–26.5 GPa on subsolidus garnet-to-bridgmanite reaction in the system $MgSiO_3\text{--}Mg_3Al_2Si_3O_{12}$ (Irifune et al. 1996). The reaction is resulted in formation of bridgmanite enriched in Al_2O_3 and applicable to simulation of the compositional relationship over the boundary between the transition zone and lower mantle. At the same time, the Al_2O_3 content in Ca-perovskites are notably low (0.01–0.66 wt% Al_2O_3) for both ultrabasic and basic Ca-perovskites from inclusions in the lower mantle diamonds. The positive Eu-anomaly which is supposedly related to the basic association (Kaminsky 2012) has been detected within the rare earths distribution patterns for some inclusions. The Ca-perovskites with relatively elevated contents of Na- and K-components, magnesiowustites $(Fe,Mg)O$ and aluminous phase “Egg” of $AlSiO_3\cdot OH$ composition may be assigned to the basic paragenesis. Hence the primary inclusions in the lower-mantle diamonds testify that not only ultrabasic but also basic stishovite-bearing associations have been involved into the in situ diamond-producing processes. The primary inclusions make also it apparent that the ultrabasic-basic evolution of the lower-mantle “ultradeep” diamonds is the realistic natural process. This conclusion may be carried over the transition-zone growth melts for diamonds and associated phases.

The combined and mutually complementary data of analytic mineralogy of primary inclusions in diamonds and results of physico-chemical experimental studies on the diamond-producing systems give sufficient proof of the concept of physico-chemically similar mechanisms which are responsible for genesis of diamonds and associated phases at all mantle depths. The obtained conclusions are contradictory to alternate hypotheses on the subduction transfer of the basic oceanic crust, including the ultradeep diamond-producing components, into the ultrabasic lower mantle. The primary inclusions of variable carbonate minerals especially aragonite Arg CaCO_3 , dolomite $\text{Ca}(\text{Mg,Fe})(\text{CO}_3)_2$ Dol, nyererite Nyer $\text{Na}_2\text{Ca}(\text{CO}_3)_2$, nahkolite Nah NaHCO_3 in the transition zone and lower mantle ultradeep diamonds (Brenker et al. 2010; Stagno et al. 2011; Kaminsky 2012) are symptomatic as the crystallization products of the multicomponent oxide-silicate-carbonate-carbon parental melts for diamonds and heterogeneous primary inclusions. This circumstance makes it possible to attack the problem of ultradeep diamonds origin within the framework of the mantle-carbonatite concept of diamond genesis (Litvin 2007, 2009, 2013; Litvin et al. 2012, 2014).

2.5 Xenoliths of Diamond-Bearing Rocks in Kimberlites

Highly differentiated ultrabasic peridotite-pyroxenite and basic eclogite-grosopydite rocks are presented as the upper-mantle xenoliths in kimberlitic pipes of South Africa, Yakutia, Australia, Northern America, the northern European region of Russia and other provinces. In the main, the xenolithic rocks are diamond-free but occasionally diamond-bearing peridotites, pyroxenites, eclogites, and grosopydites have occurred among them. Diamond-bearing basic rocks in 1–2 order dominate over the ultrabasic ones. Thereto the peridotitic rocks dunites and harzburgites prevail over lherzolites, pyroxenitic garnet websterites over verhlites, and eclogitic bimineral variety over corundum, kyanite, coesite eclogites and grosopydites. The weight for a majority of diamond-bearing xenoliths is about 50–70 g. The greatest samples are eclogites from kimberlite pipes Roberts Victor, South Africa (8.6 kg) (Jacob and Jagoutz 1994), Udachnaya, Yakutia (6.9 kg) (Shatsky et al. 2008) and 8.8 kg (Stepanov et al. 2007, 2008).

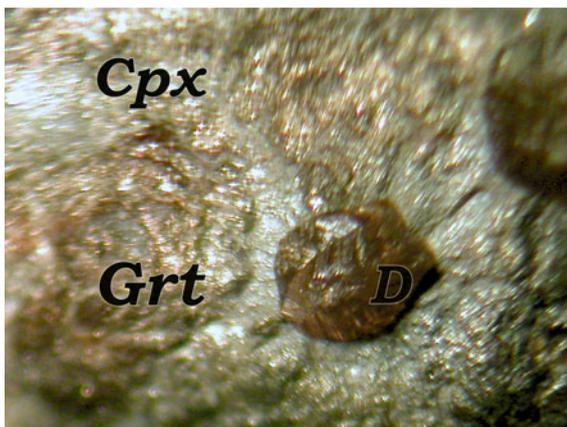
Serpentinized diamond-bearing peridotites have been found in kimberlitic pipe Aikhal, Yakutia (Sobolev et al. 1969). The rock-forming garnets demonstrate high Cr_2O_3 , moderate CaO contents and low ferriferosity (14.3 wt%) that is completely identical to the garnets from inclusions in diamonds (Sobolev 1977). Later on, the xenolith of diamond-bearing peridotites with retaining olivine were disclosed including dunite (Ilupin et al. 1982), harzburgite (Logvinova et al. 2005), lherzolites (Griffin et al. 1993; Barashkov and Zudin 1997 Sobolev et al. 2008, 2009) and pyroxenite (Ponomarenko et al. 1980). It was also reported about investigations of the diamond-bearing peridotites xenoliths from the craton Slave, Canada (Creighton et al. 2008; Aulbach et al. 2011), pipes Finch, Roberts Victor and Premier, South Africa (Dawson and Smith 1975; Viljoen et al. 1992, 1994, 2004), Southern

Wyoming, USA (McCallum and Eggler 1976) and Udachnaya pipe, Yakutia (Logvinova et al. 2015).

Historically, the first finds of diamond-bearing rocks are represented by two xenoliths of eclogites with two and ten diamond crystals over its surfaces from the diamond-bearing pipe Newlands, Griqualand-West, South Africa (Bonney 1899, 1900). These samples are kept on deposit at the mineralogic museum of the Mining Academy in Freiburg (#№ 001508) and in the Natural History Museum in London (№ 84661), respectively. Later on, it was stated that diamond-bearing eclogites are found in the pipes Crown, Djagerfontein, Roberts Victor, Premier, and repeatedly in Newlands, South Africa (Corstophine 1908; Wagner 1909, 1928; Holmes and Paneth 1936; Williams 1932). The sample of diamond-bearing eclogite rock is shown in the Fig. 2.3. Numerous diamond crystals and polycrystalline intergrowth of 80 diamond grains in a reasonably large-sized xenolith of diamond-bearing eclogite have been disclosed (Bartoshinsky 1960) as well as “eclogitic” composition of ferrous garnet was first determined (Bobriyevich et al. 1959). Thereafter it has repeatedly reported of the new finds and investigations of diamond-bearing eclogites (Rickwood et al. 1969; Sobolev 1977; Spetsius and Taylor 2008; Sobolev et al. 2008; Taylor et al. 2000). Diamond-bearing corundum eclogites, coesite eclogites, grosspydites have been found in kimberlites of South Africa and Yakutia (Sobolev and Kuznetsova 1965; Davidson 1967; Dawson 1968; Gurney et al. 1969; Switzer and Melson 1969; Rickwood and Mathias 1970; MacGregor and Carter 1970; Sobolev et al. 1974; Ponomarenko et al. 1976; Pokhilenko et al. 1982). Most of them was presented in the xenolith association of the Roberts Victor pipe that is a rare exception among kimberlitic pipes because of essential predominance of the diamond-free eclogitic xenoliths (more than 90 vol%) over the peridotitic ones.

Investigation of omphacite and garnes compositions from inclusions in diamond of diamond-bearing eclogite in a comparison with the compositions of rock-forming eclogitic minerals is extremely significant (Sobolev et al. 1972). The resulting data testifies that the minerals included in diamond, on the one hand, and the

Fig. 2.3 Diamond-bearing eclogite



rock-forming minerals of the enclosing diamond-bearing eclogite, on the other hand, have closely analogous compositions and are typical for eclogite rocks. The FeO content in garnet from inclusion is somewhat higher than for the rock-forming eclogite but the K₂O content in omphacite from inclusion is considerably above than at the rock-forming omphacite. Most likely the original mineral compositions inside the hermetic inclusions is kept constant, whereas the eclogitic rock-forming minerals having most probably the same initial composition could partially change the FeO and K₂O contents in their open contacts to the transporting kimberlitic magmas with the volatile compounds. The K₂O content of omphacite in inclusion may be a marker of the K-component elevated concentration in the silicate-carbonate growth media of diamonds and associated mineral phases. This is in a good agreement with variable compositions of the hardened K-rich silicate-carbonatitic diamond-parental media of the fragmentary inclusions in Botswanian diamonds (Schrauder and Navon 1994) with the high diamond-forming efficiency which has been experimentally established (Litvin and Zharikov 1999, 2000). The role of the high-potassium growth melts for the upper-mantle origin of diamonds and associated phases has taken into account at the mantle-carbonatite concept of diamond genesis (Litvin 2012, 2013). The practical coincidence of garnets and omphacites chemical compositions in the case of the diamond-included and rock-forming eclogitic minerals is particularly remarkable fact. The coincidence is demonstrative in that the both rock-forming and diamond-hosted minerals are belonging to the overall mineral generation which phases have been originated in association with diamonds at their common silicate-carbonate parental melts with dissolved carbon.

A number of typomorphic indications of the diamond-bearing rocks and their rock-forming minerals allow to distinguish them from the native diamond-free rocks of the upper mantle. It was stated (Sobolev 1977) that garnets of the diamond-bearing peridotites have characterized with higher Cr₂O₃ and lessened CaO content in distinction to their diamond-free analogues. A similar behavior of Cr₂O₃ and CaO components is typical for garnet inclusions in diamonds as well as for the paragenetic accretions of peridotitic garnets with diamonds. Compared to the upper-mantle diamond-free eclogite rocks, garnets of the diamond-bearing eclogitic mineral assemblages are of higher Na₂O content (0.10–0.22 wt%) due to an admixed Na-majoritic component Na₂MgSi₅O₁₂ (Bobrov et al. 2011; Bobrov and Litvin 2011; Dymshits et al. 2013). A compositional resemblance of mineral inclusions in diamonds with rock-forming minerals of the diamond-bearing peridotites and eclogites is extremely significant. The typomorphic features are basically confirmed in the example of the rock-forming minerals and diamond-hosted mineral inclusions without the profound secondary alterations (Taylor and Anand 2004; Shatsky et al. 2008; Spetsius and Taylor 2008).

The diamond-bearing peridotites, pyroxenites, and eclogites have essential distinctions in compositions and origin by comparison with the native diamond-free differentiated ultrabasic-basic rocks of the garnet peridotite facies.

At all times mineralogical analyses of diamond-associated rocks, minerals and volatiles has been accompanied by the attempts to discern the natural chemical conditions of diamond formation. Disclosure in 1897 of first diamond-bearing

eclogites in south-African kimberlitic pipes gave rise to consider eclogitic magma as the diamond-parental medium (Bonney 1899). Speculations about potential diamond-producing silicate peridotitic and eclogitic magmas can be followed to till recently (Williams 1932; Meyer and Boyd 1972; Sobolev 1977; Marakushev and Bobrov 1998; Taylor and Anand 2004). The presumption of silicate diamond-parental chemistry was based on modal similarity of rock-forming minerals of upper-mantle peridotitic and eclogitic rocks with silicate phases of diamond-hosted inclusions. Much attention is given to kimberlitic version of diamond-parental magma (Sobolev 1960) due to the visible diamondiferousness of kimberlites that was actually happened as a consequence of diamonds capturing by kimberlitic magmas in transportation them from parental chambers to the crust pipes. The “brain attack” was also led to the versions of sulfide (Marx 1972), carbonatite (Von Eckermann 1967), C–O–H–fluid (Haggerty 1986), metallic (Wentorf and Bovenkerk 1961) diamond-forming natural media. But no one of the versions is beneath criticism because diamond-forming efficiency of these substances at melting cannot be detected by any one of analytical mineralogical methods. Moreover, diamond-forming efficiency of melts-solutions for all these and some other materials was disclosed in testing syntheses of diamonds. It was found that melts of some alkaline silicates, chlorides, and fluid phases of water and carbon dioxide are also effective. But all the tested materials associated with natural diamond do not match the requirements of the syngensis criterium for diamonds and paragenetic phases.

References

- Akaogi M (2007) Phase transitions of minerals in the transition zone and upper part of the lower mantle In: Ohtani E (ed) *Advances in high-pressure mineralogy*, Geological Society of America Special Paper 421, pp 1–13. doi:10.1130/2007.2421(01)
- Akaogi M, Akimoto S (1979) High-pressure phase equilibria in a garnet lherzolite, with special reference to Mg^{2+} – Fe^{2+} partitioning among constituent minerals. *Phys Earth Planet Inter* 19:31–51
- Angel RJ, Alvaro M, Nestola F, Mazzucchelli MI (2015) Diamond thermoelastic properties and implications for determining the pressure of formation of diamond-inclusion systems. *Russ Geol Geophys* 56(1–2):208–220
- Aulbach S, Stachel T, Heaman LM, Carlson JA (2011) Microxenoliths from the Slave craton: archives of diamond formation along fluid conduits. *Lithos* 126:419–434
- Barashkov YP, Zudin NG (1997) Composition of garnets with diamond inclusions from kimberlite pipe Krasnopresnenskaya (Yakutia). *Geol Geofiz* 38(2):353–357
- Bartoshinsky ZV (1960) On diamonds from eclogites of the kimberlitic pipe Mir. *Geol Geofiz* 6:129–131
- Bobriyevich AP, Bondarenko MN, Gnevushev MA et al (1959) *Diamond deposits of Yakutia*. Gosgeoltechizdat, Moscow
- Bobrov AV, Litvin YA (2009) Peridotite-eclogite-carbonatite systems at 7.0–8.5 GPa: concentration barrier of diamond nucleation and syngensis of its silicate and carbonate inclusions. *Russ Geol Geophys* 50(12):1221–1233

- Bobrov AV, Litvin YA (2011) Mineral equilibria of diamond-forming carbonate-silicate systems. *Geochem Int* 49(13):1–97
- Bobrov AV, Litvin YA, Dymshits AM (2011) Experimental studies of mantle carbonate–silicate systems and problem of the diamond formation. *GEOS, Moscow*, p 208
- Bonney TG (1899) The parent rock of the diamond in South Africa. *Geol Mag* 6:309–321
- Bonney TG (1900) Additional notes on boulders and other rock specimen from the Newlands Diamond Mines, Griqualand-West. *Proc R Soc Lond* 67:475–484
- Brenker FE, Vollmer C, Vincze L et al (2010) Carbonates from the lower part of transition zone or even the lower mantle. *Earth Planet Sci Lett* 260:1–9. doi:[10.1016/j.epsl.2007.02.038](https://doi.org/10.1016/j.epsl.2007.02.038)
- Corstophine GS (1908) The occurrence in kimberlite of garnet-pyroxene nodules carrying diamonds. *Trans Geol Soc S Afr* 10
- Creighton S, Stachel T, McLean H et al (2008) Diamondiferous peridotitic microxenolith from the Diavik Diamond Mine, NT. *Contrib Miner Petrol* 155:541–554
- Davidson CF (1967) The so-called “cognate xenoliths” of kimberlite. In: Wyllie PJ (ed) *The ultramafic and related rocks*. New York, pp 269–278
- Dawson JB (1968) Recent researches on kimberlite and diamond geology. *Econ Geol* 63(5): 504–511
- Dawson JB (1980) *Kimberlites and their xenoliths*. Springer, Berlin
- Dawson JB, Smith JV (1975) Occurrence of diamond in a mica-garnet lherzolite xenoliths from kimberlite. *Nature* 254:580–581
- Dymshits AM, Bobrov AV, Litasov KD et al (2010) Experimental study of the pyroxene-garnet phase transition in the $\text{Na}_2\text{MgSi}_5\text{O}_{12}$ system at pressures of 13–20 GPa: first synthesis of sodium majorite. *Dokl Earth Sci* 434(1):1263–1266
- Dymshits AM, Bobrov AV, Bindi L et al (2013) Na-bearing majoritic garnet in the $\text{Na}_2\text{MgSi}_5\text{O}_{12}$ – $\text{Mg}_3\text{Al}_2\text{Si}_3\text{O}_{12}$ join at 11–20 GPa: phase relations, structural peculiarities and solid solutions. *Geochim Cosmochim Acta* 105(1):13. doi:[10.1016/j.gsa.2012.11.032](https://doi.org/10.1016/j.gsa.2012.11.032)
- Fei Y, Wang Y, Finger LW (1996) Maximum solubility of FeO in $(\text{Mg}, \text{Fe})\text{SiO}_2$ perovskite as a function of temperature at 26 GPa: implication for FeO content in the lower mantle. *J Geophys Res* 101(B5):11525–11530
- Forbes RB (1965) The comparative chemical composition of eclogite and basalts. *J Geophys Res* 70:1515–1521
- Fursenko BA, Goryanov SB, Sobolev NV (2001) High pressures in coesite inclusions in diamond: combination scattering spectroscopy. *Dokl Earth Sci* 379:812–815
- Gasparik T (2002) Stability of $\text{Na}_2\text{Mg}_2\text{Si}_2\text{O}_7$ and melting relations on the forsterite-jadeite join at pressures up to 22 GPa. *Eur J Miner* 9(2):311–326
- Gasparik T, Litvin YuA (1997) Stability of $\text{Na}_2\text{Mg}_2\text{Si}_2\text{O}_7$ and melting relations in the forsterite-jadeite join at pressures up to 22 GPa. *Eur J Mineral* 9:311–326
- Glinnemann J, Kusaka K, Harris JW (2003) Oriented graphite single-crystal inclusions in diamond. *Z Kristallogr* 218:733–739
- Griffin WL, Sobolev NV, Ryan CG et al (1993) Trace elements in garnets and chromites: diamond formation in the Siberian lithosphere. *Lithos* 29:235–256
- Gurney JJ, Siebert JC, Whitefield GG (1969) A diamondiferous eclogite from the Roberts Victor mine. In: *Upper mantle project*. Geological Society of South Africa Special Publication 2, pp 351–357
- Haggerty SE (1986) Diamond genesis in a multiply-constrained model. *Nature* 520:34–38
- Harte B (2010) Diamond formation in the deep mantle: the record of mineral inclusions and their distribution in relation to mantle dehydration zones. *Mineral Mag* 74(2):189–215
- Harte B, Harris JW (1994) Lower mantle mineral association preserved in diamonds. *Mineral Mag* 58A:384–385
- Harte B, Cox KG, Gurney JJ (1975) Petrography and geological history of upper mantle xenoliths from the Matsoku kimberlite pipe. *Phys Chem Earth* 9:477–506

- Harte B, Harris JW, Hutchison MT et al (1999) Lower mantle mineral association in diamonds from Sao Luiz, Brazil. In: Fei Y, Bertka CM, Mysen BO (eds) *Mantle petrology: field observations and high pressure experimentation: a tribute to Francis R. (Joe) Boyd*. Geochemical Society Special Publication 6, pp 125–153
- Hayman PC, Kopylova MG, Kaminsky FV (2005) Lower mantle diamonds from Rio Soriso (Juina area, Mato Grosso, Brazil). *Contrib Mineral Petrol* 149:430–445
- Hirose K (2002) Phase transitions in pyrolytic mantle around 670-km depth: Implications for upwelling of plumes from the lower mantle. *J Geophys Res* 107. doi:[10.1029/2001JB000597](https://doi.org/10.1029/2001JB000597)
- Hirose K, Fei Y, Ono S et al (1999) The fate of subducted basaltic crust in the Earth's lower mantle. *Nature* 397:53–56. doi:[10.1038/16225](https://doi.org/10.1038/16225)
- Holmes A, Paneth FA (1936) Helium ratios of rocks minerals from the diamond pipes of South Africa. *Proc Royal Soc Lond A* 154:385–413
- Ilupin IP, Yefimova ES, Sobolev NV et al (1982) Inclusions in diamond from diamond-bearing dunite. *Dokl Acad Nauk SSSR* 264(2):454–456
- Irifune T (1987) An experimental investigation of the pyroxene-garnet transformation in a pyrolite composition and its bearing on the constitution of the mantle. *Phys Earth Planet Inter* 45: 324–336
- Irifune T, Ringwood AE (1993) Phase transformations in subducted oceanic crust and buoyancy relationships at depths of 600–800 km in the mantle. *Earth Planet Sci Lett* 117:101–110. doi:[10.1016/0012-821X\(93\)90120-X](https://doi.org/10.1016/0012-821X(93)90120-X)
- Irifune T, Koizume T, Ando J (1996) An experimental study on the garnet-perovskite transformation in the system $MgSiO_3$ – $Mg_3Al_2Si_3O_{12}$. *Phys Earth Planet Inter* 96:147–157. doi:[10.1016/0031-9201\(96\)03147-0](https://doi.org/10.1016/0031-9201(96)03147-0)
- Izraeli ES, Schrauder M, Navon O (1998) On the connection between fluid and mineral inclusions in diamonds. In: VII International Kimberlite Conference Extended Abstracts, Cape Town, p. 352–354
- Izraeli ES, Harris JH, Navon O (2001) Brine inclusions in diamonds: A new upper mantle fluid. *Earth Planet Sci Lett* 187:323–332. doi:[10.1016/S0012-821X\(01\)00291-6](https://doi.org/10.1016/S0012-821X(01)00291-6)
- Jacob D., Jagoutz E (1994) A diamond-graphite bearing xenolith from Robbers Victor (South Africa): indications from petrogenesis from Pb-, Nb-, and Sr-isotopes. In: Meyer HOA, Leonardos OH (eds) *Kimberlites, Related rocks and Mantle Xenoliths*. Special Publication 1A-CPRM, p. 304–317
- Kaminsky F (2012) Mineralogy of the lower mantle: a review of 'super-deep' mineral inclusions in diamond. *Earth Sci Rev* 110:127–147. doi:[10.1016/earscirev.2011.10.005](https://doi.org/10.1016/earscirev.2011.10.005)
- Kaminsky FV, Zakharchenko OD, Davies R et al (2001) Superdeep diamonds from the Juina area, Mato Grosso State, Brazil. *Contrib Mineral Petrol* 140:734–753
- Klein-BenDavid O, Logvinova AM, Izraeli ES et al (2003) Sulfide melt inclusions in Yubileinyan (Yakutia) diamonds. In: 8th International kimberlite conference extended abstracts, p 111
- Klein-BenDavid O, Wirth R, Navon O (2006) TEM imaging and analysis of microinclusions in diamonds: a close look at diamond-growing fluids. *Am Mineral* 91(2–3):353–365
- Klein-BenDavid O, Izraeli FS, Hauri I, Navon O (2007a) Mantle fluid evolution—a tale of one diamond. *Lithos* 77:243–253
- Klein-BenDavid O, Izraeli FS, Hauri I, Navon O (2007b) Fluid inclusions in diamonds from the Diavik mine, Canada and the evolution of diamond-forming fluids. *Geochim Cosmochim Acta* 71(3):723–744
- Lee KKM, O'Neil B, Panero WR et al (2004) Equation of state of the high-pressure phases of a natural peridotite and implications for the Earth's lower mantle. *Earth Planet Sci Lett* 223(3–4):381–393
- Leung IS, Guo W, Friedman I, Gleason J (1990) Natural occurrence of silicon carbide in diamondiferous kimberlite from Fuxian. *Nature* 346:352–354. doi:[10.1038/346352a0](https://doi.org/10.1038/346352a0)
- Leung IS, Taylor LA, Tsao CS, Han Z (1996) SiC in diamond and kimberlites: implications for nucleation and growth of diamond. *Int Geol Rev* 37:483–496
- Litvin YA (1991) Physicochemical studies of melting in the earth's interior. Nauka, Moscow, p 312

- Litvin YA (1998) Hot spots of the mantle and experiment to 10 GPa: alkaline reactions, lithosphere carbonatization, and new diamond-generating systems. *Russ Geol Geophys* 39(12):1761–1767
- Litvin YA (2007) High-pressure mineralogy of diamond genesis. In: Ohtani E (ed) *Advances in high-pressure mineralogy*. Geological Society of America Special Paper 421, pp 83–103. doi:[10.1130/2007.2421\(06\)](https://doi.org/10.1130/2007.2421(06))
- Litvin YuA (2009) The physicochemical conditions of diamond formation in the mantle matter: experimental studies. *Russ Geol Geophys* 50(12):1188–1200
- Litvin YA (2012) Physico-chemical formation conditions of natural diamond deduced from experimental study of the eclogite-carbonatite-sulfide-diamond system. *Geol Ore Deposits* 54(6):443–457
- Litvin YA (2013) Physico-chemical conditions of syngensis of diamond and heterogeneous inclusions in the carbonate-silicate parental melts (experimental study). *Mineral J* 35(2):5–24
- Litvin YuA (2014) Stishovite paradox in genesis of the super-deep diamonds. *Dokl Earth Sci* 455 (1):274–278. doi:[10.1134/S1028334X14030064](https://doi.org/10.1134/S1028334X14030064)
- Litvin YA, Zharikov VA (1999) Primary fluid-carbonatite inclusions in diamond: experimental modeling in the system $K_2O-Na_2O-CaO-MgO-FeO-CO_2$ as a diamond formation medium at 7–9 GPa. *Dokl Earth Sci* 367A:801–805
- Litvin YA, Zharikov VA (2000) Experimental modeling of diamond genesis: diamond crystallization in multicomponent carbonate-silicate melts at 5–7 GPa and 1200–1570 °C. *Dokl Earth Sci* 373:867–870
- Litvin YA, Litvin VY, Kadik AA (2008) Experimental characterization of diamond crystallization in melts of mantle silicate-carbonate-carbon systems at 7.0–8.5 GPa. *Geochem Int* 46(6):531–553
- Litvin YA, Vasiliev PG, Bobrov AV et al (2012) Parental media of natural diamonds and primary mineral inclusions in them: evidence from physicochemical experiment. *Geochem Int* 50(9):726–759
- Litvin YA, Spivak AV, Solopova NA, Dubrovinsky LS (2014) On origin of lower-mantle diamonds and their primary inclusions. *Phys Earth Planet Int* 228:176–185. doi:[10.1016/j.pepi/2013.12.007](https://doi.org/10.1016/j.pepi/2013.12.007)
- Litvin YA, Spivak AV, Kuzyura AV (2016) The bases of the mantle-carbonatite conception of diamond genesis. *Geochem Int* 10 (accepted)
- Logvinova AM, Klein-BenDavid O, Izraeli ES et al (2003) Microinclusions in fibrous diamonds from Yubileynaya kimberlite pipe (Yakutia). In: VIII International kimberlite conference long abstract. Mineralogical Society of America, Victoria, Canada
- Logvinova AM, Taylor LA, Floss C, Sobolev NV (2005) Geochemistry of multiple diamond inclusions of harzburgitic garnets as examined in-situ. *Int Geol Rev* 47:1223–1233
- Logvinova AM, Wirth R, Fedorova EN, Sobolev NV (2008) Nanometre-sized mineral and fluid inclusions in cloudy Siberian diamonds: new insights on diamond formation. *Eur J Mineral* 20:317–331
- Logvinova AM, Taylor LA, Fedorova EN et al (2015) A unique diamondiferous peridotite xenolith from the Udachnaya kimberlite pipe (Yakutia): role in subduction in diamond formation. *Russ Geol Geophys* 56(1–2):397–415
- MacGregor ID, Carter JL (1970) The chemistry of clinopyroxenes and garnets of eclogite and peridotite xenoliths from the Roberts Victor Mine, South Africa. *Phys Earth Planet Int* 3:391–397
- Marakushev AA (1984) Peridotite nodules in kimberlites as the indicators for deep structure of lithosphere. In: *Doklady of soviet geologists to the 27th session of international geological congress*. Petrology. Publishing House “Nauka”, Moscow, pp 153–160
- Marakushev AA, Bobrov AV (1998) Specificity of crystallization of eclogitic magmas within the diamond deep-situated facies. *Dokl Acad Sci* 358(4):526–530
- Marx PC (1972) Pyrotine and the origin of terrestrial diamonds. *Mineral Mag* 38:636–638
- Mathez EA, Fogel RA, Hutcheon ID, Marshintsev VK (1995) Carbon isotopic composition and origin of SiC from kimberlites of Yakutia, Russia. *Geochim Cosmochim Acta* 59:781–791. doi:[10.1016/0016-7037\(95\)00002-H](https://doi.org/10.1016/0016-7037(95)00002-H)

- Mathias M, Siebert JC, Rickwood PC (1970) Some aspects of the mineralogy and petrology of ultramafic xenoliths in kimberlite. *Contrib Mineral Petrol* 26:75–123
- McCallum ME, Egglar DH (1976) Diamonds in upper mantle peridotite nodule from kimberlite in Southern Wyoming. *Science* 192:253–256
- Meyer HOA, Boyd FR (1972) Composition and origin of crystalline inclusions in natural diamonds. *Geochim Cosmochim Acta* 36:1255–1273
- Navon O (1991) High internal pressures in diamond fluid inclusions determined by infrared absorption. *Nature* 353:746–748. doi:10.1038/353746a0
- Navon O (1999). Diamond formation in the Earth's mantle In: Gurney JJ, Gurney JL, Pascoe MD, Richardson SH (eds) *Proceedings of the VII international kimberlite conference: red roof design*, Cape Town, vol 2, pp 584–604
- Navon O, Hutcheon ID, Rossman GR, Wasserburg GL (1988) Mantle-derived fluids in diamond micro-inclusions. *Nature* 335:784–789. doi:10.1038/335784a0
- Navon O, Izraeli ES, KleinBen-David O (2003) Fluid inclusions in diamonds of the carbonatitic connection. In: VIII International kimberlite conference long abstract. Mineralogical Society of America, Victoria, Canada
- Nestola F, Nimis P, Angel RJ et al (2014) Olivin with diamond-imposed morphology included in diamond. Syngensis or protogenesis? *Int Geol Rev* 56:1658–1667
- O'Hara MJ (1968) The bearing of phase equilibria on synthetic and natural systems on the origin and evolution of basic and ultrabasic rocks. *Earth Sci Rev* 4:69–133
- O'Hara MJ, Yoder HS (1967) Formation and fractionation of basic magmas at high pressure. *Scott J Geol* 3:67–117
- Ono S, Ito E, Katsura T (2001) Mineralogy of subducted basaltic crust (MORB) from 25 to 37 GPa, and chemical heterogeneity of the lower mantle. *Earth Planet Sci Lett* 190:57–63. doi:10.1016/S0012-821X(01)00375-2
- Palot M, Pearson DG, Stern RA et al (2014) Isotopic constraints on the nature and circulation of deep mantle C–O–H–N fluids: carbon and nitrogen systematics within ultra-deep diamonds from Kankan (Guinea). *Geochim Cosmochim Acta* 139:24–46
- Pokhilenko NP, Sobolev NV, Sobolev VS, Lavrent'ev YG (1976) Xenolith of diamond-bearing ilmenite-pyropic lherzolite from Udachnaya pipe (Yakutia). *Dokl Acad Nauk SSSR* 231(2):438–441
- Pokhilenko NP, Sobolev NV, Yefimova ES (1982) Xenolith of kataklazed diamond-bearing disten eclogites from the Udachnaya pipe, Yakutia. *Dokl Acad Nauk SSSR* 266(1):212–216
- Ponomarenko AI, Sobolev NV, Pokhilenko NP et al (1976) Diamond-bearing grosspyrite and diamond-bearing disten eclogites from the kimberlite pipe Udachnaya, Yakutia). *Dokl Acad Nauk SSSR* 226(4):927–930
- Ponomarenko AI, Spetsius ZV, Sobolev NV (1980) New type of diamond-bearing rocks—garnet-bearing pyroxenites. *Dokl Acad Nauk SSSR* 251(2):438–441
- Rickwood PC, Mathias M (1970) Diamondiferous eclogite xenoliths in kimberlite. *Lithos* 3:223–235
- Rickwood PC, Gurney J, White-Cooper DB (1969) The nature and occurrences of eclogite xenoliths in the kimberlites of Southern Africa. *Geol Soc S Afr Spec Pub* 2:371–393
- Ringwood AE (1975) *Composition and petrology of the earth's mantle*. McGraw-Hill, New York, p 618
- Ringwood AE, Major A (1971) Synthesis of majorite and other high pressure garnets and perovskites. *Earth Planet Sci Lett* 12:411–418
- Satsukawa T, Griffin WT, Piazzolo S, O'Reilly SY (2015) Messengers from the deep: fossil wadsleyite-chromite microstructures from the mantle transition zone. *Sci Rep* 5:16484. doi:10.1038/srep16484
- Schrauder M, Navon O (1994) Hydrous and carbonatitic mantle fluids in fibrous diamonds from Jwaneng, Botswana. *Geochim Cosmochim Acta* 58:761–771. doi:10.1016/0016-7037(94)90504-5
- Shatsky VS, Ragozin A, Zedgenizov D Mityukhin S (2008) Evidence for multistage evolution of diamond-bearing eclogite from the Udachnaya kimberlite pipe. *Lithos* 105:289–300

- Snyder GA, Taylor LA, Crozaz G et al (1997) The origin of Yakutian eclogite xenoliths. *J Petrol* 38:83–113
- Sobolev NV (1977) The deep-seated inclusions in kimberlites and the problem of the composition of the upper mantle. American Geophysical Union, Washington, D.C., 304 p
- Sobolev NV, Kuznetsova IK (1965) New data on mineralogy of eclogites from kimberlitic pipes of Yakutia. *Dokl Acad Nauk SSSR* 163(2):471–474
- Sobolev NV, Botkunov AI, Lavrent'ev YG (1974) Diamond-bearing corundum eclogite from kimberlite pipe Mir, Yakutia. *Geol Geofiz* 5
- Sobolev NV, Efimova ES, Pospelova LN (1981) Native iron in diamond from Yakutia and its paragenesis. *Geol Geofiz* 22:25–29
- Sobolev NV, Fursenko BA, Goryainov SV et al (2000) Fossilized high pressure from the Earth's deep interior: coesite-in-diamond barometer. *Proc Nat Acad Sci U S A* 97(22):11875–11879
- Sobolev NV, Logvinova AM, Zedgenizov DA et al (2008) Petrogenetic significance of minor elements in olivines from diamonds and peridotite xenoliths from kimberlites of Yakutia. *Lithos* 112S:701–713
- Sobolev NV, Logvinova AM, Yefimova ES (2009) Syngenetic inclusions of phlogopite of diamonds from kimberlites: evidence concerning the role of volatiles in diamond formation. *Geol Geofiz* 50(2):1588–1606
- Sobolev VS (1960) Formation conditions of diamond deposits. *Geol Geofiz* 1:7–22
- Sobolev VS, Nairi BS, Sobolev NV et al (1969) Xenolith of diamond-bearing pyropic serpentinites from Aikhal pipe. *Dokl Acad Nauk SSSR* 188(5):1141–1143
- Sobolev VS, Sobolev NV, Lavrent'ev YG (1972) Inclusions in diamonds from a diamond-bearing eclogite. *Dokl Acad Nauk SSSR* 207(1):164–167
- Spetsius ZV, Taylor LA (2008) Diamonds of siberia: photographic evidence for their origin. Tranquility Base Press, Lenoir City, Tennessee, 278 p
- Spetsius ZV, Bogush IN, Kovalchuk OE (2015) FTIR mapping of diamond plates of eclogitic and peridotitic xenoliths from the Nyurbimskaya pipe (Yakutia): genetic implications. *Russ Geol Geophys* 56(1–2):442–454
- Stachel T (2001) Diamonds from the asthenosphere and the transition zone. *Eur J Mineral* 13(5):883–892
- Stachel T, Harris JW, Brey GP (1998) Rare and unusual mineral inclusions in diamonds from Mwadui, Tanzania. *Contrib Mineral Petrol* 132:34–47. doi:[10.1007/s004100050403](https://doi.org/10.1007/s004100050403)
- Stachel T, Brey G, Harris JW (2000a) Kankan diamonds (Guinea) I: from the lithosphere down to the transition zone. *Contrib Mineral Petrol* 140:1–15
- Stachel T, Brey GP, Harris W, Joswig W (2000b) Kankan diamonds (Guinea) II: lower mantle inclusion parageneses. *Contrib Mineral Petrol* 140:16–27
- Stachel T, Brey G, Harris JW (2005) Inclusions in sublithospheric diamonds: glimpses of deep earth. *Elements* 1(2):73–78
- Stagno V, Tange Y, Miyajima N et al (2011) The stability of magnesite in the transition zone and the lower mantle as function of oxygen fugacity. *Geophys Res Lett* 38:L19309. doi:[10.1029/2911GL049560](https://doi.org/10.1029/2911GL049560)
- Stepanov AS, Shatsky VS, Zedgenizov DA, Sobolev NV (2007) Causes of variations in morphology and impurities of diamonds from the Udachnaya Pipe eclogite. *Russ Geol Geofiz* 48:758–769
- Stepanov AS, Shatsky VS, Zedgenizov DA, Sobolev NV (2008) Chemical heterogeneity in the diamondiferous eclogite xenolith from the Udachnaya kimberlite pipe. *Dokl Earth Sci* 419:308–311
- Streckeisen A (1976) To each plutonic rock its proper name. *Earth Sci Rev* 12:1–33
- Switzer G, Melson WG (1969) Partially melted kyanite eclogite from the Roberts Victor mine, South Africa. *Contrib Earth Sci* 1:1–9
- Takahashi T (1986) Melting of dry peridotite KLB-1 up to 14 GPa: implication to on the origin of peridotitic upper mantle. *J Geophys Res* 91:899367–899382
- Taylor LA, Anand M (2004) Diamonds: time capsules from the Siberian mantle. *Chem Erde* 64:1–74. doi:[10.1016/j.chemer.2003.11.006](https://doi.org/10.1016/j.chemer.2003.11.006)

- Taylor LA, Keller RA, Snyder GA et al (2000) Diamonds and their mineral inclusions, and what they tell us: a detailed «pull-apart» of a diamondiferous eclogites. *Int Geol Rev* 42:959–983
- Titkov SV, Gorshkov AI, Solodova YP et al (2006) Mineral microinclusions in diamonds of cubic habitus from Yakutian deposits by data of analytic electronmicroscopy. *Dokl Earth Sci* 410 (2):255–258
- Tschauner O, Ma C, Becket JR et al (2014) Discovery of bridgmanite, the most abundant mineral in Earth, in a shocked meteorite. *Science* 346(6213):1100–1102
- Viljoen KS, Swash PM, Otter MI et al (1992) Diamondiferous garnet garzburgites from the Finsch kimberlite, Northern Cape, South Africa. *Contrib Mineral Petrol* 110:133–138
- Viljoen KS, Robinson DN, Swash PM et al (1994) Diamond and graphite-bearing peridotite xenoliths from the Roberts Victor kimberlite, South Africa. In: Meyer HOA, Leonardos OH (eds) *Proceedings of fifth international kimberlite conference, vol 1. Araxa, Brazil*, pp 285–303
- Viljoen KS, Dobbe R, Smit B et al (2004) Petrology and geochemistry of a diamondiferous Iherzolites from the premier diamond mine, South Africa. *Lithos* 77:539–552
- Von Eckermann HA (1967) Comparison of Swedish, African and Russian kimberlites. In: Wyllie PJ (ed) *Ultramafic and related rocks*. Wiley, New York, pp 302–312
- Wagner PA (1909) *Die diamantführenden Gesteine Suedafrikas. Ihre Abbau und ihre Aufbereitung*, Berlin
- Wagner PA (1928) The evidence on the kimberlite pipes on the constitution of the outer part of the Earth. *S Afr J Sci* 25:125–148
- Walter MJ, Bulanova GP, Armstrong LS et al (2008) Primary carbonate melt from deeply subducted oceanic crust. *Nature* 454:622–625
- Wang A, Pasteris JD, Meyer HOA, Dele-Duboi ML (1996) Magnesite-bearing inclusion assemblage in natural diamond. *Earth Planet Sci Lett* 141:293–306. doi:[10.1016/0012-821X\(96\)00053-2](https://doi.org/10.1016/0012-821X(96)00053-2)
- Wentorf RH, Bovenkerk HP (1961) On the origin of natural diamonds. *J Astrophys* 134: 995–1005. doi:[10.1086/147227](https://doi.org/10.1086/147227)
- Williams AF (1932) *The genesis of the diamond*, vols 1 and 2. Ernest Benn Ltd. London, 636 p
- Wood BJ (2000) Phase transformation and partitioning relations in peridotite under lower mantle conditions. *Earth Planet Sci Lett* 174:341–354. doi:[10.1016/S0012-821X\(99\)00273-3](https://doi.org/10.1016/S0012-821X(99)00273-3)
- Yoder HS, Tilley CE (1962) Origin of basaltic magmas: an experimental study of natural and synthetic rock systems. *J Petrol* 3:342–532
- Zedgenizov DA, Kagi H, Shatsky VS, Sobolev NV (2004) Carbonatitic melts in cuboid diamonds from Udachnaya kimberlite pipe (Yakutia): evidence from vibrational spectroscopy. *Mineral Mag* 68:61–73
- Zedgenizov DA, Ragozin AL, Shatsky VS et al (2009) Mg and Fe-rich carbonate-silicate high-density fluids in cuboid diamonds from the Internationalnaya kimberlite pipe (Yakutia). *Lithos* 112:638–647
- Zedgenizov DA, Ragozin AL, Shatsky VS et al (2011) Carbonate and silicate media of crystallization of fibrous diamonds from placers of north-eastern Siberian platform. *Russ Geol Geophys* 52(11):1649–1664
- Zedgenizov DA, Kagi H, Shatsky VS, Ragozin AL (2014) Local variations of carbon isotope composition in diamonds from São-Luis (Brazil): evidence for heterogenous carbon reservoir in sublithospheric mantle. *Chem Geol* 363:114–124



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