

GEOCHEMISTRY

Origin of Carbon in Diamondiferous Carbonized Ultrabasites at the Eastern Sayan

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We have studied the carbonaceous material of ultrabasic ophiolitic rocks from the Eastern Sayan. These rocks are interesting because of their high carbonization that reaches 10–12%. The presence of diamond crystals is a unique feature of their mineral composition.

The site studied is located within the Ospin–Kitoi massif, which represents a relic of the ophiolitic cover with an area of more than 150 km² [1] and a three-member structure. The lower plate is composed of a volcanogenic–sedimentary sequence with horizons of olisthostromes and carbonaceous rocks (Il'chir Formation). The middle plate is represented by volcanites, gabbroids, and the dikes. The upper plate is composed of ultrabasic restites (dunite–harzburgite). General regularities in the composition of ophiolitic complexes suggest that this cover is overturned: the deepest sections of the mantle relics occur at the higher hypsometric levels of the present-day topography. The least altered ultrabasic rocks are often encountered at levels of more than 2500 m.

Carbonized ultrabasites are mostly localized either at the boundary between the blocks of unaltered ultrabasites and serpentinites or within serpentinitized harzburgites and dunites.

The stokwork-type carbonization is observed in virtually all fields of low-altered dunites and harzburgites. The intensely carbonized zones are encountered at the boundary with serpentinites. However, serpentinites contain only insignificant carbon in the form of rare graphite crystals.

Diverse (in composition and morphology) linear-extended, sometimes dendritic bodies composed of mostly high-C metaultrabasites, are often encountered in the field of ultrabasites. These 2- to 23-m-thick dike-shaped veins are tens to hundreds of meters long and have rather distinct contacts. They are composed of black, mas-

sive, sometimes schistose, fine-grained carbonaceous–antigorite and carbonaceous–chrysotile–lizardite rocks developing in the cataclasm and mylonitization zones in ultrabasic rocks.

Relics of Cr-spinellids and olivine along with graphite pseudomorphs of enstatite are encountered in the carbonaceous matrix of large veins. Ilmenite, garnet, moissanite, sulfides (chalcopyrite, pyrite, sphalerite, and galena), rutile, corundum, zircon, etc. are distinguished as accessory minerals. The carbon content in the vein filling reaches 8–10%.

Diamond grains encountered in these carbonized ultrabasites were first found and described as long ago as the 1930s [3]. At present, more than 100 small (0.1–0.6 mm) diamond crystals have been extracted from carbonized ultrabasites of the Eastern Sayan. A narrow (1–1.5 m) zone of intense carbonization (serpentine–magnesite aggregate) is often observed at the exocontact of high-C veins.

Carbon of ultrabasites from several sections of the dike-shaped body, two diamond crystals, and carbonate material from the marginal zone were subject to isotope analysis. The isotopic composition was measured with Varian-MAT-230 mass-spectrometer. Depending on mineral composition, samples were prepared according to the methods accepted in the Laboratory of Geochemistry of GEOKhI and described in our previous works.

The analyses results are presented in the table. The $\delta^{13}\text{C}$ value varies from –10.43 to –9.17‰ in ultrabasites from the vein filling and from –8.4 to –9.7‰ in diamond crystals. The $\delta^{13}\text{C}$ value of the carbonate material varies from –5.79‰ in magnesite from the interior part of the marginal zone to –2.83‰ in the exterior carbonate rim of the vein.

In light of the obtained data on the isotopic composition, it seems that the rocks studied were carbonized in the following manner.

Dunite–harzburgite ultrabasic rocks of the ophiolitic complex were probably C-enriched at the high-temperature magmatic stage. High-temperature fluids circulating in the thermal metamorphism zone acquired the isotopic composition corresponding to the averaged isotopic composition of C from source areas (from –10

Table 1

Sample no.	Description	$\delta^{13}\text{C}$, ‰
3S-109	Carbonized ultrabasite (carbon content 8.05%)	-9.17
3S-116	Carbonized ultrabasite (carbon content 2.36%)	-10.01
3S-115	Carbonized ultrabasite	-10.43
3S-125a	Magnesite from the contact zone	-5.79
3S-125a	Magnesite from the exterior part of the contact zone	-2.83
1	Diamond from carbonized ultrabasite	-8.4
2	The same	-9.7

to -18‰) [4]. Similar carbon, involved in the melting and magma formation processes, could ensure the high carbonaceous background that characterizes the ultrabasic rocks studied. High-temperature minerals olivine and enstatite, as well as substituting minerals diopside and garnet, as a rule, contain abundant microinclusions of the carbonaceous matter [3], which should be con-

sidered as the primary magmatic form of C in the ultrabasites studied. Antigorite, developing on high-temperature minerals, also contains C, but already in the form of graphite crystals rather than microparticles.

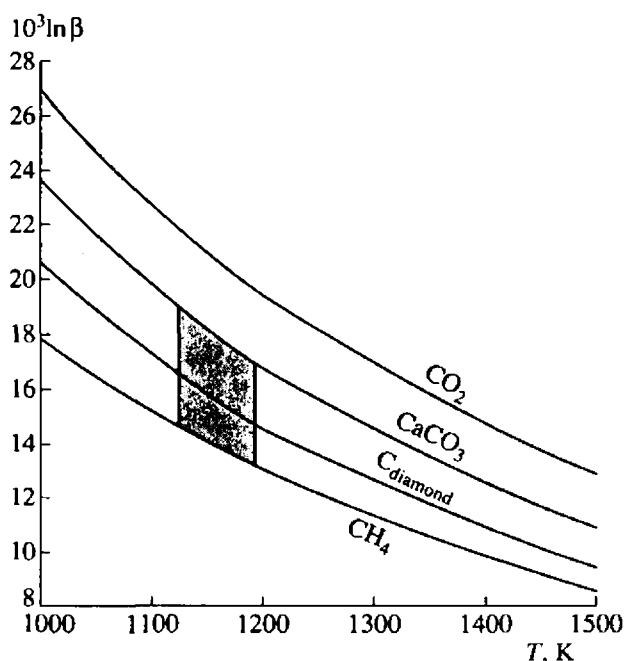
We suppose that further development of carbonaceous matter includes mobilization, transportation, and redeposition of different forms of primarily dispersed magmatic C. The subsequent tectonic motions resulted in the formation of crushing and cataclasm zones, which served as fluid conduits that were responsible for the supply and dispersion of C in ultrabasites.

In the vein zone, minerals were, evidently, formed under highly reducing conditions, and it is the abundant elemental C that governed this process. If we take CH_4 as the representative component of a fluid ($\delta^{13}\text{C} \approx -10\text{‰}$), the isotope fractionation in the system $\text{CH}_4\text{-C}_{\text{diamond}}\text{-CaCO}_3$ at 850–900°C will be approximated by the relationship $\delta^{13}\text{C}_{\text{CH}_4}(-10\text{‰}) - \delta^{13}\text{C}_{\text{C}_{\text{diamond}}}(-8.5\text{‰}) - \delta^{13}\text{C}_{\text{carbonate}}(-6\text{‰})$ shown in the figure. Precisely such relationships between the studied mineral forms are observed.

The fact that serpentinites contiguous to harzburgites are C-free indicates that fluids participating in serpentinization carried no C. The matrix was self-purified, and carbon was driven to contact zones during serpentinization. Concentration of C, forced out of serpentinous rocks, resulted in the formation of C-rich contact zones. The carbonate material of the exterior rim ($\delta^{13}\text{C} = -2.83\text{‰}$) was formed at temperatures lower than those during the formation of vein carbon.

Thus, high-C rocks of ultrabasites from the ophiolitic complex studied were formed as a result of mobilization of primarily magmatic dispersed C in rocks and its redeposition in the form of different minerals in the cataclasm and mylonitization zones.

Our work revealed that the isotopic composition of the studied diamond falls in the normal geochemical series of other carbonaceous minerals. The nature of diamond in non-kimberlite rocks is usually disputable and doubtful. In our case, we can suppose that the diamond was formed at equilibrium with other mineral forms of vein-hosted carbon under the favorable conditions locally originated in the tectonically stressed geological environments.



Temperature dependence of β -factors of CO_2 [5], diamond [5], methane [6], and calcite [7]. Isotope fractionation between the isotope-exchange reaction components in terms of $\delta^{13}\text{C}$ is determined as the difference in their values ($10^3 \ln \beta$). The shaded region displays the temperature interval, where isotope fractionation in the isotope-equilibrium system approximately corresponds to the isotope fractionation between carbonaceous material, diamond, and carbonate observed in the carbonized ultrabasic vein studied.

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