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Multicomponent Ore Mineralization in Ultrabasites of the Ospa-Kitoy Massif of the East Sayan Ophiolite Belt: Formational Parageneses and Origin (Diamond, Nephrite, Noble Metals, Chromium, Nickel)

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Abstract

It is shown that on a small (200 km^2) massif area two extensive groups of metallic (Cr, Ni, Cu, Au, Ag, Pt, Pd, Ru, Os, Ir) and non-metallic (diamond, nephrite, jewelry and ornamental rodingites, chrysolite) types of minerals are spatially and genetically combined. They are grouped into 4 ore-forming types of polycomponent ores: diamond-gold-platinum-metal, chromium-nickel-platinum-metal, gold-platinum-metal and chrysolite-nephrite-rodingite. Ore-formational types form a minerogenic series—the product of a single ore-forming system. The paragenetic kinship between diamonds, chrysolite, nephrite, chromite and noble metals has been established. There are main genetic characteristics that ensure the formation uniqueness of the ore-forming system: 1) chariage-thrust control of ore mineralization and multilevel dynamometamorphic ore genesis with a mechanochemical mechanism of mineral formation. Ore-controlling thrusts are structures of shallow dipping that do not cover the entire lithosphere, but only a section of the earth's crust; 2) carbon fluid, mainly of carbonyl form, which has subjected all types of the ophiolite complex rocks of the Ospa-Kitoy node to intensive transformation, has a crustal mechanochemical, not mantle origin; 3) a strong paragenetic ("hybrid") petrological-mineral-geochemical relation occurring between minerals groups of metallic and non-metallic types is a consequence of the participation in the ore genesis processes of a large variety in different material composition of rocks petrotypes, representing a section of the Earth's crust in the considered part of the East Sayan ophiolite belt.

Keywords

Ultrabasites, Ophiolites, Diamond, Platinoids, Nephrite

1. Introduction

The minerageny of the Ospa-Kitoy basite-ultrabasite massif, unusual in terms of the state of mineral species, including its closest environment, where two extensive groups of metallic (Cr, Ni, Cu, Au, Ag, Pt, Pd, Ru, Os, Ir) and non-metallic (diamond, nephrite, jewelry-ornamental rodingites, chrysolite) types of mineral raw materials are spatially and genetically combined, is primarily explained by the peculiarity of the geodynamic setting, structural and tectonic conditions of its formation [1] [2] [3] [4] [5].

We will discuss this issue below.

Thus, the researches of A. M. Alakshin and B. M. Pismenny [1] identified a long (2400 km), but narrow 17 - 60 km wide suture zone tracing the boundary of the Siberian platform with folded systems (Sayan-Baikal and Stanovoy) with positive gravitational maxima and accompanying them with positive magnetic anomalies. The belt of gravimagnetic anomalies contains 20 deeply eroded sections of deep magmatic and metamorphic rocks, mainly represented by ultrabasites, gabbroids, as well as crystal shales of the main composition. The authors evidently interpret the ultrabasite belt, the Ospa-Kitoy massif of which is an East Sayan branch fragment of this belt. The boundaries of the suture zone coincide with the known faults of the marginal seam of the Siberian platform: Biryusa, Davan, Abchad. Later it was shown that the bodies of ultrabasites, including the largest of them, the Ospa-Kitoy massif, of the marginal basite-ultrabasite belt, are located in zones of polymictic melange, which plays an important ore-controlling role [2].

The most famous is the ophiolite formation model of the Ospa-Kitoy massif, considering it as the Ospa allochthonous plate underlain by the melange zone [3] [4]. At the same time, the massif under consideration is located at the junction of the northern and southern branches of the East Sayan ophiolite belt of the Neoproterozoic, the Riphean age rocks of which frame on almost all sides the Garga block, composed of a highly metamorphosed Early Precambrian complex. In turn, the Ospa-Kitoy plate consists of small tectonic scales separated by melange rocks and dynamometamorphites of the foliation zones. The upper largest scale of the plate under consideration is represented by serpentinized harzburgites and dunites of a reticulated-banded complex composing its central part (**Figure 1**).

The Garga block is heterogeneous in geological structure and material composition. Its oldest amphibolite core (AR) to the periphery is successively replaced by the carbonate complex of the cover (PR) and volcanogenic sedimentary rocks of the island-arc complex and basite-ultrabasites of deep thrust (PR-R),

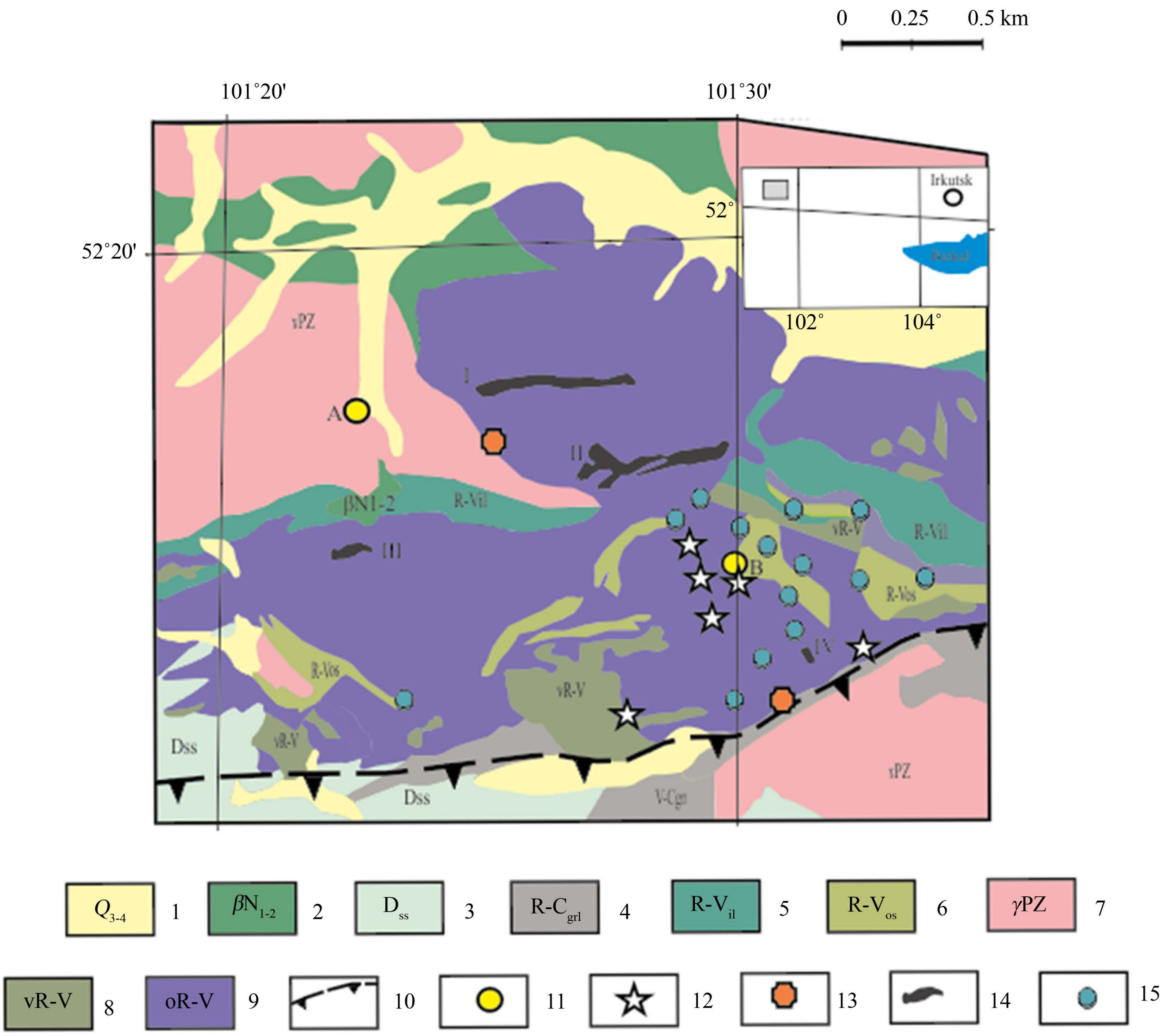

Figure 1. The scheme of the geological structure and minerageny of the Ospa-Kitoy massif. Compiled from the materials (3, 30, 34, 39, 40, 42). 1—quaternary deposits; 2—Neogene basalts; 3—molasses (SaganSayr formation); 4—carbonate series (Gorlykgol suite); 5—metaaleurolites and carbonaceous shales (Ilchir suite); 6—sericite-carbonate-chlorite shales with zones of sulfidized and auriferous rocks (Ospa suite); 7—granitoids; 8—gabbroids; 9—ultrabasite complex of ophiolites; 10—thrusts; 11—auiriferous deposits; 12—diamond occurrences and finds; 13—nickel ore occurrences; 14—chromite bodies; 15—nephrite deposits.

and the north-eastern part is composed of granitoids of the Sumsunur batholith of Late Riphean-Phanerozoic age [5]. The main phase of the batholith is represented by quartz diorites, granodiorites, tonalites, granites and trondemites with gradual transitions between them. Geochemical data on amphibolites of the Garga block and tonalites of the Sumsunur batholith indicate that Archean metamorphic rocks are the most likely protolith of granitoids [5].

The basite-ultrabasite complex of the East Sayan ophiolite belt is so peculiar that it is difficult to find complete analogues for it. Its distinctive features are as follows:

- High-temperature boninite type of the ophiolite section basite part, including not only volcanites, but also subvolcanic orthopyroxene dikes and plutonic gabbro. The generation of primary boninite magmas occurred at a temperature of T = 1400˚C - 1570˚C and a pressure of 20 - 35 kbar at a depth of 60 - 105 km [6] [7] [8];

- The presence of zinc chromium spinelides with an admixture of nickel and vanadium [9] [10] [11] [12];
- Intensive processing all types of the ophiolite belt rocks by hydrocarbon fluids [13] [14] [15] [16] [17].

On the one hand, the mentioned features of the East Sayan ophiolite belt made it possible to attribute the latter to the boninite-ophiolite association of ensimatic island-arc systems [17] [18]. On the other hand, it has many features peculiar to the Early Precambrian greenstone belts of the Olekma granite-greenstone region, confined to the eastern end of the considered above [1] edge basite-ultrabasite belt. The belonging of the Olondo greenstone belt, as well as the East Sayan ophiolite belt to a single marginal suture, brings them closer not only in tectonic-geodynamic, but also mineragenic terms.

In the published work devoted to the prediction of diamond deposits in the Olondo greenstone belt [19], the data of some researchers testifying to its spreading-subduction origin are given. So G. I. Makarychev [20], based on the analysis of isotope dating and the petrochemical composition of rock complexes, came to the conclusion that the foundation of the Olekma granite-greenstone region is proto-aphiolites of the Olondo series, usually considered as part of the greenstone strata of the Olondo belt. In his opinion, the Olondo trog is an encymatic island arc formed at the end of the late Archean. I. A. Alexandrov and O. V. Avchenko [21] proposed a geodynamic model according to which the Dzhugdzhur-Stanovoy block is an ancient subduction zone. V. Ya. Fedchuk and co-authors [22] believe that the appearance in the early Precambrian of the submeridional Olondo and other greenstone belts of the Chara-Olekma craton is caused by the beginning of the sublatitudinal Stanovoy zone subduction functioning, *i.e.* by the subduction of the Stanovoy plate under the Aldan block.

The metallogeny specificity of the East Sayan belt is determined by the fact that it combines the petrological-geochemical traits of the classical Phanerozoic ophiolite and Precambrian greenstone belts. It is considered as a consequence of the subduction and plume zone combination, with the formation of a melting zone ("window") in a sinking slab serving as a powerful ore-generating "pipe" for deep degassing of recovered hydrocarbon fluids [17]. Accordingly, the East Sayan ophiolite belt is characterized by "hybrid" metallogeny, on the one hand, characteristic of typical oceanic ophiolites (Cr, Au, nephrite), and on the other hand—greenstone belts with komatiites (Ni, diamonds, PGE).

As the example of the Ospa-Kitoy massif (ore node of the same name) shows, these factors determine the high productivity of its basite-ultrabasite association for diamonds, Cr, Ni, Au, PGE, nephrite and also the multicomponent nature of ore mineralization, spatial combination of unusual ("hybrid") ore-formational types of minerals.

2. A Brief Overview of the Deposits Scrutiny Level and Mineral Resources Occurrence of the Ospa-Kitoy Massif

2.1. Non-Metallic Group

The purposeful study of the massif diamond-bearing rocks began in 1934-1937. The basis for this was the finds of small diamonds by M. F. Shestopalov in the acid decomposition insoluble residues of "carbonaceous peridotites" samples and in a thin section of strongly "ographed quartz-feldspar rocks" from ore samples taken by him in 1934 in the talus of the Zmeevik rivulet upper reaches and on the northwestern slope of Graphite mountain [23] [24]. The diamond bearing was established not only of carbonaceous peridotites, but also of "mica peridotites close to kimberlites" (in our opinion, this is a cementing substrate of melange ultrabasites).

The expedition of 1936 was conducted in order to search for "the bedrock outcrops of carbonaceous peridotites and to solve the issue of technology for extracting diamonds from them" [23]. As a result of this expedition works, 5 "veins" and a "veined stockwork" of carbonaceous peridotites were found on Graphite mountain, several samples were processed, from which 0.2 carats of diamond crystal fragments with a size of less than 0.4 mm were extracted.

In 1937, a party led by P. D. Pripechko from the Leningrad branch of the Mining and Technical Trust confirmed the diamond-bearing properties of the "veins" previously identified by M. F. Shestopalov on Graphite mountain, called "xenolith 15" and "xenolith 13", and also discovered two new diamond-bearing "veins": X-14, X-16. In addition, diamond-containing carbonaceous peridotites were found in the southern circus of the Karkh mountain ("veins" No. 1 and No. 2) and diamond-bearing mica peridotites there. In the northern circuses of the Ospa golets, productivity is established of V-7, V-9, V-11, and in the southern (Zmeevik) circus of the same golets—V-13 "young" dunites and V-14. A total of 195 diamond grains were diagnosed on May 1, 1938 and 359 were registered in cathode rays [24].

Subsequent work in 1938-39 was aimed at detecting diamonds in loose slope, proluvial and proluvial-alluvial deposits in the valleys of the Khusha-Gol and Zeleny rivulets. A total of 1530 m^3 of rock has been removed from the pits over the years. Of this volume, 859.6 m^3 of "sands" were washed. As a result, diamonds were not found in loose Quaternary deposits. At the same time, repeated sampling confirmed the diamond-bearing "veins" of X-14 and X-15 on the Graphite mountain.

In 1940, the work on the problem of "diamond bearing of the East Sayan" was unexpectedly closed. Later, the reason for this was formulated as follows: "… due to unsuccessful attempts to develop a technology for extracting diamonds from hard rocks such as carbonaceous peridotites" (archival materials, Shestopalov, 1956). Diagnosis of diamonds did not cause doubts. A total of 490 diamond grains were extracted from 1936 to 1939 and another 301 were registered in cathode rays. Most of these diamonds collection was lost in Leningrad (now

Saint Petersburg) besieged by German troops during World War II.

In 1988-95, the area of the Ospa-Kitoy massif was covered by a geological survey (GDP50). One of the survey work tasks was to confirm the presence of diamonds in carbonaceous hyperbasites. The following results were obtained: a 0.2 mm diamond fragment was found in the ore sample from the "vein" of X-15. The initial weight of the sample was 1 kg. Its processing by the thermochemical method was carried out in the laboratory of the Oka expedition;

- In a gross sample weighing 2 tons, 4 diamonds up to 0.5 mm in size were extracted from the X-14 vein. Their diagnosis is made by X-ray diffraction analysis.

The sample was processed in IRGIREDMET in compliance with the rules that exclude contamination of the sample with diamonds. A vibrating screen, a foam separator and an electric furnace for the thermochemical decomposition of concentrates were made specifically for the study of Sayan samples;

- In 1991, the same institute processed a sample taken from the vein No 13 eluvium which did not contain diamonds based on the materials of its predecessors. The initial sample volume was 3 m^3. The weight of the sieve concentrate of class −4 mm obtained by wet screening and submitted for processing in IRGIREDMET was 2 tons. 18 diamonds up to 1 mm in size were obtained from the concentrate; diamonds were found at 4 points on the Graphite mineral occurrence.

In the period 1988-1993, only 31 pieces of diamond individuals were extracted from the bedrock. The mineral was not searched for in loose sediments. Samples were processed in Oka GRE (Mondy settlement), IRGIREDMET (Irkutsk), TulNIGP (Tula), ZabNII (Chita) and SB TsNIGRI (Arkhangelsk). Diamonds were obtained in the first three ones. The diagnosis of the mineral was confirmed by X-ray diffraction definitions and does not cause doubts.

As a result of technological research, the possibility of extracting +0.2 mm diamonds from carbonaceous hyperbasites by methods used in the practice of enriching kimberlite ores has been established. Studies of the −0.2 mm class products of were not carried out.

"Ospa" diamonds are mainly represented by crystals and crystals fragments of the I mineralogical variety [25]. Diamonds of II, V, VI, VIII and IX varieties are less common. The size of individuals is from 0.2 to 1.5 mm.

In accordance with the classification of Y. L. Orlov, the reference diamonds of the I variety are octahedra and the combinational form crystals of the kimberlite tube "Mir", as well as crystals of octahedral habitus with curved surfaces of dissolution, dodecahedra with blunted vertices and smooth-sided from deposits of the non-kimberlite type of the Urals that do not have a spatial-genetic connection with ophiolites. Cubic crystals with rounded edges, sometimes transformed into cuboids and dodecahedra when dissolved, referred to mineralogical variety II are found among diamonds from placers of the Urals, Pre Lena and Anabar regions, from kimberlite pipes "Udachnaya", "Kimberley" by Yu. L. Orlov [25], it is also noted that diamonds II are very characteristic of diamonds extracted from placers of the tertiary age of Ukraine and Northern Kazakhstan.

Diamonds of mineralogical variety V are represented by octahedral crystals with external zones saturated with graphite. When dissolved, these crystals acquire the combinational or rounded shape of a dodecahedron. This variety is often found in diamond-bearing placers of the Pre Lena and Anabar regions, less often in the Urals, as well as in kimberlite deposits (pipes "Mir", "Aikhal" and "Udachnaya").

Spherulites of diamond, called ballas, are assigned to the VI mineralogical variety of classification [25]. They are dark gray and black, have a finely radiant structure. They are often found in the Krasnovishersk district of the Urals and in Brazil. The last two habitus types from the collection of "Ospa" diamonds installed in IRGIREDMET, according to the mineralogical classification of Y. L. Orlov, belong to border VIII (an aggregate of numerous well-cut small crystals of more or less the same size, resembling a gelatinous druse) and to border IX (have the appearance of irregular pieces representing aggregates of irregular small grains deprived of regular crystalline forms). Both of these varieties are characteristic of diamonds extracted from the "Mir" and "Aikhal" kimberlite pipes of the Siberian Platform. An approximate evaluation of diamond crystal raw materials contents in carbonized ultrabasites of the Ospa-Kitoy massif was carried out by M. F. Shestopalov (up to 40 carats per 1 ton) and Yu. I. Kulikov (0.004 - 4.2 carats per 1 ton) with expected forecast resources of 2 - 4 billion tons).

Below we give a brief description of the geological and genetic concepts of the diamond-bearing carbonized ophiolite ultrabasites formation and some other rocks petrotypes of the Ospa-Kitoy massif:

- The discoverer of Sayan diamonds M. F. Shestopalov [23] believes that diamond in ultrabasites is formed when a pneumatolite phase is superimposed on them;
- A group of researchers [13] [15] [16] considers the occurrence of diamond and noble metal mineralization exclusively in ultrabasic tectonites, dynamometamorphites subjected to the interaction of deep high-carbon fluids;
- E. M. Galimov and co-authors [14] came to the conclusion that the hyperbasites of the Ospa-Kitoy massif are enriched with carbon, which was assimilated by magmatic melt at the stage of the oceanic crust forming, and then mobilized by fluids that penetrated through the zones of cataclase, foliation and fracturing. As a result, the recomposed carbon formed stockwork and vein morphogenetic types of carbonization in hyperbasites;
- A more complex geological and genetic scenario of abundant ultrabasites carbonization was proposed by S. M. Zhmodik with a group of co-authors [17]. It is proposed: a favorable geodynamic situation of diamond-bearing formation and noble metal ultrabasites carbonification arose in the conditions of combining a subduction zone with a plan or hot spot, which provided the formation of a melting zone ("window") in a sinking slab.

It is believed that, by analogy with the formation mechanisms of auriferous deposits in Alaska [26] PGE occurrence (platinum group elements) on Hokkaido Island [27], the transport of noble metals was carried out in the form of carbonyls, halogen-carbonyls, metallofulerenes.

Nephrite

Alluvial placers of nephrite along the valleys of the Onot, Kitoy and Urik rivers were developed in the middle of the nineteenth century, and at the very end of it L. Ya. Yachevsky discovered nephrite in the root occurrence [28]. The specialized prospecting and exploration works of the 60 - 70 years of the twentieth century were the most productive, the result of which was the discovery of more than a dozen indigenous deposits, the largest of which are Ulan-Khoda, Ospa, Zun-Ospa, Bortogol and Gorlykogol, totaling about 100 vein bodies. In addition, to date, a large number of placer occurrences and finds of nephrite have been identified in the vicinity of the Ospa-Kitoy massif.

A large number of publications are devoted to the characteristics of the Sayan nephrite deposits. We list those of them that most affect the geological-tectonic and petrological-mineralogical issues of this jewelry-ornamental stone origin [9] [11] [28]-[37]. Following the time sequence of this publications plan appearance, we note the following:

- Yu. P. Kolesnik expressed the idea of nephrite tangled-fibrous structure appearance in jade from the indigenous deposit located in the serpentinites of the Ospa ultrabasites “array” due to the high Ca potential caused by the increased alkalinity of mineral-forming solutions [29]. Somewhat later [30] he concluded that nephrite is formed when replacing early ultrabasites before the process of their serpentinization;
- A great contribution to the study of apohyperbasite nephrite deposits of the East Sayan and in particular, localized in the Ospa-Kitoy massif was made by A. P. Sekerin [31]. Firstly, he was the first to determine the absolute age (K-Ar method for phlogopite mica of the Ospa deposite nephrite vein No. 17) of nephrite formation, equal to 98 million years. Secondly, using the method of physicochemical modeling on a computer, the possibility of graphite formation in the course of serpentinization and during the interaction of carbonated serpentinite with hydrogen has been established. Two floors of calcium metasomatic transformations of alp type hyperbasites are distinguished: the first is the formation of garnet-containing rodingites without nephrite. It is associated with chrysotile-lizardite serpentinization. The second stage is later non-garnet rodingites and nephrites, accompanied by recrystallization halo zones of chrysolite-lizardite serpentinites into antigorite ones;
- A group of researchers who received the first data on ore minerals in the nephrites of the Ospa deposit, established the fact of high ZnO concentrations (11.90% and 9.45%) in chromspinelides, which sharply distinguishes the latter from the chromspenelide hosting ultrabasites nephrites [9]. It

turned out that the association of chromespinelides, garnet, and tremolite in nephrites is equilibrium, which is fixed by the uniform distribution of Cr, Al, Fe, Mg, Ca, *i.e.*, the constancy of the composition of garnet and tremolite at the points of microprobe analysis removed at various distances from the chromespinelide. It is concluded that chromspinelide in nephrites is not a relic mineral of ultrabasites, as indicated by data on its composition and reaction relationships with tremolite and garnet.

Somewhat later, A. N. Suturin and R. S. Zamaletdinov [11] also found significant concentrations of ZnO (1.24 - 5.10 wt%) and MnO (0.67 - 2.02) in chrome spinelids from nephrites of the Ospa-Kitoy "massif" three veins, usually characteristic of komatiites:

- F. A. Letnikov and A. P. Sekerin [32] believe that nephrite formation in hyperbasites occurs due to pseudomorphic substitution of the serpentinite matrix. At the same time, a rodingitization bimetasomatic process of basic, medium and acidic rocks was performed, characterized by a significant introduction of Ca into serpentinites and removal of H_2O;
- In [33] it was shown that the chromspinelides of apohyperbasite nephrites are always surrounded by a garnet zone of the uvarovite-androdite series and differ sharply in chemical composition from chromspinelides hosting rodingite-nephrite mineralization of ultrabasites. Therefore, chromspinelides from jade associations should not be considered as relics of chromite ultrabasites. It is also known that nephrite zones of rodingites do not gradually turn into antigorite serpentinites, but are separated from them by talc fringes. It is stated that the tangled fibrous nephrite tremolite, in its bulk, is formed in the final stage of rodingitization of metabasites, gabbroids and other aluminosilicate rocks on contact with serpentinites in melange zones tracing the thrusts of shallow occurrence;
- The features of the internal structure and the material composition of nephrite-bearing melange structures in the ophiolites of the Ospa-Kitoy area were further studied in detail by S. A. Prokhor [34]. He found that randomly distributed nephrite-containing rootless blocks of plagiogranites, diorites, gabbro, meta-effusives and other rocks in the zones of serpentinite melange are surrounded by dense fringes of small thickness (the first meters, rarely 10 - 15 m) of antigorite serpentinites. The melange matrix is of highly cataclysmic chrysotile-lizardite serpentinites and talc-carbonate rocks. The nephrite veins are localized in the contact of rootless blocks of aluminosilicate rocks with antigorite serpentinites. S. A. Prokhor paid special attention to the characteristics of intensively occurred in nephrite deposits dynamometamorphic transformations not only of the rocks associated with nephrite, but also of the nephrite deposits themselves. The latter acquire superimposed dynamometamorphogenic textures: fluid, conglomerate and porphyroblast (of secondary recrystallization);
- The main regularities of apohyperbasite and apocarbonate nephrite formation, characterizing the world's largest nephrite-bearing province covering

the orogenic belts framing the Siberian Platform from the south, are summarized by N. V. Sekerina [35]. In this work, materials on deposits and nephrite occurrences the Ospa-Kitoy alp type hyperbasites are widely used. Its author points to the convergent nature of apohyperbasite and apocarbonate nephrites. In both cases, the formation of nephrite-containing parageneses was carried out under the conditions of the ore genesis recovery mode. At the same time, it is emphasized that the fibrousness of the nephrite amphibole is due to the reducing environment of mineral formation, which is consistent with the results of experimental work and physico-chemical modeling of the nephrite formation process on a computer.

In addition, it is noted that garnet-containing rodingites do not show a genetic relation with the bodies of nephrites aporhyperbasites, and their formation is determined by the mass serpentinization of dunites and harzburgites under oxidative conditions of the mineral formation environment;

- 5 years ago, a group of researchers performed isotope-geochemical work to determine the fluid sources that formed nephrite deposits of apohyperbasite and apocarbonate genetic types in the south of East Siberia. They also included the study of oxygen and hydrogen isotopes for nephrite and serpentinite at four sites of the Ospa-Kitoy massif and the adjacent area [36]. The conducted investigations allowed us to draw the following conclusion: the fluid phase of Sayan apohyperbasite nephrites was mobilized from serpentinites according to the mechanism developed by N. L. Dobretsov and V. A. Tatarinov [33] (see above);
- Recently, platinum group minerals, previously unknown in the lists of ore minerals contained in nephrite deposits, have been found in the nephrite of one of the veins of the Gorlykgol deposit eastern part of the Ospa-Kitoy massif [37]. The nephrite of this vein has an unusual tremolite-diopside composition (about 50% diopside), and is characterized by a homogeneous fibrous microstructure (**Figure 2**, **Figure 3**). It has been established that relict (xenogenic) chromspinelides, PGM (platinum group minerals) and other ore minerals in nephrite from the Gorlykgol deposit form three successively formed parageneses: 1st generation aluminochromite + rutheniridosmin + ruthenium + ruthenium iridium, 2nd generation Zn-Mn aluminoferrochromite + laurite + gudmundite, 3rd generation Mn-Zn ferrochromite + omeyite + iridoarsenide + allemontite + tellurantimonite (**Table 1**, **Figure 4**, **Table 2**, **Figure 5**). Their source is chromites localized in harzburgites and dunites of the Ospa-Kitoy massif, the compositions of which enter the fields of chromspinelides from "depleted peridotites" [17]. Among them, there are often varieties containing inclusions of the refractory group of platinoids (rutheniridosmin, native Ru) [12]. PGM phases enriched with As, Sb and S are also known. The evolution of the chromspinelides composition with PGM, the release and cataclase of the letter grains are caused by deformation mechanisms of ophiolite transformation in serpentinite mélange zone [38].

Figure 2. The scheme of the geological structure and mineragency of the Ospa-Kitoy massif. Compiled from the materials (3, 30, 34, 39, 40, 42).

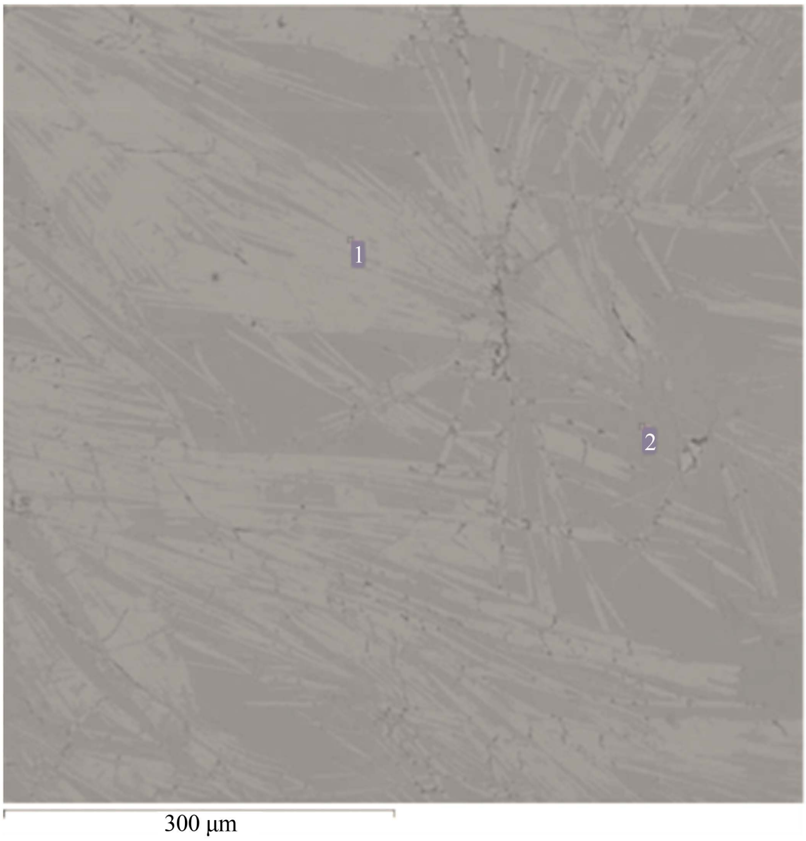

Figure 3. A polished sample of Nef-11. 1—diopside (diopside-87%, hedenbergite-13%); 2—tremolite (tremolite—80%, ferrotremolite—19%).

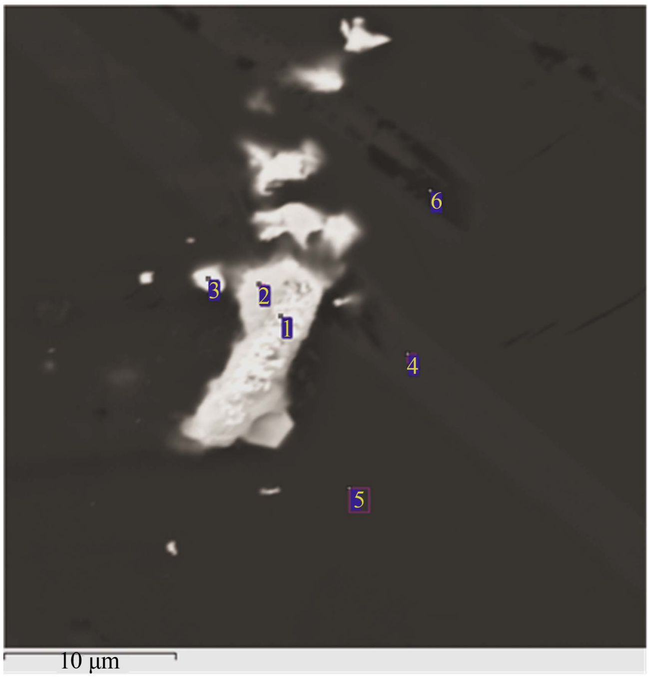

Figure 4. Micro- and nano-platinoids inclusions in the nephrite sample NEF-11 (see legend in **Table 1**). 1 - 3 in **Table 1**, 4—clinopyroxene (87%-diopside, 6%-hedenbergite, 4%-ferrosilite), guartz (44%), magnetite (2%), 5—tremolite (tremolite-79%, ferrotremolit-14%, clinoenstatite-2%), 6—tremolite (tremolite-45%, ferrotrimolite-16%, serpentine-19%, brucite-6%).

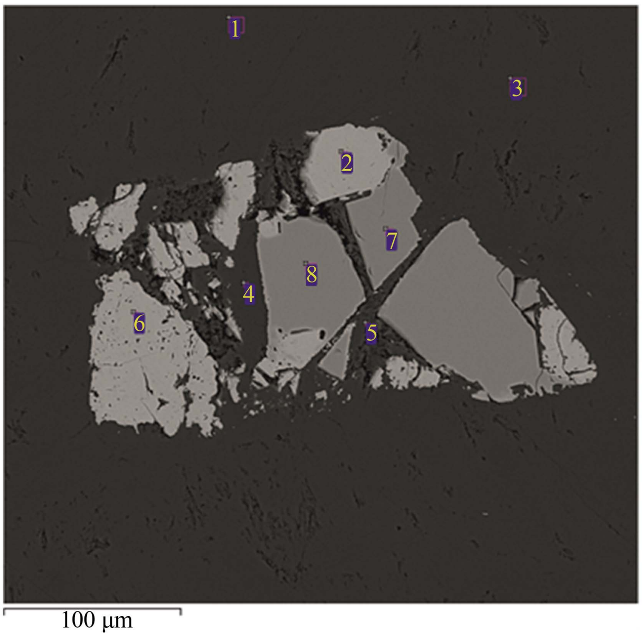

Figure 5. The fragments aggregate of disintegrated relict chromspinelide grains in nephrite of the sample Nef-11. 1—tremolite; 2—Mn-Zn ferrochromite (ferrochromite—89%, franklinite—8%, jacobsite—2%, magnetite—1%); 3 - 5—tremolite; 6—Zn-Mn ferrochromite (ferrochromite—79%, jacobsite—7%, chromite—5%, magnetite—5%, franklinite—3%); 7 - 8—alumochromite (chromite—84%, hercynite—7-8%, spinel—6 - 7%, galaxite—2%).

Table 1. Relic minerals composition of the platinum group in the nephrite of the Gorlykgol deposit (sample Nef-11).

Points numbers in Figure 3	Fe	Ni	Ru	Os	Jr	S	As	Fe	Sb	Total
1	1.01	1.40	14.88	57.05	25.73					100.07
2	0.63		22.82	5.64	19.08	1.28	18.26	19.38	13.35	100.44
3			5.02		47.32		35.35	2.76	9.55	100.0

1—early rutheniridosmin with an admixture of Ni and Fe; 2—association of late PGM (iridoarsenide 34%, omeyite—8%, laurite—2%) with tellurantimonite (31%) and gudmundite (2%). Nanophases of early Ru (23%) with an admixture of Os (14%); 3—paragenesis of late iridoarsenide (70%) with allemonite (13%) and telluroantimonite (4%). Relic nanophases of early ruthenic iridium (13%) of the composition: Jr—8 wt%, Ru—5 wt%. Analyses of the element contents (wt%) were performed on the LEO-1430 VP electron microscope with the JNCA Energy 350 energy dispersive microanalysis system.

Table 2. Composition of relict chromespinelides from a nephrite sample with PGM (Nef-11) from the Gorlykgol deposit.

Oxides, wt%	1 (13)	2 (3)	3 (15)
Al_2O_3	9.36	8.82	0.39
Cr_2O_3	61.73	57.50	59.14
FeO	17.82	25.64	35.76
MnO	0.15	1.57	2.10
MgO	9.81	3.08	0.69
ZnO	н.о	2.76	1.76
Total	98.87	99.37	99.84
Cr/(Cr + Al)	0.90	0.89	0.99
Fe/(Fe + Mg)	0.70	0.91	0.99
Components (%):			
$MgAl_2O_4$	13	11	0.5
$FeAl_2O_4$	–	1	–
$(Fe, Mg)Cr_2O_4$	64	–	5
$FeCr_2O_4$	21	78	81
$MnCr_2O_4$	0.5	–	–
$(Zn, Mn)Cr_2O_4$	–	7	–
$ZnCr_2O_4$	–	2	–
$MnFe_2O_4$	–	–	2
$(Zn, Mn)Fe_2O_4$	–	–	10
$FeFe_2O_4$	–	–	1

Note: elements contents analyses of converted into oxides by stoichiometric ratios were performed on a LEO-1430 VP electron microscope with an INCA Energy 350 energy dispersive microanalysis system. 1 - 3 generation of chromespinelides, in parentheses—the number of definitions. n.o.—was not detected.

A polished sample of Nef-11 tremolite-diopside composition from the vein body of nephrite from the PGM of the Gorlykgol deposit. Light—diopside, dark—tremolite. Diopside and tremolite have tangled fibrous nephrite structure (see **Figure 3**).

2.2. Metal Group

Chromium-nickel mineralization

Specialized predictive prospecting works for chromium in the Ospa massif in 1964-1965 and 1967 were carried out by the Oka expedition of the BGD (Buryat Geology Department) with the participation of the Institute of Geochemistry, SB Academy of Sciences, USSR. The main results of these works are as follows [39] [40].

4 ore zones were allocated and 3 ore zones were preliminarily evaluated (**Figure 1**). The Main zone (Ilchir site) on the 700 × 120 m segment was the most studied. The length of the zones along the stretch is 500 - 3000 m.

Ore zones consist of a series of flame-shaped parallel lenses up to 100 m long and chromite "schlieren" displaced by transverse tectonic disturbances and accompanied by numerous chromite "conductors". Chromite ores of the Main zone contain from 21% to 57% Cr_2O_3; 8% - 23% FeO with a weighted average content per capacity of 43.8% Cr_2O_3. O. M. Glazunov allocated 3 genetic types of chromspinelides in the Ospa massif: accessory, schlier and vein [39]. Obviously, it would be more correct to call this classification morphogenetic. A. I. Goncharenko and A. I. Chernyshov, grouping chrome ores by texture into massive, densely disseminated and disseminated, associate their formation with the deformation mechanism [38]. Later this point of view was supported by other researchers [41]. In terms of Cr content and mineralization scales, the schlier type is the most highly productive.

The schlier and vein chromitites of the Ospa massif differ slightly from each other in chemical composition. Accessory chromespinelids are more ferruginous. The chromite module $Cr_2\ O_3/FeO$ of schlier ores varies from 1.5 to 3.0, indicating their suitability for ferrochrome production without saying about good possibility of use in the chemical industry. Chromites of the Ospa massif are similar in composition to the ore chromites of the Kempirsay massif (Ural). According to the chemistry and the ratios of the component composition, they correspond to chromite, aluminochromite and subferrichromite [12]. It is believed that alumochromites predominate [10]. The finds of zinc-containing chromspinelides with admixtures of Mn, Ni, V in chromites and chrommagnetites of the Ospa-Kitoy massif (ZnO = 0.20 - 0.82 wt%) attract attention. It is known that metamorphic modified chromites from ore-bearing komatiites are significantly enriched in zinc (>0.6 wt%), compared with rocks of similar composition belonging to the ore free series.

Increased nickel bearing is a characteristic feature of the ore-rock complexes of the East Sayan ophiolite belt and, first of all, its eastern part, which includes the ultrabasite massif under consideration, which distinguishes [40] the latter from similar arrays of other Siberia ophiolite belts. The highest concentrations of Ni were observed [39] (analysis of trenching samples) in vein chromite ores (Ni = 0.03 - 1.0 to 1.58 wt%), in their schlier type (Ni = 0.6 wt%) and densely disseminated ores (Ni = 0.6 wt%).

Nickel minerals in chromitites of the Ospa massif are represented by avaruite, shendite ($NI_3PB_2S_2$), hizlewudite, orselite, bravoite and polydimite [42]. Avaruit and hizlewudite predominate. In the southern contact of the quartz talc-carbonate rocks [39], the widespread of Ni-silicate—nepuit plaques was also marked.

Noble metal mineralization in chromites

A large number of scientific publications have been devoted to the characterization of the noble metal occurrence and finds in chromite ores of the Ospa-Kitoy massif. The most informative of them are [12] [17] [42] [43] [44]. Currently, Au - Ag minerals and numerous micro and nano inclusions of platinoids in chromite ores of the Ospa-Kitoy massif have been found in 2 occurrences and 13 mineralization points, represented by zones of low-power (up to 10 cm) chromite veins and drain (massive) chromitites in the bedrock, blocks of eluvial-deluvial ruins. The chromites of the Ospa massif enriched with PGE are divided into 2 groups, differing in the ratio of refractory (Os, Ir) and lower-melting (Pt, Pd) platinoids [12] [42] [43].

Chromites of the first group, with a total PGE content of 2.96 and 3.34 g/t, are characterized by a predominance in their composition of (Os + Ir + Ru) exceeding Pt concentrations (1.03 g/t). The second group of chromites with total PGE contents of 1.34 and 2.79 g/t has higher Pt and Pd contents (total concentrations of 0.85 g/t and 2.13 g/t) compared with (Os + Ir + Ru). PGE mineralization in chromites of the first group is represented by solid solutions of the Os-Ir-Ru system: rutheniridosmin, less often—ruthenoosmiride, osmiride and native Ru. Elevated concentrations of Pt are constantly present. In addition, PGE sulfoarsenides (osarsite, irarsite and presumably a mixture of these minerals), as well as sulfides of the laurite-erlikmanite series, have been established. In sulfides and sulfoarsenides, increased concentrations of Pt are observed, up to Pt-containing varieties of sulfoarsenides (up to 15.85 wt% Pt). Isoferroplatin, tulaminite, Pt-containing rutheniridosmin, platinum osmiride, Pt-Fe-Cu-Sb alloy, Pt-Ir-Cu compound were found in rutheniridosmin in the form of microinclusions.

Platinum-metal mineralization in chromites of the second group is represented by Pt-Cu and Pt-Fe-Ni-Cu compounds [12]. Pt-Fe-Ni-Cu alloys were found as relic formations in the central part of $PtCu_3$ grains.

Noble metal mineralization in carbonized ophiolite metasomatites

Carbonaceous metasomatites form 2 morphogenetic types as mentione above when characterizing diamond mineralization: stockwork and vein. If the stockwork type covers dunite-harzburgite fields in the southern part of the Ospa-Kitoy massif, then intensely carbonized dynamometamorphites in serpentinites, talc-carbonate rocks, weakly serpentinized dunites and harzburgites are attributed to the vein type. According to [44], the average contents of Au in these metasomatites are 2.4 g/t, Ag—265.2 g/t, Pt—1.6 g/t, Pt—0.13 g/t. PGE minerals are mainly represented by Pt-Pd alloys, in some cases by Pt and Pd chalcogenides, and very rarely by a group of refractory PGEs (Ru, Ir, Os). In addition to Au-Sn intermetallides, compounds of Pt and Pd with Sn corresponding to maslenitskovite $(Pt, Pd)_3$ Sn and intermetallic compounds of Pt, Pd and Sn were also found [43]. Au minerals, for the most part, are represented by mercury, copper and native gold.

Noble metal mineralization of sulfidization zones in serpentinites

These zones are widely distributed in the Ospa-Kitoy ultrabasite massif and its surroundings [44]. They contain disseminated sulfidization in serpentinites, often containing bodies of rodingites, nephrites, dikes of metabasites. Sulfide minerals form an association: pyrite, pentlandite, pyrrhotite, chalcopyrite, millerite, zigenite, bornite (+heazlewudite, orselite, covellin). All of them have elevated concentrations of Pt (up to 0.34 g/t), Au (up to 0.35 g/t), Ag (up to 19.5 g/t) to varying degrees. Native Au, copper Au and sperrilite ($PtAs_2$) were determined from the minerals of noble metals. Especially the massive and veined-disseminated pyrites bodies of the Ilchir olistostromic strata are marked by an increased level of platinum bearing [42]. In massive pyrrhotite (sometimes with chalcopyrite and arsenopyrite) ores of the Olginsk zone, platinum contents from 0.2 to 1.25 g/t were found, in disseminated and massive pyrite (with galena and sphalerite) ores of the Barungol zone—from 0.9 to 16.7 g/t and in pyrrhotite-chalcopyrite ores of the Mednaya zone—from 0.8 to 5.4 g/t. All deposits are characterized by high saturation with carbonaceous matter.

3. Ore-Formational Typification of the Ospa-Kitoy “Massif” Ophiolite Minerals

The variety of ore mineralization occurrences of the Ospa node is grouped into a number of ore formations differing in geochemical specialization and mineral associations. All of them are promising for industrial mineralization.

3.1. Diamond-Gold-Platinum-Metal Formation

The occurrences of diamonds, gold and platinum group elements (PGE) attributed to this formation are spatially and genetically related to carbonized and tectonized ultrabasites. The ore association is represented by a large group of native elements: diamond, Au, Ag, Pd, Fe, Zn, Cu, Pb, Sb and intermetallides of composition: Pd-Pt, Pt-Pd-Sn, Pb-Sn-Sb, Pd-Pb, Fe-Si, SiC, etc. The accessory oxides and sulfides of various compositions (chlorite, magnetite, ilmenite, rutile, hematite, corundum, pyrite, chalcopyrite, galena, sphalerite, molybdenum, cinnabar, pyrrhotite) are identified in them. The composition of aluminosilicate minerals is specific (garnet, chlorite, phlogopite, distene, pennine, tremolite, actinolite, anthophyllite, hornblende, tourmaline, etc.). Garnets are diverse in composition: spessartin, almandin, pyrope-almandin, grossular, uvarovit. Apatite and fluorite are also present.

3.2. Chromium-Nickel-Platinum Metal Formation

They can be attributed to the "chromite complex PGM, mainly Os-Ir-Pt mineral and geochemical type of deposits", characterized by a "higher than average" degree of platinum bearing. Since the chromium-noble metal component of this formation is characterized above, here we provide information on its nickel bearing.

A number of occurrences, finds of Ni-mineralization have been revealed by geological survey work. Among them, the Arlyk-Gol occurrence deserves attention, represented by mineralized zones with a thickness of 10 to 100 m and a length of 200 - 1000 m with disseminated and veined-disseminated oxide-sulfide ore mineralization (pyrrhotite, millerite, chalcopyrite, pyrite, chromite, magnetite), confined to serpentinite melange. Ni content—0.06 - 0.38 wt%, Cu—2.85 wt%. Three zones with bornite lenses of size 10 × 35 cm (Cu up to 19.3 wt%) were found here. In addition, the Verkhny-SaganSayr site is of interest, where a 2 m thick zone of calcification and sulfidization in talc-carbonate rocks of the serpentinite melange zone has been established (Starchak, Ananyin, 1960). The zone consists of inclusions, nests and veinlets of solid sulfides and oxides (millerite, pyrite, pyrrhotite, magnetite, chromspinelide, chalcopyrite). The content of Ni is 0.05 - 1.7 wt%, Co—up to 0.04 wt%, Cr—up to 1.16 wt%. A zone of Ni mineralization (pyrrhotite, millerite, chalcopyrite, magnetite, chromite and pyrite) with a length of 5.7 km and a width of 20 - 60 m has been allocated in the western part of the Ospa-Kitoy massif. Nickel rarely forms contents reaching industrial ones. Taking into account its consistently high concentrations in chromite ores (on average 0.6 wt%), it should be considered as their most important component. The hypothetical resources of nickel in chromitites can be very significant, approximately 96 thousand tons.

3.3. Gold-Platinum-Metal Formation

Representatives of this type ore objects in the Ospa ore node are the deposits of Zun-Ospa (gold-sulfide type) and Tainsk (quartz-vein type). The latter is attributed to the type of porphyry gold deposits [42]. Spatially, ore bodies of the ore formational type under consideration are confined to melange structures, and in them to blocks of plagiogranites, plagiogranite porphyries, zones of listvenitization, rodingitization, sulfidization and silicification. Among the ore minerals, Bi and Ag tellurides are characteristic, as well as argentite, bornite, and cobaltin. A typomorphic feature of this type ores is high Pt and Pd contents with unidentified occurrence forms.

As a result of neutron activation analysis with microprobe termination (GEOCHI RAS) of auriferous (Au—67.7 g/t) quartz, pyrrhotite (Au—296 g/t) and veined-disseminated gold-quartz-sulfide (Au—99 g/t) ore types of the Tainsk deposit, high Pt contents were revealed (15.8, 12.6 and 26.8 g/t, respectively). The Pd content in these ores varies from 0.19 to 1.20 g/t.

The most common are Pt and Pd compounds with different ratios of these elements: from native Pd with 15.6% Pt ($PdPt_{0.1}$) to palladium platinum ($PtPd_{1.1}$) with a content of Pt—47.42 wt% and Pd—46.11 wt%. Among palladium platinum, compounds with the ratios of elements $PtPd_{1.2}$-$PtPd_{1.5}$ are most often found. In almost all platinum and palladium compounds, Sn, Pb, Bi, Ba are fixed as impurities up to 1 and more by weight %. Compounds of Pt and Pd with Sn, with Pb impurities up to 0.85 - 2.32; Bi up to 0.22 and Ba up to 0.83 wt% and ratios of elements corresponding to maslenitskovite—$(PtPd)_3Sn$, atokite—Pd_3 Sn and rustenburgite—Pt_3Sn are found. As an impurity Pt—0.58 wt%; Pd—up to 4.43 wt% are identified in an intermetallic compound of the composition $Sn_{2.5}Pb$. Platinum and palladium compounds of unusual composition have been found that require further study, namely: PdSnPb, PtPdSnPbCu, PtPdPbSn (probably zvyagintsevite).

3.4. Chrysolite-Nephrite-Rodingite Formation

The bodies of nephrites and rodingites are confined to the zones of serpentinite melange and inherit the geochemical features of ultrabasites (Ni, Cr, Co). According to the scale of mineralization and nephrite high quality, the Ospa-Kitoy ore node has no analogues in the world [11] [28].

The largest nephrite deposits are Ospa, Zun-Ospa, Bortogol, Gorlykgol, Sagan-Sayr, Pogranichny, Gorlyk-Daban-Zhalgin [34].

Jewelry and ornamental diopside, garnet and hydrogarnet rodingites are used to be slightly distributed in the ultrabasites of the Ospa node [45]. They are represented by light green, grass-green, emerald green and purple varieties, forming nest-like and lenticular separations in high-temperature pyroxene-garnet-vesuvianite rodingites and are rarely found as relics among rodingites associated with nephrite. All varieties of jewelry and ornamental granatites, without exception, have a fine-grained structure and translucency to a considerable depth (up to 1 cm). Of the grossularites of the East Sayan, purple-colored varieties are the most interesting for the gemstone industry. Purple grossularites (deluvial fragments) were revealed in the zones of serpentinite melange at the base of the Ospa-Kitoy ultrabasite massif. Purple granatites are almost entirely composed of fine-grained aggregates of grossular, which differs from other garnets of the Ospa massif rodingites by slightly elevated titanium contents and insignificant concentrations of other elements from the ferrum group. Of the mineral impurities in purple grossularite, albite is present. The most highly decorative are granatites (chromgrossularites) of bright green (to emerald) color, consisting mainly of chromgrossular and containing admixtures of chromspinelide, chlorite, albite, diopside in various combinations and quantities. In the Ospa massif, such rocks are met among banded rodingites, in which bands of bright green chromgrossular alternate with light brown grossular and albite. The bright green chromegrossular contains approximately equal amounts of uvarovite (9%) and andradite (8%) components, which sharply distinguishes it from garnets of light green and light brown colors.

Highly decorative bright green varieties of diopside rodingites composition (dipsiditites), characterized by a stable association of chromium-containing pyroxene and chromspinelide, are genetically related to a single, relatively low-temperature paragenetic type of rodingites. With the same type, occurrences of the best quality nephrite-like diopsidites (karkaro) were observed. Chromdiopsidites are found in the rodingites bodies of diopside-plagioclase-garnet composition and are represented by veinlets, lenses of grass-green, to emerald diopsidites with a significant admixture of albite and inclusions of chromspinelide. Grass-green pyroxene forms short-prismatic and tabular secretions. Its composition corresponds to diopside (83.5%) with an admixture of hedenbergite and nephrite components.

It should be noted that the rodingites of the Ospa ore node, despite their high artistic and decorative properties, have not yet attracted the attention of organizations specializing in gemstones. The resources assessment of rodingites varieties suitable for the stone-carving industry, has not been carried out. According to preliminary data, they may not be inferior to the identified nephrite reserves. Some of them are able to compete with nephrite. Jewelry and ornamental Transvaal diopsidites (karkaro) are widely known in the world. There are deposits of jewelry and ornamental rodingites in Kazakhstan and the Urals. The jewelry chrysolite occurrences are established in two massifs: Ospa-Kitoy and Khara-Nur. In the first case, chrysolite crystals are confined to low-power serpentine-talc veinlets in carbonized peridotites. Pyrite and chalcopyrite are associated with talc. In the Khara-Nur massif, chrysolite is observed in a thin-slate rock, lying in the form of vein-like bodies in serpentinites and dunites. The mentioned chrysolite occurrences are not yet of industrial interest, due to the difficulty of extracting crystals.

The quality of Sayan chrysolite is very high. The sizes of defect-free transparent crystals sometimes reach 2.5 - 3 cm. Currently, there is an electric pulse technology for extracting individual grains of minerals from dense massive crystalline rocks. In this regard, pilot tests of chrysolite-bearing dunites and serpentinites are needed in order to develop a technology for extracting high-quality chrysolite.

4. The Main Traits of the Geological and Genetic Model of a Polycomponent Ore-Forming System in the Ospa-Kitoy “Massif” Ophiolites

The ore-formational types of complex ores discussed above characterize mainly spatially coincided, but not genetically combined into an integral ensemble of one ore-forming system, various types of metallic and non-metallic minerals. This article authors made such combination based on the involvement of their original materials and reinterpretation of some genetic conclusions presented in separate publications of other researchers. This made it possible to establish a genetic relationship between diamonds, chrysolite, nephrite, chromite and noble metals through carbonyl and mechanochemical mechanisms of mineral formation. Below are the facts that were not taken into account by the predecessors in the genetic constructions concerning the listed types of mineral raw materials.

Diamond

First of all, we note that most researchers, except A. F. Shestopalov, did not pay attention to the following paradox: with large diamond contents in carbonaceous ultrabasites: loose quaternary deposits on them do not contain finds of placer diamond crystals. In this regard, A. F. Shestopalov quite correctly identified the main diamondiferous geological feature of carbonized peridotites—the presence of diamond crystal raw materials in very strong, not amenable to physical weathering (except for the formation of blocky material) ultrabasites. For this reason, due to the lack of technology for extracting diamond crystals without damaging and other gemstones (ruby, spinel, chrysolite) from strong petrotypes of rocks until the 70s of the twentieth century, the release of their large individuals as a result of thermochemical decomposition of a concentrates small weight from crushed samples is practically impossible. Therefore large jewelry diamonds were missed but their small varieties (0.2 - 0.6 mm) were recorded, as well as approximately the same fragments of large crystals. The find of a 1.5 mm diamond grain on the Graphite mountain mentioned in section 1 indicates the possibility of the jewelry large diamonds formation in carbonaceous ultrabasites. Turning to the aforementioned hypotheses of diamond formation in the ophiolite hyperbasites of the East Sayan, it should be noted such a contradictory fact as the discrepancy between the crystallomorphological types of diamonds detected in the Ospa-Kitoy massif and the kimberlite type of Yu. L. Orlov's genetic classification [25], which clearly indicates the uniqueness of their origin, and on the other hand, significant disadvantages [46] of the kimberlite genetic model of diamond formation without taking into account also the natural polygenicity of diamond formation [47]. The article by V. S. Trofimov [48] is very interesting, who found analogues of Sayan ophiolite ultrabasites especially in the diamondiferous ore-formational parageneses of Canada peridotites (British Columbia, Southern Quebec, Ontario in the Rem district). In British Columbia, in the Tulamin river area, diamonds together with platinum (0.7 g/t), partly with gold, are closely associated with chromite ores. Diamonds form two varieties. The first one is represented by spherical and irregularly shaped grains of brown, fulvous and yellow colors, usually opaque, attributed to the border. The second variety is formed by colorless, transparent octahedra of a pinhead size and smaller, saturated with numerous liquid and gas inclusions. V. S. Trofimov in his article gives the characteristics of several more diamond finds confined with chromite ores and ultramafites, singling them out as an independent "Canadian" type of indigenous diamond sources. He believes that the source of carbon, due to which the diamond was formed, was the primary carbon of ultrabasic magmas. It is assumed that it crystallized simultaneously and, possibly, somewhat later than chromite. According to M. F. Shestopalov ([23], p. 50), V. I. Vernadsky identifies a special genetic type of diamonds… "in deep dunites, where it is concentrated in chromites with gold and platinum" At the same time, he did not name examples of this type occurrences in Canada.

One of the most important works shedding light on the genetic relationship of diamonds, chromites with noble metal mineralization in the ore formation we have identified, except for [17], is the doctoral dissertation of I. S. Rudashevsky [49]. In it, and his numerous articles, a model of carbonyl differentiation of the primary native platinoid mineralization of ophiolite ultrabasites under the action of mantle fluids is presented. Thus, the assumption of S. M. Zhmodik and co-authors [17] about carbonyl transport of noble metals during hyperbasites carbonization of the Ospa-Kitoy massif is confirmed. Unfortunately, the carbonyl model of the natural diamonds synthesis is currently forgotten [50] [51]. According to this hypothesis, in the presence of catalyst metals (e.g. Fe, Cr, Ni, etc.), the decomposition of carbonyls is accompanied by the decay of active CO molecules to diamond and atomic oxygen: $M_x(CO)_y$ = xM + ySO, CO = C(diamond) + O. Atomic oxygen. interacting with the by-product, it oxidizes it to carbon monoxide or carbon dioxide with (graphite) + O = CO, C (graphite) + 2O = CO_2. This stimulates the active growth of diamond crystals. This hypothesis also allows for the mechanism of diamond formation, in which carbonyl metal complexes catalyze Boudouard reactions 2CO = CO_2 + C (diamond). According to [52], the process of diamond formation through metal carbonyls was performed in the laboratory of metal carbonyls GNIIHTEOC at relatively low temperatures and pressures.

Nephrite is the most valuable and most studied jewelry and ornamental stone from the polycomponent chrysolite-nephrite-rodingite formation and causes acute discussions regarding its genesis. First of all, they concern the origin of the most common specific nephrites (of tremolite composition) structures of fibroblast (tangled-fibrous), tangled-parallel-fibrous, porphyroblast sheaf with porphyroblast main tissue [53]. There are 2 points of view on the nephrite-type structures formation: 1) the result of pseudomorphic substitution inheritance of antigorite structural patterns [31] and 2) geochemical conditions of the mineral formation environment [29]. A. V. Tatarinov in the 90s proposed a fluid-geochemical factor of the nephrite genesis [54]. After the appearance of publications [55] [56], we were able to involve the carbonyl hypothesis of ore genesis in the genetic interpretation of the nephrite structures specifics. Thus, detailed researches of the fluid component composition in serpentinite samples from various ophiolite complexes [54] have shown that the highest concentrations of H_2, CH_4 are characteristic of early apoolivine serpentines of harzburgites. The presence of CO was found in all samples of the studied serpentines. For an early antigorite containing Fe-Ni alloys, the paragenesis of fluids (CO, H_2) is different, fixing, according to [55], the earliest stage of mantle ultrabasites transformation.

At the same time, it is believed that H_2O could have arisen in situ due to hydrogen and carbon monoxide.

As the researches shown [56] obtained during ores smelting, containing shungite and carbonized (bituminous) limestones as a flux, they are dominated by needle and thin-plate nephrite like macro- and microstructures similar to the komatiites spinefex structures.

It has been established that needle and thin-plate olivine and pyroxene crystals forming the framework of spinifex structures in copper slags are formed during the degassing of the fluid-saturated part of the semi-solidified melt. In [54], the appearance of a thin fibroblast structure and apocarbonate nephrite of the Vitim district is explained by fluorine, the admixture of which is very significant, reaching 1.0 wt%. Fluorine here acts as a chemical element modifier of the nephrite structure. In apohyperbasite nephrite, the admixture of fluorine is insignificant and therefore, we believe that the role of the geochemical modifier here passes to CO. Although, according to the carbonyl model of the ore-forming system of the Ospa-Kitoy metallogenic node, partial participation of fluorine in the form of CF fluoride cannot be excluded [50].

Within the framework of the carbonyl model, we are giving our understanding of the cardinal problem of a multicomponent ore-forming system, which consists in determining the places of carbonyl fluids origin in the geological section of the lithospheric block to which the ore node in question is spatially confined. The published information on this issue is mostly speculative and poorly correlated with many aspects of the structural-tectonic and petrological-mineralogical development of the ophiolite complex, with an unusually wide range of distribution over a small area of a large number of metallic and non-metallic minerals types with industrial ore concentrations. The explanation of the coevolutionary ore-geochemical relationship between these and other species is particularly difficult.

This question is very complicated and, as the example [36] shows, even modern methods of isotope geochemistry do not allow it to be solved (see the results above in Section 1.1, “Nephrite”). Below we offer our approach, taking into account several important factors:

- Chariage-thrust control of ore mineralization and multilevel dynamometamorphic ore genesis with a mechanochemical mechanism of mineral formation. Ore-controlling thrusts are structures of shallow dipping, they do not cover the entire lithosphere, but only a section of the earth’s crust;
- Carbon fluid, mainly of carbonyl form, which has subjected all types of the ophiolite complex rocks of the Ospa-Kitoy node to intensive transformation, has a crustal mechanochemical, and not mantle origin. The model of its formation is considered in detail in a number of publications [57] [58] [59] [60];
- A strong paragenetic (“hybrid”) petrological-mineral-geochemical relation that has arisen between groups of metallic and non-metallic types of minerals is a consequence of the participation in the ore genesis processes of a large

variety of different material composition rocks petrotypes, representing a section of the Earth's crust in the considered part of the East Sayan ophiolite belt.

5. Conclusions

The Ospa ore node, with an area of 200 km^2, has been studied for many years with varying degrees of detail for individual types of minerals without taking into account the multicomponent (complex) nature of mineralization. First of all, large-scale searches for nephrite were performed, with less intensity—for gold and diamonds. Work on chrome was stopped at the level of general prospects and predictive estimates. Little attention was paid to nickel and platinoids by production organizations. As a result of such a "monometallic" approach, the economic value of multicomponent ores, in which only one type of mineral was studied, was not clarified. In this regard, it is sufficient to point out the bodies of chromitites, the industrial value of which can be determined to a greater extent by Ni and PGE (rather than Cr), the contents of which are very significant, reaching a level characteristic of well-known industrial nickel and platinum-metal deposits. The same applies to the diamond-bearing carbonaceous complex of restite ultrabasites enriched with noble metals.

To date, the prospects for cost-effective "monometallic" development of mineral resources have deteriorated sharply due to a number of circumstances:

- Closure of ore gold underground mining at the Zun-Kholba deposit, the largest in Buryatia, due to its low contents;
- The lack of prepared technological methods for the enrichment and extraction of "invisible" micro- and nano-scale fine gold, as well as contained in organometallic clusters. Therefore, there are no opportunities to explore and put on balance sheet numerous sulfidization zones suitable for quarrying;
- Development of more than 90% of the identified and explored reserves of jewelry and ornamental nephrite within the Ospa-Kitoy melange structures. A sharp drop in demand on the world market for nephrite raw materials.

In 2010, at the initiative of the Geological Institute, SB RAS and the Department for Mineral Resource Use of the Buryat Republic a group was created under the scientific leadership of A. V. Tatarinov, who presented to the Federal Agency for Subsoil Use of Russia the project justification "Prospects for industrial deposits of diamonds, chromium, nickel, noble metals and nephrite in the Ospa node of the East Sayan ophiolite belt in 2011-2015". The geological task was provided for the work purpose: localization and of resources assessment of categories P2 and P1 diamonds, chromium, nickel, gold, platinoids, nephritis and rodingitis. Their result should be a new minerogenic zoning of the ore node with the allocation of fields, ore-bearing and ore zones, for subsequent technical feasibility of the development efficiency: multicomponent ores. The proposed project was not funded. In the future, highest Russian state structures are also unlikely to be interested in.

Taking into account the uniqueness of the multicomponent ore-forming system of the Ospa node, we propose to make it a training ground for students, postgraduates, mining geologists, enrichment technologists, economists, which would allow attracting the necessary investments to continue further research.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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