Petrogenetic characteristics of mafic-ultramafic massifs in Nizhne-Derbinsk complex (East Sayan Mountains)

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Abstract: The article describes the results of petrographic, petrochemical, petrofabric, mineralogical and geochemical studies of the major rock groups potentially Cu, Ni, Pt ore-bearing mafic-ultramafic massifs in the Nizhne- Derbinsk complex (Eastern Sayan Mountains). Based on the data interpretation the investigated massifs can be classified as peridotite-pyroxenite-gabbronorite formation of geosynclinal regime in Altai-Sayan folding area. Significant massif deformation occurred during the final post-consolidation formation stage. The petrographic features of gabbro and petrofabric patterns of the rock-forming minerals in the Burlakski and Nizhne-Derbinsk massifs indicated the fact that massifs were involved in the accretion-collisional development stage of the Central Asian folding belt during the final formation stages the Nizhne-Derbinsk complex.

1. Introduction
Most ultramafic rock bodies are various in forms, petrographic and chemical composition, while only a few massifs are enriched with commercially ore [1]. The physical rock form and geological position of massifs excludes their classification into ore-bearing and ore-free. In this case, the mineragenic type of the massifs and their potential mineralization could be evaluated only by petrological and geochemical criteria. Therefore, the study of the natural geological features embraces the formation morphology and distribution of not only the deposits and occurrences but also genetically related mineral deposits (Cu, Ni, Cr, Pt) in the crust [2-4]. Mafic-ultramafic complexes play an important role in the reconstruction stages of the Earth's history [5].

2. Methodology
The investigation of the rock composition was based on the following methods: petrographic analysis (National Research Tomsk Polytechnic University and National Research Tomsk State University), silicate analysis / solution chemistry (Institute of Geochemistry and Mineralogy SB RAS-Irkutsk) and microprobe analysis ICP-MS (Rb, Sr, U, Zr, Ta, Nb, Hf, REE) (Institute of Geology and Mineralogy SB RAS-Novosibirsk). The integrating analysis results revealed the basic petrographic types with a detailed composition description of the major rock-forming minerals (olivine, pyroxene, plagioclase).

To reconstruct the thermodynamic and tectonic formation conditions of studied massifs, the petrofabric analysis of the main rock-forming minerals was conducted.

3. Regional setting

The research target was the massif area of Nizhne-Derbinsk mafic-ultramafic complex, which is located in the N-W of Eastern Sayan, left bank of Krasnoyarsk water reservoir, interstream areas of Sisim, Kizhart, Derbina and Tubil rivers. The massifs are confined to the Eastern-Sayan and East-Kuzbass fault zones intruding Early Proterozoic and Late Riphean Derbinsk and Urmansk suites. Nizhne-Derbinsk intrusive complex merges mafic-ultramafic massifs as a lateral zone extending 40km. and 100km. southward of Krasnoyarsk.

The mineragenic type and metallogeny of the Nizhne- Derbinsk mafic-ultramafic massifs complex (Derbinsk area – East Sayan), identified by S.S. Serduk, V.A. Kirilenko, G.R. Lomaeva, V.E. Babushkin, A.V. Tarasov et al. [6] as highly potential explorable commercial Cu, Ni and Cr concentrations, still remains a controversial issue. T.Y. Kornev, A.P. Romanov consider these massifs complex as Late Archaean ophiolites of intrusive magmatism, having emerged in the Kuzeevsk greenstone belt [7]. A.E. Izokh, R.A. Shelepaev and others [8] consider these rocks to be derivatives of gabbro-monzodiorite magmatism within the Altai-Sayan fold area (ASFA). S.S. Serdkom, A.I. Zverev do not exclude such a fact as the simultaneous occurrence of both Late Riphean and Ordovician gabbro in the Nizhne-Derbinsk complex [6]. The geological setting, genesis and metallogeny of above-described massifs are still under discussion.

4. Research results

In accordance with the results of previous studies, several differentiated ultramafic-mafic massifs have been defined within the Nizhne- Derbinsk complex: Ashtatski, Azertakski, Nizhne-Derbinsk, Pravoderbinski, Burlakski, Medvezhi and Tubilski, Verhne-Tubilski. To investigate the rock material composition two centrally located massif complexes – Burlakski and Nizhne-Derbinsk – were taken into consideration. Burlakski massif could be considered a reference complex massif as practically all magmatic rock types can be found here, comparable to other massifs; whereas only ultramafites are found in Nizhne- Derbinsk massif.

Ultramafites embrace wehrlites, websterites (aluminite) and clinopyroxenites with subordiante apodunite and apoharzburgite serpentinite. Websterites, clinopyroxenites and wehrlites reveal gradual rock alteration interchange from one type to another. The above-described ultramafites are mainly composed of clinopyroxene, including a small content of olivine and orthopyroxene and still smaller content of hornblende, and, it is this composition ratio that indicates their difference. The rocks often reveal cumulate structure where the cumulus phase is composed of tabular and sub-isometric clinopyroxene grains and, rarely, of orthopyroxene ones; the interstices of which are xenomorphic olivine and hornblende grains. The formation of banded ultramafites is obviously due to the fractional melt crystallization in the steady-state chamber.

Hornblende pyroxenite and hornblendites (hornblende being the primary igneous mineral) in the upper horizon indicate a rather high (over 3%) water saturated magmatic melt formed during the late-magmatic crystallization stage. Wehrlites and pyroxenite are usually fresh. Secondary changes are associated with the replacement of pyroxene by tremolite, actinolite or uralite, or the formation of pseudomorphs. Olivine is replaced by cellular lizardite. Under intrusion conditions dunites and harzburgites are unstable and completely serpentinized, which, in its turn, is obvious in the auto-metasomatic processes. Olivine is usually replaced by platy and sectorial lizardite aggregates, while orthopyroxene is usually replaced by tabular bastite grains.

The Burlakski massif gabbro mainly includes unchanged leucocratic gabbronorites and partially olivine gabbro, which are characterized by an ophitic texture and, rarely, gabbroic or trachytoid texture. Gabbroids are subjected to extensive plastic deformation, observed in the curved elongated prismatic plagioclase crystals, recrystallization on the periphery of their crystals and, sometimes, disintegration within separate sub-blocks. Trachytoid rocks demonstrate the plane surface and direction of rock flowage. Structural study of Burlakski and Nizhne- Derbinsk massifs rocks shows the evidence of the final stages of active dynamic massif environment formation yielding subsequent structural elements synformal with the rim rocks. It should be noted that Burlakski massif gabbro are more susceptible to the rock flowage, which could be observed in the gabbro distinct directive texture. This, in its turn, mineralogical-petrographic features is consistent with the plastically deformed gabbronorites.

Olivines in Burlakski and Nizhne- Derbinsk massif wehrlite are compositionally similar to high-magnesia chrysolites (Fa = 14.3...15.3%). NiO content in olivines of Burlakski massif increases as iron content increases. A similar trend is observed for olivines in Kingashski massif ultramafites, located eastward of the Kansky greenstone belt. Significant differences were observed in the olivines of the studied Ospinski massif intrusions and metamorphic ultramafic rocks (ophiolite complex SE of East Sayan). The latter has significant low iron content under consistent high NiO content. Such an element behavior in olivines is typical for magmatic rocks formed as a result of crystallization differentiation. A distinctive feature of Nizhne- Derbinsk complex olivines is their insignificant deformation which is only characteristic of olivines from alpinotype ultrabasites.

Petrostructural study of olivine in Burlakski and Nizhne- Derbinsk massif wehrlites revealed that the crystallization of the magmatic melt apparently occurred in steady-state conditions forming semi-isotropic fabric of olivine crystal optical axes due to its crystal decantation providing insignificant influence of the laminar flow in the subhorizontal plane. Further superimposed plastic deformation, which wehrlites have been subjected to, presumably occurring within active tectonic environment during massif consolidation. Plastic deformation of olivine at this stage obviously occurred at decreasing temperatures and increasing deformation rate with a heterogeneous intracrystalline slippage, where the temperature shift is from high {0kl}[100] to low (100)[001] [9]. Olivine shows petrofabric patterns as a result of primary magmatic processes including metamorphic processes in the final massif formation stages. In this case, the number of crystals increases and they respond to the dynamic load under the influence of the external stress field.

The most abundant and predominate mineral rock in Nizhne- Derbinsk complex is clinopyroxene. A specific feature of this mineral rock is that it forms euhedral grains comparable to the xenomorphic minerals, especially olivine. In wehrlites, websterites and clinopyroxenites its chemical composition corresponds to augite and diopside. Enstatite component (En = Mg / (Mg + Fe + Ca) · 100%) of clinopyroxene ranges from 56% in ultramafites and up to 41% in gabbroids. Ferrosilite component (Fs = Fe / (Mg + Fe + Ca) · 100%) varies from 5 to 18%. Wollastonite component (Wo = Ca / (Mg + Fe + Ca) · 100%) ranges from 29 to 46%. Orthopyroxene has wide chemical composition variation: in ultramafites it corresponds to bronzite with iron content of 17 to 21% and in gabbronorites corresponds to hypersthene (Fs = 32 ... 33%), which is consistent with the magmatic matter differentiation.

Orthopyroxene in gabbronorites differs from that in ultramafites by the increased content of Ti, Mn, Fe, Na and decreased content of Al, Cr, Mg. According to the optical (symmetric extinction angle) and chemical properties, plagioclase could be aligned to labrador № 55…57. Fine plagioclase grains are fresh, however, their composition is more acidic comparable to megaphenocrysts related to andesine № 45...47. Plagioclase grains are sometimes slightly sericitized and pelitized. Brownish-yellow iron hydroxides, greenish-yellow chlorite flakes and fine carbonate grains are observed in the cracks. Plagioclase forms not only large banded units in gabbronorites forming porphyric structure but also fine grains. The size of porphyritic megaphenocrysts is 4...8 mm., sometimes up to 15 mm. Plagioclase forms on liquidus after olivine and pyroxene, thus it has a more acidic composition corresponding to labrador-andesite, whereas plagioclase crystallizes with olivine being more mafic in composition (anorthite-bytownite) in troctolitic massifs.

Hornblende shows obvious allotriomorphism in relation to units of olivine and clinopyroxene. Its chemical composition corresponds to edenitic hornblende which is characterized by increased Mg and alkalinity. In Nizhne- Derbinsk massif monomineral rocks, composed of magmatic hornblende, top the layered intrusion cross-section. The results of petrographic studies showed Burlakski and

Nizhnederbinsk massifs are related to layered mafic-ultramafic intrusions of intra-geosynclinal folded areas.

5. Discussion

The major geological feature revealing the restitic nature of ophiolite complexes (relict fragments of ancient oceanic crust) is their tectonic contacts with hosting rocks of banded and lenticular-banded structure with predominant dunite-harzburgite rock association. A.E. Izokh [10] identified intrusive contacts of Burlakski massif with hosting rocks in the Fadeev stream (left tributary of Derbin River). Here, taxitic irregularly grained gabbroids with large porphyritic plagioclase segregations (including small hornfel xenoliths) outcrop. Nizhne- Derbinsk massif- Urmansk shale suite contact was defined in a channel within the Bezimyanni stream, where these shales are hornfelsed [10]. According to the chemical composition of Nizhne- Derbinskif massif rocks are divided into three groups: ultramafic (dunites, wehrlites), sub-ultramafic (clinopyroxenites, websterites) and mafic (gabbronorites, gabbro) [11].

Obtained rare earth element (REE) distribution spectra, standardized to chondrites for Burlakski and Nizhne- Derbinsk massif rocks, has the same REE spectra. Depleted content of light REE is typical under conditions of heavy REE" planar" distribution and most rocks are characteristic of a weak Eu minimum. The multi-element spectra, standardized to primitive mantle rocks of Nizhne-Derbinsk complex, have pronounced typomorphic features typical for magma melting out of depleted supra-subduction mantle. In this case, they are enriched by ion lithophile elements (Rb, Ba, U, K) and Sr, as well as, depleted highly- charged elements (Nb, Zr, Hf) [12]. The similar distribution pattern of REE and rare elements in Burlakski and Nizhne-Derbinsk massifs are indicators of a single formation source for both ultramafic and mafic sequences.

6. Conclusions

Based on the integrated research of the Nizhne-Derbinsk massif composition it was possible to evaluate its mineragenic type-peridotite-pyroxenite-gabbronorite. The cumulative structures in Burlakski and Nizhne-Derbinsk massif ultramafites and ophitic in gabbroids indicate the fact that these massifs formed in mesoabyssal conditions at relatively shallow depths. Mineral plastic deformation showed the severe plastic deformation of massif rocks during the post-magmatic stage. Petrochemical characteristics of rocks reflect the evolution path of magmatic melt from ultramafic to gabbronorites.

According to the geological, mineralogical, petrographic and petrogeochemical data, Burlakski and Nizhne-Derbinsk massif rocks are derivates of one and the same magma forming system, the parent melt of which was high-magnesia basaltic magma resulting from partially significant melting of the suprasubduction mantle under the influence of metasomatized water. Geographically, Nizhne-Derbinsk complex is confined to the magmatic associations of the Altai-Sayan folding area, which, in its turn, is located within the Central Asian folding belt. The Burlakski massif is related to Ordovician period (~ 490 million years) [11].

Another important fact is that during the post consolidation formation stage of the Nizhne-Derbinsk complex, these rock massifs were involved in Early Ordovician accretion-collisional stage of the Altai-Sayan folding area (490-475 mln. years). Based on the research results the Nizhne-Derbinski complex massifs could be associated with both massive copper-nickel ores, confined to deeper horizons and unexposed at the ore zone erosion, and isolated dotted PGE mineralization. The latter fact was identified in the investigated mafic-ultramafic Idzhinsk massif complex (Western Sayan) via scanning electron microscope [13]. By applying the electron microscopy the mineral phases in PGE mineralization could be observed in the thin sections at 5 mill micron [14].

Acknowledgments

The research was supported by National Research Tomsk Polytechnic University, project No. 114-2014

References

[1] Li C, Ripley EM and Naldrett AJ 2003 Compositional variations of olivine and sulfur isotopes in the Noril'sk and Talnakh intrusions, Siberia: Implications for ore forming processes in dynamic magma conduits. *Economic Geology* **98** 69–86

[2] Maier WD, Gomwe T, Barnes S-J, Li C and Theart H 2004 Platinum-Group Elements in the Uitkomst Complex, South Africa. *Economic Geology* **99** 499–516

[3] Taranovic V, Ripley EM, Li C and Rossell D 2015 Petrogenesis of the Ni-Cu-PGE sulfide-bearing Tamarack Intrusive Complex, Midcontinent Rift System, Minnesota. *Lithos* **212–215** 16–31

[4] Mao Y-J, Qin K-J, Li C, Xue, S-C and Ripley EM 2014 Petrogenesis and ore genesis of the Permian Huangshanxi sulfide ore-bearing mafic-ultramafic intrusion in the Central Asian Orogenic Belt, western China. *Lithos* **200–201** 111–25

[5] Pearse J A 2008 Geochemical fingerprinting of oceanic basalts with application to ophiolite classification and the search for Archean oceanic crust *Lithos* **100** 14–48

[6] *Geology and prospects of sulfide Pt-Cu-Ni mineralization of Eastern part of the Altai-Sayan folded area* ed S S Serdyak, V A Kirilenko, G L Lomaeva, B E Babushkin, A V Tarasov and A I Zverev 2010 (Krasnoyrsk: Gorod) p 184

[7] Kornev TY, Romanov A P, Ekhanin AG, Knyazev VN and Sharifulin SK 2008 Platinum greenstone belts of Eastern Sayan and the Yenisei Ridge *Platinum of Russia* **5** 358–80

[8] Izokh A E, Shelepaev R A, Lavrenchuk A V, Borodina E V, Yegorova V V, Vasjukova E A and Gladkochub D P 2005 Cambro-Ordovician Variety of ultramafic-mafic associations of the Central Asian fold belt as a reflection of the interaction of the plume and lithospheric mantle. Geodynamic Evolution of the Lithosphere of the Central Asian Mobile Belt (from Ocean to Continent) *Proceedings of scientific conference on the Programme of Basic Research* **1** 106–108

[9] Nicolas A 1976 *Crystalline plasticity and solid state flow in metamorphic rocks* ed Poirier J P (New York: Wiley-Interscience) p 444

[10] Izokh A E, Kargopolov S A, Shelepaev R A, Travin V A and Yegorova V V 2001 Mafic magmatism of Cambro-Ordovician stage of the Altai-Sayan folded area and the connection of metamorphism of high temperatures and low pressures *Actual issues of geology and minerageny of Southern Siberia: The materials of scientific conference (31 October – 2 November 2001 Elan village, Kemerovo Oblast, Novosibirsk, Lavrentyev Institute of Hydrodynamics, Siberian Branch of the Russian Academy of Sciences)* pp 68–72

[11] Cherkasova T and Chernyshov A 2009 Petrochemical characteristics of the stratified mafic-ultramafic massifs of the Nizhne-Derbinski complex (NW of the Eastern Sayan Mountains) *Tomsk State University Journal* **324** 390–94

[12] *Interpretation of geochemical data* 2001 ed E V Sklyrova (Intermed Engeneering) p 288

[13] Cherkasova T and Korotchenko T 2014 Noble-metal mineralization in olivine clinopyroxenite within Idgimski gabbro-peridotite-pyroxenite complex (West Sayan Mountains) *IOP Conf. Ser.: Earth Environ. Sci.* **21** 012008

[14] Cherkasova T, Timkin T and Savinova O 2015 First native silica findings in bismuth from garnet skarns of Ribny Log – 2 gold ore target in Topolninsk ore deposit (Gorny Altai) *IOP Conf. Ser.: Earth Environ. Sci.* **24** 012033