Noble-metal mineralization in olivine clinopyroxenite within idgimskiy gabbro-peridotite-pyroxenite complex (West Sayan Mountains)

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Abstract
The study of noble-metal mineralization in olivine clinopyroxenite within idgimskiy gabbro-peridotite-pyroxenite complex was carried out. Palladium minerals were identified: palladium telluride and palladium and platinum telluride with mercury impurity. The discovered noble-metal mineralization in olivine clinopyroxenites suggests the presence of perspective low sulfidation platinemetal mineralization in mafic within Verkhne-Amyl ore field.

Introduction
The study is concerned with noble-metal mineralization samples collected in idgimskiy gabbro-peridotite-pyroxenite complex. The provenance area is supposed to be a small massif located 7..8 km south-east from the well-studied Kalininsk massif which contains rock associations similar to the composition of the samples being studied. The samples containing platinum group minerals (PGM) were studied at Innovative Scientific-Education Center “Uranium Geology”, National Research Tomsk Polytechnic University using electronic scanning microscope Hitachi S3400N (operator S.S. Ilyenok).

Methodology
Macroscopically, olivine clinopyroxenerites are young, earthy green colour, with small dark veinlets of partially replaced olivine. Grain size ranges from 2 to 4 mm Rock structure is compact, heterogeneous and massive. The texture is panidiomorphic and medium-coarse grained. Olivine comprises 10% of the rock bulk. Clinopyroxene is represented by diopside making up the bulk of the rock, with grain size ranging from 3 to 6 mm. The same weakly altered diopsidites comprising late dykes in dunite-harzburgite rocks of the ophiolitic series were identified within Kalininsk massif by A. Ekhanin [1]. However, the presence of noble-metals in these dykes has not been identified.

Sulfide impregnation is visually defined and is 8-10% of the rock bulk. Sulfide grains are randomly dispersed within the rock and can be identified both in clinopyroxene and at the boundary of olivine. The sulfide grain composition is not homogenous and basically includes copper pyrite, pyrrhotite and pentlandite, but less in bornite. Along with the identified minerals, fibrous pyrite and copper mica are also found. False galena and galena are identified as single ambiguous grains. Palladium mineralization was identified as intergrowth with platinum phase in copper pyrite grain enclosed in pentlandite (Fig.) and independent phase of palladium telluride. This type of mineralization includes: palladium telluride with mercury impurity, compositionally similar to temagamite Pd$_3$HgTe$_5$. 
palladium and platinum telluride; palladium and platinum sulfide, compositionally similar to cooperite (Pt,Pd)S or braggite (Pt,Pd)S.

**Results and discussion**

Similar ore mineralization was identified in olivine clinopyroxenites within Urals Dzelyatyshor massif [2] and interpreted by the authors as a new sulfidation gold platinemetal type of ore mineralization. According to A. Pystin [2], Dzelyatyshor massif, based on its geological features, chemical composition of rock-forming minerals and geochemical characteristics, cannot be associated with ophiolites where it is embedded. That’s why, authors consider Dzelyatyshor massif to be either a fragment of dismembered intrusive, or a part of platinum-bearing dunite-pyroxenite-gabbro complex in Ural association. The composition of noble-metal mineralization in Dzelyatyshor massif is diverse: native gold (Au), native silver (Ag), braggite ((Pt,Pd)S, kotulskite PdTe , vysotskite (PdS). In the studied olivine clinopyroxenites, the following minerals were identified: native gold (Au), native arsenic As with impurities (Co, Ni), native silver (Ag), awaruite (Ni, Fe), zinc yellow metal (Cu, Zn).

![Figure](image.png)

**Figure.** Ore grain fragment element composition including PGE mineralization. Cpt – copper pyrite, Pnt – pentlandite; 1 – palladium telluride with mercury impurity, 2 – palladium and platinum telluride.
Such a diversity of native metals and their alloys, as well as the presence of minerals which contain platinum, palladium and mercury impurities prove the high degree of ore solution fluid saturation and their renewability. For example, in the Owendale Complex from New South Wales (Australia), noble-metal mineralization was identified within pegmatoid, biotite- and magnetite-poor clinopyroxenites (“P-units”) which form irregular lenses and vein-like bodies within biotite- and magnetite-rich, fine grained clinopyroxenites. The concentration of PGM is probably related to the presence of a reducing fluid phase during final evolution stages of “P-units”, themselves emplaced in the most oxidized pyroxenites of the Owendale Complex [3].

The similar point of view concerning the origin of noble-metals in mafic-ultramafic complexes of different genesis is expressed by Shengrong Li, Zhenmin Gao [4]. According to their opinion, the abnormal enrichment of noble-metal element is closely associated with hydrothermal fluid that flew out on the sea floor through deep cycling and reaction with ultramafic-mafic igneous rocks forming noble-metal rich fluid.

There is a variety of research authors of which share the above-mentioned point of view, as magmatic ore-bearing fluids are considered to be basic condition for commercial Cu-Ni PGE ore deposit. The sulfides became PGE-rich due to interaction with a large volume of ore-bearing fluids that were introduced into different types of mafic-ultramafic bodies during a juvenile stage of their development as a conduit through which magma has passed to the main chamber [5,6,7].

Thus, the prospects of the studied area concerning the presence of noble metal mineralization have been discussed since 1950s. At this time, A. Krukov [1] identified the following platinum-group metals in placers of the Kalna river: osmiridium (OsIr), rutheniridosmine (RuIrOs), isoferrroplatinum (Pt3Fe), tetraferroplatinum (PtFe), chalybeate, tulameenite (Pt3FeCu), ferronickelplatinum (Pt3FeNi), high nickel platinum (Pt(FeNi)2), sperrylite (PtAs2), allopalladium (PtHg), as well as sulfides, sulfedenes, tellurides, arsenide ore minerals, palladium and rhodium antimonides. Then, in 2003, A.Krivenko, M.Polipskiy [1] identified sperrylite (PtAs2), various palladium alloys Pt-Fe-Ni, palladium containing antimonide (Pd3CuSb) and osarsite ((Os,Ru)AsS) in impregnated chromitites within Kalninsk massif during chrome exploration surveying.

With contemporary element composition analysis methods there appear new opportunities to obtain new data about noble-metal accumulation, redistribution, and concentration in mafic-ultramafic complexes of different genesis. Based on the conducted study, it is possible to state that not only chromitites, but also olivine clinopyroxenites within idgimsky gabbro-peridotite-pyroxenite (West Sayan Mountains) are the source of platinum group noble-metal mineralization. The main consumers of such research data are Noril'sk nickel Ltd, Krasnoyarsk Research Institute of Geology and Mineral Resources, one of the perspective development trends of which is prospecting and exploration of noble metal deposits located in Krasnoyarsk Krai [8].

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