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GEOLOGY

# Platinum Metal Mineralization in the Western Pana Massif (Kola Peninsula)

**D. A. Gabov, T. V. Rundkvist, and V. V. Subbotin**

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New data on the geological structure and composition of the platinoid (PGE) mineralization in the Upper Layered Horizon (ULH) of the Western Pana Massif made it possible to compare them with the data on mineralization in the Lower Layered Horizon (LLH). The two horizons differ significantly in the abundance and assemblage of mineral species and classes. The new data confirm the concept of the formation of layered horizons in two different magmatic subphases.

The Western Pana Massif, a member of the Fedorova–Pana layered (ultramafic–mafic) complex of Early Proterozoic age, extends over approximately 30 km as a 3840-m-thick magmatic body dipping at 30°–40°. The massif is sandwiched between Archean rocks and Karelides of the Imandra–Varzuga zone. The massif represents a stratified body mainly composed of gabbronorites and includes two horizons of intensely layered rocks identified above as LLH and ULH (Fig. 1) [1, 2].

The ULH (100–150 m thick) is mainly composed of inequigranular and trachytoid gabbronorites with the subordinate gabbros, anorthosites, and norites. The most significant Cu–Ni sulfide and PGE mineralizations are confined to the anorthosite bed (up to 10 m thick) at the ULH base. Sulfides are also developed in the adjacent rocks near anorthosite lenses (Fig. 2). The Cu–Ni sulfide and PGE mineralizations are less developed in the numerous anorthosite and leucogabbro lenses at the upper levels. The ore occurrence confined to the ULH is known as the Southern Platiniferous Reef of the Western Pana Massif.

The ULH is overlain by a 160- to 250-m-thick horizon of rhythmic intercalation of olivine-bearing rocks (ORH) mainly composed of olivine gabbronorites, troctolites, normal gabbronorites, and anorthosites (Fig. 2). This horizon can be divided into two distinct rhythms. In each rhythm, the basal unit is composed of olivine gabbronorites with interlayers and schlieren of anorthosites, whereas the upper unit is composed of troctolites. The rhythms are separated by a layer of olivine-free fine-grained gabbronorites [3].

Many researchers have investigated in detail various issues of the LLH [4–6]. The LLH (40–80 m thick) is characterized by the alternation of beds and extended lenses of inequigranular gabbronorites, leucogabbros, anorthosites, norites, and orthopyroxenites. The Northern Platiniferous Reef is confined to the LLH.

It has been established that the PGE mineralization shows spatial and genetic correlation with Fu–Cu–Ni sulfide mineralization, but the reverse correlation is not obligatory. In both ULH and LLH, sulfide mineralization is mainly developed as low-grade dissemination with the sulfide content varying from 0.1–2 wt % in anorthosites and gabbros to 1–5 wt % in norites and pyroxenites (maximum 10 wt %). The size of sulfide segregations varies from 0.001*n* to 2–3 mm (up to 5–15 mm in rare cases). The patchy-disseminated and stringer-disseminated ores are confined to the LLH.

The ores are mainly composed of pyrrhotite, chalcopyrite, and pentlandite. Accessory minerals are represented by variable amounts of millerite, pyrite, talnakhite, covellite, polydymite, sphalerite, galena, ilmenite, and magnetite. The ULH is marked by the relatively higher contents of secondary low-temperature minerals, such as bornite, violarite, cubanite, digenite, and chalcocite. In terms of the content of Cu and the degree of PGE concentration in sulfides, the ULH mineralization differs significantly from the LLH mineralization and thin sulfide zones in gabbronorites (Fig. 3).

At present, 27 PGE–Au minerals and 6 mineral phases have been identified in the ULH. Vysotskite, kotulskite, keithkonnite, moncheite, sperrylite, braggite, Pd-gold, stillwaterite, vincentite, and telluropalladinite are the major minerals. Rare minerals are represented by isoferroplatinum, hollingworthite, isomertieite, merenskyite, sopcheite, telargpalite, atokite, cupro-

*Geological Institute, Kola Research Center, Russian Academy of Sciences, ul. Fersmana 14, Apatity, Murmansk oblast, 184200 Russia;*
*e-mail: sub@geoksc.apatity.ru*

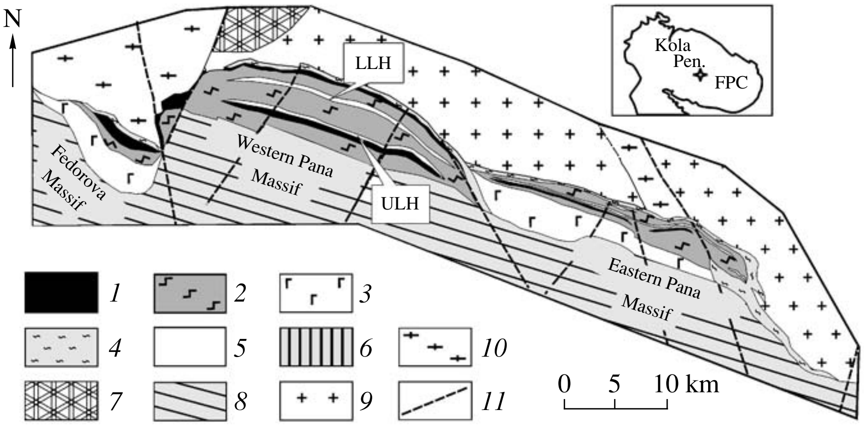


**Fig. 1.** Schematic geological structure of the Fedorova–Pana Complex (FPC): (*1–6*) FPC zones (2.5 Ga): (*1*) norite, (*2*) gabbronorite, (*3*) gabbro, (*4*) marginal, (*5*) layered horizons, (*6*) olivine; (*7–10*) framing of the FPC: (*7*) Tsaga gabbro–labradorite massif (2.8 Ga), (*8*) volcanosedimentary rocks of the Imandra–Varzuga zone, (*9*) alkali granitoids of the Belye Tundry region (2.6 Ga), (*10*) Archean gneisses of the Kola Group; (*11*) faults.

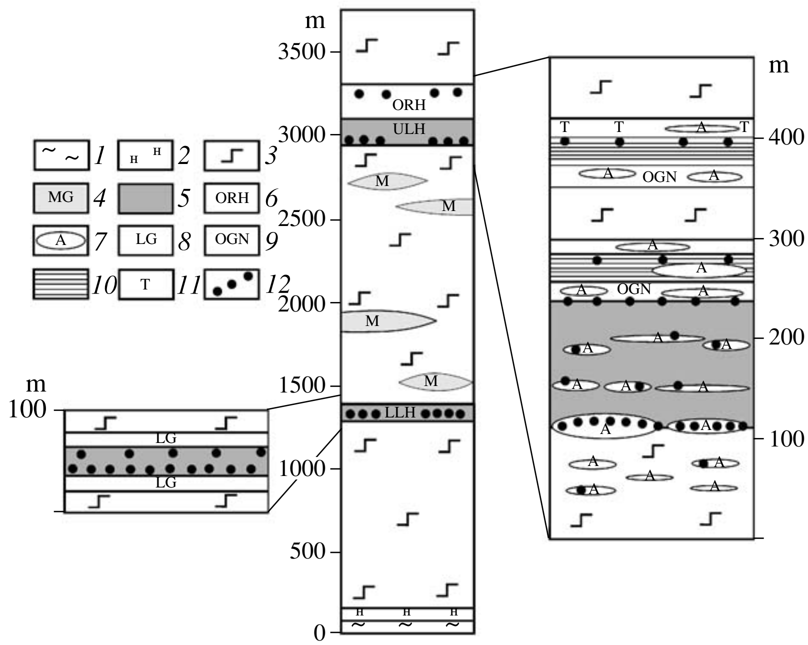


**Fig. 2.** Schematic geological columns of the Western Pana Massif and the ULH (right side) and LLH (left side). (*1*) Plagioclase–amphibole rocks of the marginal zone; (*2*) norites; (*3*) gabbronorites; (*4*) magnetite gabbroids; (*5*) horizons with intercalations of gabbros, gabbronorites, norites, and anorthosites (ULH and LLH); (*6*) horizon of olivine-bearing rocks (ORH); (*7*) anorthosite and leucogabbro lenses in the ULH; (*8*) leucogabbro and leucogabbronorite lenses in the LLH; (*9*) olivine gabbronorites; (*10*) member with the intercalation of troctolites, olivine-bearing gabbronorites, anorthosites, and olivine-free gabbronorites; (*11*) troctolites; (*12*) Cu–Ni sulfide and PGE mineralizations.

rhodsite, laurite, irarsite, hongshiite, silver, palladium, vasilite, and laflammeite. The ores also contain rare mineral phases, such as $(Pd,Ag)_4S$ and $Pd_3(Te,As)$. The latter phase often includes fine ingrowths of the $Pd_3(Ge,Te)$ composition. If we take the grain size into consideration, vysotskite accounts for more than 90 wt % of the total PGE content.

At present, 12 PGE–Au minerals have been identified in the Kievei sector of the LLH. Kotulskite, merenskyite, moncheite, and braggite are the major minerals. Rare minerals are represented by electrum, Pd-gold, vysotskite, vincentite, hollingworthite, sopcheite, michnerite, and sobolevskite. Figure 4 demonstrates differences in the abundance of PGE mineral classes in the ULH and LLH.

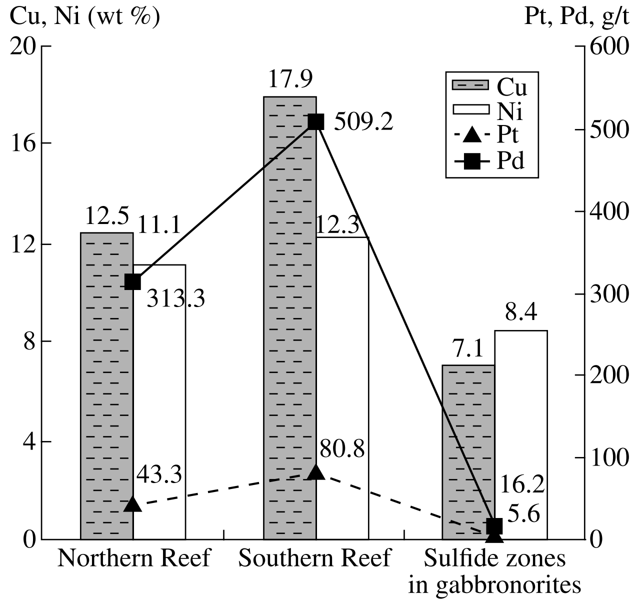


**Fig. 3.** Average contents of nonferrous and noble metals in mineralized rocks of the Western Pana Massif (recalculated to the 100%-sulfide composition).

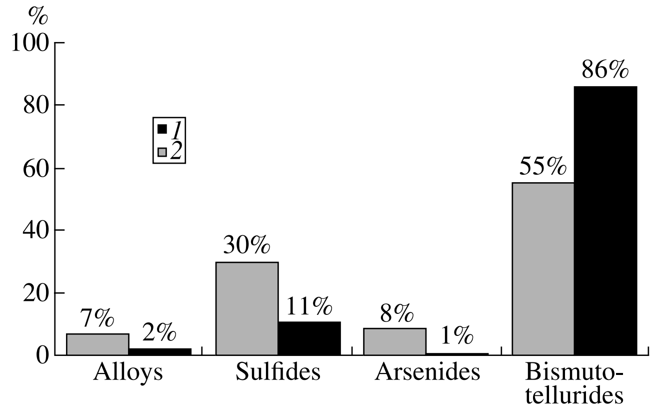


**Fig. 4.** Frequency of occurrence of PGE minerals of various classes in layered horizons of the Western Pana Massif. (*N*) Number of identified grains. (*1*) ULH, Southern Kievei, *N* = 697; (*2*) LLH, Eastern Kievei, *N* = 82.

Mineralization in the ORH is much less studied. The PGE minerals are represented by moncheite, kotulskite, braggite, keithkonnite, zvyagintsevite, and sperrylite. Moncheite and braggite make up the largest grains (up to 40 μm across).

In the Northern Platiniferous Reef, PGE minerals and sulfides associate with the primary magmatic orthopyroxenes and clinopyroxenes, plagioclase, olivine, magnetite, ilmenite, quartz, and postmagmatic amphiboles. In the Southern Platiniferous Reef, PGE minerals and sulfides of primary silicates associate with plagioclase. Amphiboles, chlorites, and quartz are more abundant. Albite, biotite, accessory apatite, clinozoisite, epidote, and leucoxene are rare minerals. Sulfide phenocrysts almost always contain rims of postmagmatic minerals (amphiboles, chlorite, clinozoisite, quartz, and others).

The complex mineralization is usually confined to anorthosite lenses in the thick sequence of compositionally diverse rocks of the ULH and ORH. Although more persistent in space, the LLH mineralization is not rigorously associated with any rock type.

As early as 1973, Kozlov [7] suggested that the Western Pana Massif could form in the course of the injection of several melt portions into a magma chamber. This concept has been confirmed by later data on petrology [8], noble gas isotopy [9], and direct geological observations [3].

Portions of the residual melt enriched in volatile components and PGE were driven into the basal section of the magma subchamber during ULH formation. This is indicated by the migration of processes of crystallization from the roof of the intrusion to its base. These processes were accompanied by the formation of a thick anorthosite bed with the major portion of minerals. The long-term in situ differentiation of material was accompanied by the formation of numerous anorthosite lenses in the ULH and ORH, where the environment was favorable for the development of various mineral phases. The in situ differentiation was subordinate during the LLH formation.

Thus, differences in the pattern of PGE and sulfide mineralizations in the ULH and LLH are probably related to genetic features, including the composition of magmas and the degree of fluid concentration in the melt.

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