# Low-Sulfide Platinum Deposit in the Upper Endocontact Zone of the Noril'sk-1 Pluton: Data from Detailed Geological Exploration

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Low-sulfide platinum ores of the Noril'sk ore district were first described in (Sluzhenikin, *et al.,* 1994). One of the ore deposits, occurring at the Zapolyarnyi mine exploiting the Noril'sk-1 deposit of disseminated Cu-Ni-PGE ores, has been recently explored by underground drilling. These works resulted in correcting data for the low-sulfide horizons and showed that their reserves are comparable with those of the disseminated Cu-Ni-PGE ores.

The low-sulfide platinum-bearing horizons occupy a specific position in the Noril'sk pluton. They are confined to its upper endocontact zone and are separated from the major ores by a barren horizon with a thickness exceeding 50 m (Fig. 1).

The endocontact zone is formed of many rocks different in mineralogical composition, structure, and texture. Typical rocks are eruptive breccias, olivine-free to olivine gabbro-dolerites, gabbro-diorites, and leucogabbroids (including leucogabbro and taxitic chromite-bearing gabbro). Olivine-rich rocks, similar in composition to the picritic and taxitic gabbro-dolerites of the pluton bottom differentiates, are subordinate in the zone.

The ore mineralization is mainly hosted in leucogabbro and especially in taxitic chromite-bearing gabbro (Figs. 1 and 2).

The leucogabbro is composed of large (up to 2 cm) tabular crystals of basic plagioclase ($An_{70-75}$) separated by more acidic ($An_{54-70}$), fine-grained and lath-shaped plagioclase. Minor and accessory minerals are intercumulus augite ($Fs_{10-13}Wo_{39-44}En_{71-77}$), titaniferous phlogopite (XMg = 76-82 %), titanomagnetite, ilmenite, chromite, and apatite.

The taxitic gabbro is characterized by a heterogeneous distribution of plagioclase and femic minerals. The rock is composed of plagioclase (60-70 vol %), augite (20-25 %), olivine (up to 5 %), with minor orthopyroxene, phlogopite, titanomagnetite, sphene, apatite, and baddeleyite.

Early cumulus plagioclase ($An_{75-85}$) occurs as large (1-20 mm) zoned plates. Their interstices are filled with prismatic and lath-shaped plagioclase ($An_{54-61}$) and xenomorphic clinopyroxene ($Fs_{10-11}Wo_{41-44}En_{46-47}$). Olivine ($Fo_{73-79}$) is a rare mineral occurring as single grains or their groups. Orthopyroxene ($Fs_{26}Wo_{2}En_{70}$) forms prismatic crystals or rims olivine grains. Brown phlogopite has a magnesian fraction of 98 %.

The taxitic gabbro typically contains water-, chlorine-, and fluorine-bearing minerals: prehnite, actinolite, pennine, clinochlore, septechlorite, hydrotalcite, saponite, pumpellyite, analcime, thomsonite, apatite, and others. The minerals are developed after primary silicates and sulfides and also form almond-shaped inclusions measuring to 15 mm and constituting to 20-25 vol % of the rock. The actinolite, apatite, chlorite, and saponite contain much chlorine (to 2 wt %). High concentration of chrome spinellides is another characteristic of the taxitic gabbro. They occur as segregations to several centimeters in size, and in these places the spinellides constitute to 40 vol % of the rock. These minerals usually form rims on the almonds of water-bearing silicates.

In the pluton roof, leucogabbroids occur as lenses measuring from several meters to a few hundred meters. Thickness of the lenses ranges up to 25 m. In some sections the leucogabbroids are in contact with wall rocks, while in other sections they are separated from wall rocks by gabbro-dolerites, gabbro-diorites, or eruptive breccias. Taxitic gabbros compose several zones in the leucogabbroid horizon (Fig. 2), with their main zone confined to the horizon bottom. The leucocratic and taxitic gabbros have gradational contacts with each other. The gradation develops in an interval of a few centimeters. Olivine-rich rocks are usually located at the bottom of leucogabbroid bodies.

Bulk concentration of platinum-group elements (PGE) in all upper endocontact rocks of the Noril'sk-1 pluton exceeds 0.3 ppm. The PGE background concentration in the endocontact zone is 0.3-2.0 ppm.

PGE concentration in the low-sulfide ores exceeds 3 ppm: usually from 3 to 12 ppm, less usually up to 20-40 ppm, and occasionally up to 60 ppm. In the upper platinum-bearing horizons, the PGE concentration correlate with concentrations of base metals and sulfur; however, the correlation is less strong than that studied in Cu-Ni-PGE ores.

Bulk concentration of copper and nickel in the low-sulfide ores usually does not exceed 0.25 %. The concentration ratio of PGE (ppm) to sulfur (wt %) for the low-sulfide horizon of Noril'sk-1 is over 5 (up to 40-70), while similar ratio for the disseminated Cu-Ni-PGE ores of Talnakh and Noril'sk-1 is less than 1.2 and 3.5, respectively.

The low-sulfide ores contain rhodium (0.19-0.89 to 2.8 ppm), iridium (0.022-0.24 to 0.75 ppm), ruthenium (0.1-0.49 to 0.75 ppm), and gold (0.06-0.49 to 1.03 ppm). The ores have (Rh + Ir + Ru)/S ratio of 0.23-2.4 to 4.4 and Au/S ratio of 0.14-0.59 to 1.18. For comparison, similar characteristics of the disseminated ores are 0.09 and 0.08 for Talnakh and 0.26 and 0.2 for Noril'sk-1, respectively. Hence, when calculated for the sulfide mass, concentrations of rare PGE and gold are higher in the low-sulfide ores than in the main ore horizons.

Pt/Pd ratio of the low-sulfide ores is close to that of the disseminated Cu-Ni-PGE ores: it ranges from 0.23 to 0.63 (mainly from 0.33 to 0.5), increasing to 0.8-0.9 in the ores with low PGE concentrations.

PGE distribution in the low-sulfide horizon is irregular both laterally and vertically. The lateral irregularity is mainly explained by the distribution of leucogabbroids, which usually host the low-sulfide mineralization. However, elevated PGE concentrations (up to 5 ppm) are also revealed in eruptive breccias and gabbro-dolerites.

Several peaks of PGE concentration are usually found in vertical sections of the low-sulfide horizon. Most of them are connected with taxitic gabbroids, which are rich in minerals with volatiles and chrome and contain productive sulfide assemblages (Fig. 2). The abundance of $H_2O$-, Cl-, and F-bearing minerals and chrome spinellides directly correlates to the PGE concentration. Peak PGE concentrations are typical of the bottom of the low-sulfide horizons. However, they are also revealed in other sites (Figs. 1 and 2).

The minor PGE portion of the low-sulfide ores (about 1 % Pt and 5 % Pd) relates to solid solutions in sulfides, which is very different from the disseminated ores of main platinum-bearing horizons. Palladium concentration in pentlandite ranges from 30-100 to 300 ppm. Rhodium is concentrated in pyrrhotite and pentlandite (about 1 ppm), as well as in sperrylite. Pyrrhotite contains iridium (about 1 ppm).

PGE are more abundant in Ni, Co, and Fe arsenides and sulfarsenides: nickeline, maucherite, Co-gersdorffite, and Ni-cobaltite contain Pt (up to 0.41 wt %), Pd (up to 0.89 wt %), and Rh (up to 0.44 wt %). These minerals host fine inclusions (< 5 μm in diameter) of majakite, $(Pd,Ni)_2As$, $Pd_2(Sb,As)$, and sperrylite. The arsenides and sulfarsenides are occasionally found to form intergrowths with hollingworthite (a platinum-containing sulfarsenide of rhodium) and sperrylite.

The major PGE portion of the low-sulfide ores is bonded in proper minerals (29 mineral species), which belong to several groups: intermetallides, iron-platinum alloys, sulfides, and sulfarsenides. Predominant among the platinum minerals are sperrylite (15 %), iron-platinum alloys (15 %), and Pt-atokite (25-35 %).

The iron-platinum alloys are isoferroplatinum, tetraferroplatinum, the alloy with $Pt_2Fe$ composition (the dominant species), and tulameenite. They occasionally form intergrowths with each other, especially tetraferroplatinum with $Pt_2Fe$: $Pt_2Fe$ borders tetraferroplatinum. Pt-atokite is the prevalent mineral of the $Pd_3Sn$-$Pt_3Sn$ (atokite-rustenburgite) isomorphous series. Wide isomorphous series are $A_5B_2$ and $A_8B_3$, where $A$ is Pt and Pd while $B$ is Sn, As, Sb, and occasionally Te.

About 30 % of the PGE mineral grains identified in the low-sulfide ores are members of the $Pd_2B$ series, including paolovite ($Pd_2Sn$), palladoarsenide ($Pd_2As$), species with $Pd_2(Sn,As)$ and $Pd_2(As,Sb)$ compositions, and species with various proportions of Sn, As, and Sb. Prevalent among them are minerals with $Pd_2(Sn,As)$ composition. Analyzed bismuth tellurides are members of the PdTe-PdBi series and Bi-containing merenskyite and moncheite.

Identified Pt and Pd sulfides are cooperite, braggite, vysotskite, and a sulfide of Pt, Pb, Cu, Ni, and Fe with haraelakhite composition. In many cases, the sulfide grains are zoned from cooperite to braggite and from braggite to vysotskite.

Hollingworthite is the only mineral of rare PGE revealed the low-sulfide platinum-bearing ores.

The PGE minerals occur as grains measuring from 3 to 90 μm, usually from 5 to 50 μm. The proper PGE minerals and PGE-containing arsenides and sulfarsenides (90 % of the mineralization) are associated with $H_2O$-, Cl-, and F-containing minerals replacing sulfides. In many cases, they are found at sulfide grains replaced by the secondary silicates.

As a result of the exploration works, the geological, petrographic, and mineralogical characteristics of the low-sulfide platinum ores were obtained. They are considered as the criteria for forecasting similar ores in other plutons of the Noril'sk region and the Taimyr Peninsula.

## References


Sluzhenikin, S.F., Distler, V.V., Dyuzhikov, O.A., *et al.,* Low-Sulfide Platinum Mineralization in the Noril'sk Differentiated Intrusive Bodies, *Geol. Rudn. Mestorozhd.,* 1994, vol. 2, no. 3, pp. 171-195.


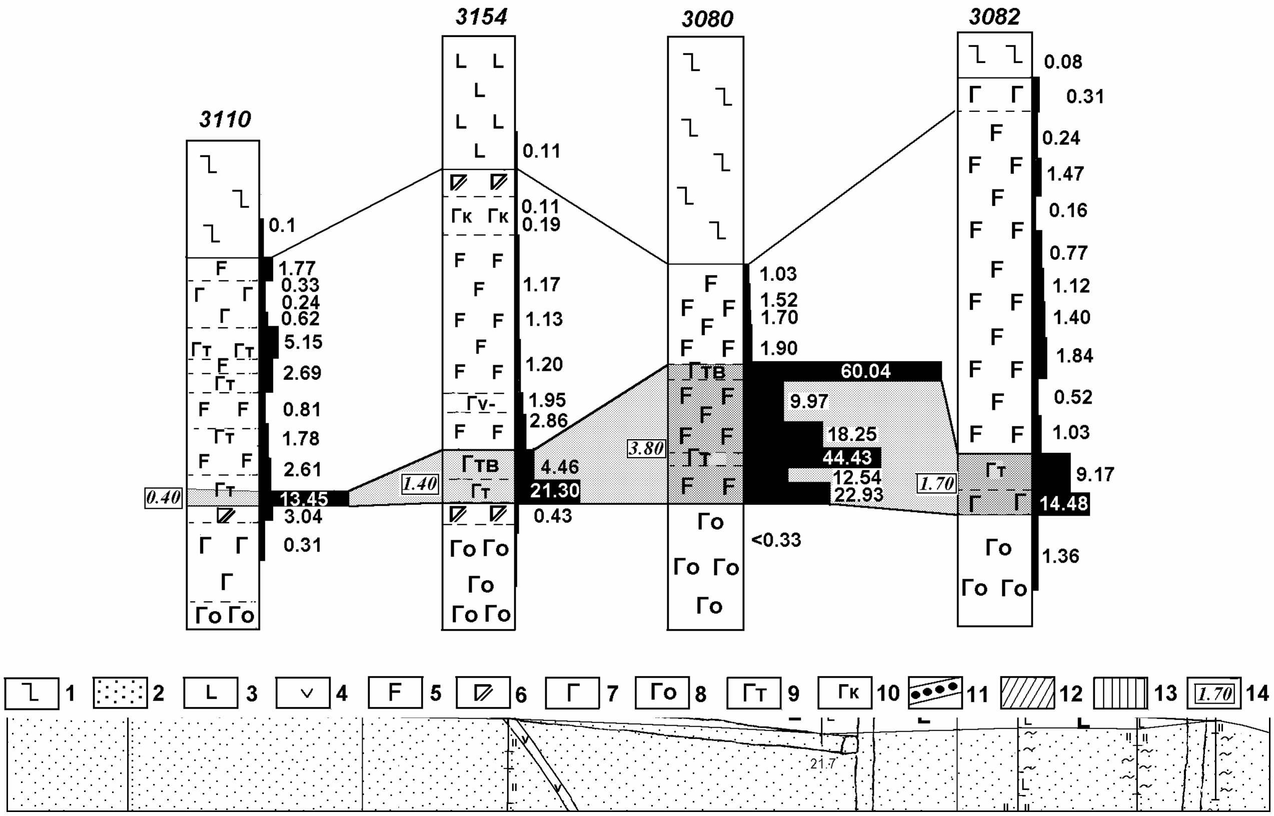


***Figure 1.*** *Geologic setting of the low-sulfide platinum-bearing horizon in the upper endocontact zone of the Noril'sk-1 differentiated ultrabasic-basic pluton: 1—basalts; 2—sandstones and siltstones of the Tunguska Formation; 3—titanaugite dolerites; 4—microdolerites; 5-10—the pluton rocks: 5—leucogabbro; 6—gabbro-dolerites; 7—olivine-free gabbro-dolerites; 8—olivine gabbro-dolerites; 9—taxitic gabbro; 10—contact gabbro-dolerites; 11-13—symbols in the geological section: 11—low-sulfide platinum-bearing horizon; 12—the upper gabbros; 13—the main horizon of the disseminated Pt-Cu-Ni ores; 14— the horizon thickness in geological columns.*

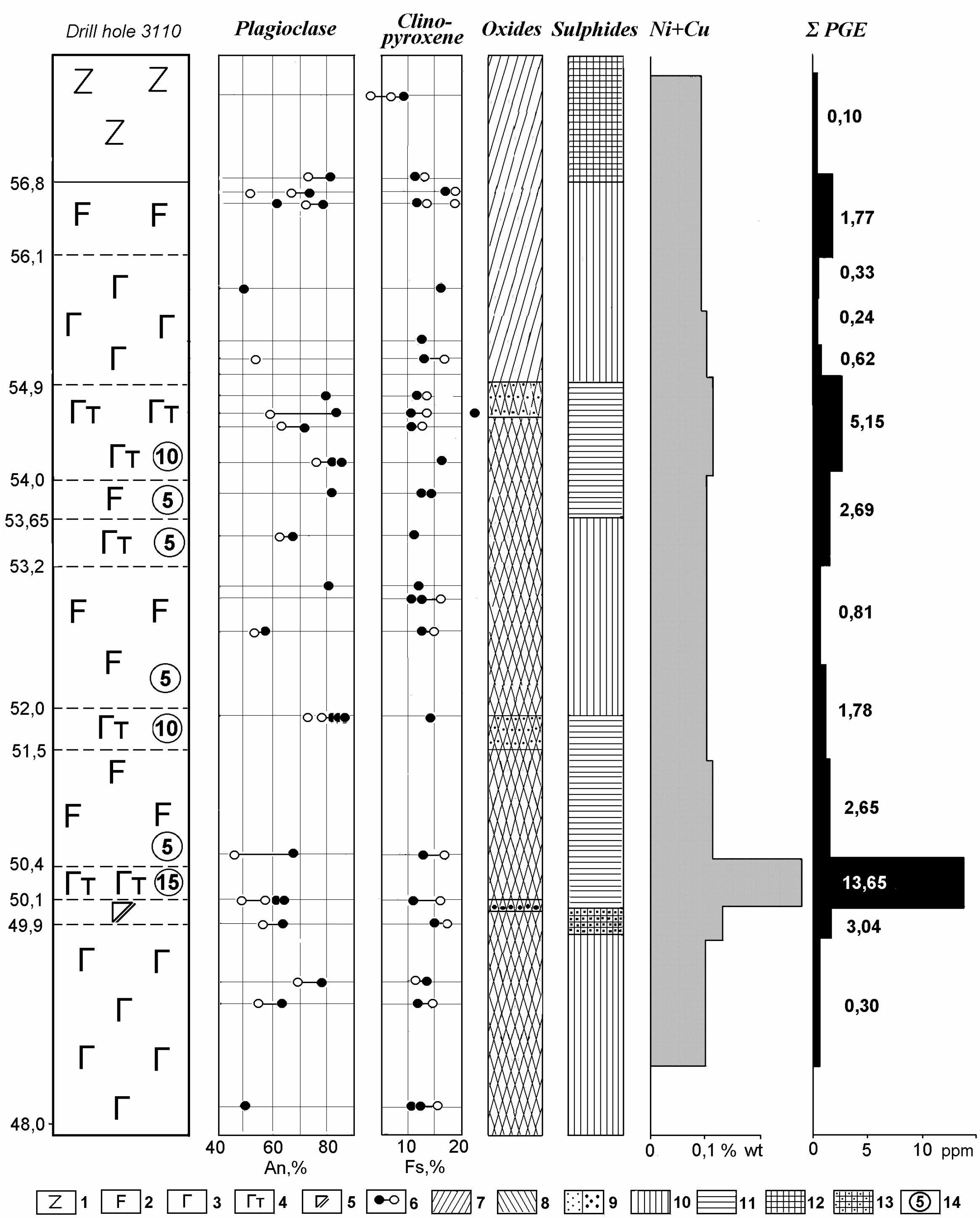


***Figure 2.*** *Composition of rock-forming minerals, oxide and sulfide mineral assemblages, and concentrations of base metals and PGE in the upper endocontact zone section of the Noril'sk-1 pluton with the low-sulfide platinum ore mineralization: 1—basalts; 2—leucogabbro; 3—olivine-free gabbro-dolerites; 4—taxitic gabbro; 5—gabbro-diorites; 6—mineral composition (center-periphery); 7-9—oxide mineralization: 7—ilmenite; 8—titanomagnetite; 9—chromite (less and more than 10 vol %); 10-13—sulfide mineralization: 10—pyrrhotite; 11—chalcopyrite-pentlandite-pyrrhotite; 12—pyrite; 13—millerite-chalcopyrite-pyrite; 14—percentage (vol %) of almond-shaped inclusions of secondary minerals.*