Platinum-Group Element Minerals in Lode and Placers Associated with Galmoenan Complex (Ural-Alaska-type), Koryak-Kamchatka Region, Russia

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The gabbro – clinopyroxenite – dunite Galmoenan complex (Ural-Alaska type intrusions) is a part of Koryak-Kamchatka platiniferous belt. Commercial placers of platinum-group minerals (PGM) (Fig. 1) being mined nowadays and numerous lode ore of platinum are associated with this complex. The source of the most expanded placer of the Levterinvayam River is the eastern part of the complex where among dunites wehrlite, clinopyroxenite and gabbro al also abundant. Platinum from placers of the Creeks Ledyanoy and Penisty was traspotrted from, the western and south-western parts of the complex and originated from rocks and ores of dunite core, whereas clinopyroxenite and wehrlite taking minor part.

Basic platinum-group element (PGE) mineral of bedrocks and ores of Galmoenan complex and associated placers are Pt-Fe alloys. They are represented by anhedral isoferroplatinum Pt_3Fe grains among chromite crystals or by fine euhedral inclusions in dunite. Fine rolled platinum grains with rare chromite inclusions are typical for the Levtyrinvayam River placer. Their composition range is widely varying from native platinum up to ferruginous platinum (Fe is 30-35 at.%) and they differ from lode rock platinum in generally increased ferrum content conditioned by secondary processes. Ferruginous platinum areas are localized along cracks and in the margins of isoferroplatinum grains. Ledyanoy Creek platinum differs from that of the Levtyrinvayam River in larger grains and in abundance of their intergrowth with chromite. Ir predominates among miner elements in Pt-Fe alloys. Its concentration amounts to 9.23 wt.% for Pt-Fe alloys from lode rocks and 8.73 wt.% for Pt-Fe alloys from the placers. Primary Pt-Fe alloys are altered with formation of Pt-Fe-Cu alloys that are equally typical both for lode rocks and placers. Two trends of Pt-Fe alloy replacement are noted for lode rocks. In dunites they are replaced by minerals of tetraferroplatinum-tulameenite series while in chromitites by tulameenite and more cuprous alloys of Fe-PGE-Cu system (Fig. 2).

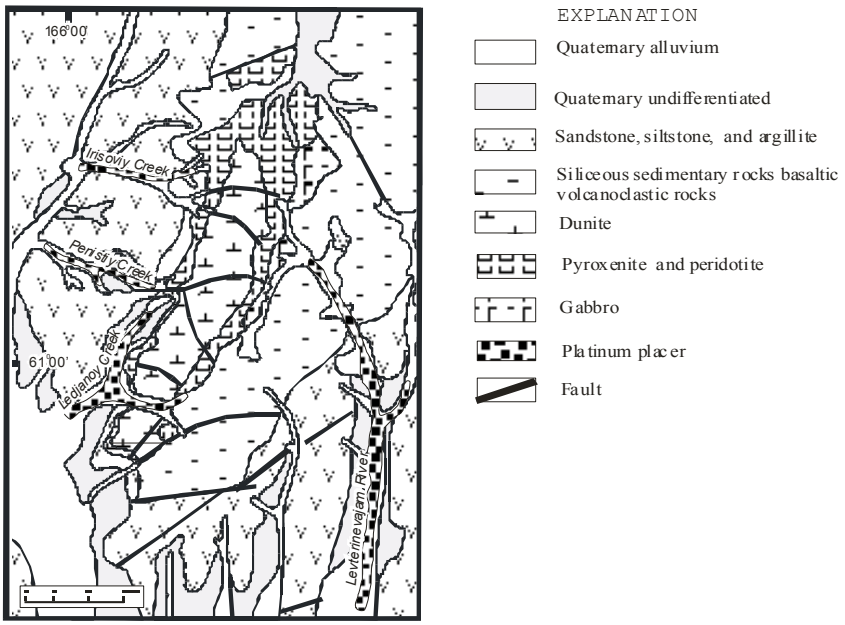

Figure 1. *Chart of Galmoenan massive and adjacent placers.*

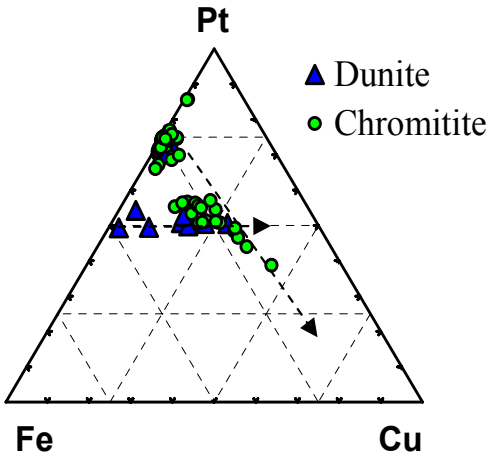

Figure 2. *Ttrends of Pt-Fe alloy composition alteratins in Galmoenan massive lode rocks.*

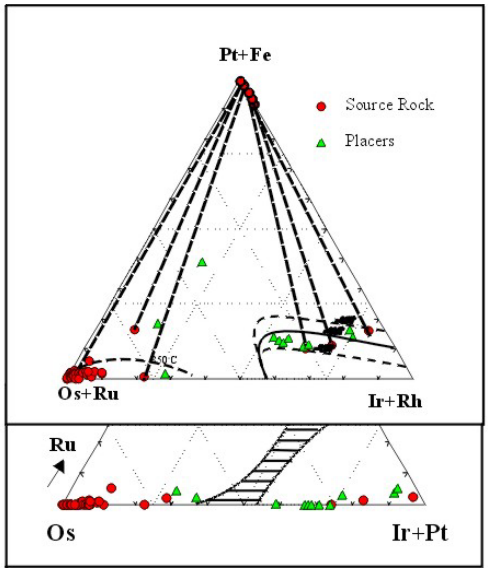

Figure 3. *Composition of Os-Ir alloys and 2-phase isoferroplatinum-osmium and isoferroplatinum-iridium parageneses in lode rocks of Galmoenan massive and placers.*

Os-Ir alloys in platinum grains are typical mineral inclusions. Principally, they are represented by native osmium in placers of the Levtyrinvayam River and by iridium inclusions in platinum grains from lode bodies. Two primary-magmatic parageneses are revealed for both of them: isoferroplatinum-osmium and isoferroplatinum-iridium (Fig. 3), though Os inclusions in isoferroplatinum are very rare for lode rocks. Ru concentration in Os-Ir alloys is not considerable and determines osmium trend of compositions in hexagonal Os-Ir alloys. The fact that Pt content is up to 30 at.% in Ir-Os cubic variety is the evidence of the wide range of their exsolution temperatures with isoferroplatinum (from 750 up to 850°C) (Fig. 3).

Ru and Os sulphides are represented by the series of compositions from laurite RuS_2 to erlichmanite OsS_2, with laurite being typical for lode rocks and all varieties including Rh bearing erlichmanite without Ru occurring in the Pt-Fe grain from placer (Fi. 4). According to its morphological features Rh-bearing erlichmanite belongs to later generation of sulphides developing along osmium crystals in comparison with the majority of $(Ru,Os)S_2$ that is supposed to be of magmatic origin. Abundance of laurite-erlihnanite euhedral inclusions in Pt-Fe matrix conditions low Ru concentration in Os-Ir alloys doe to extraction at early stage of the ore-forming system development under high sulphur activity.

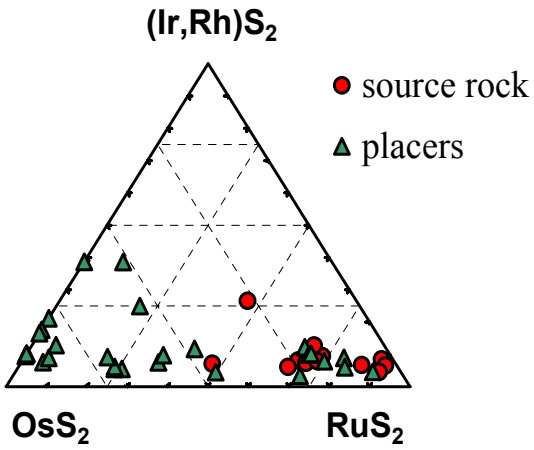

Figure 4*.Composition of laurite-erlihmanite series minerals.*

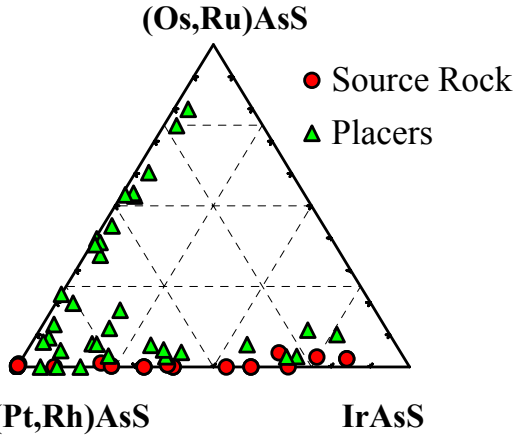

Figure 5*. PGE sulphoarsenode compositions.*

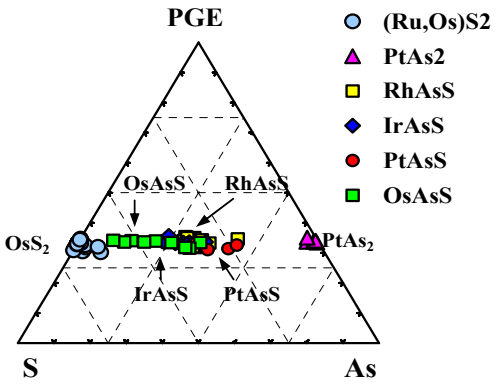

***Figure 6**. Isomorphic series of PGE sulphides, sulphoarsenides and arsenides.*

PGE sulphoarsenides are also found in PGM microparageneses. They are represented by all varieties except for ruarsite as being the most chalcophile element Ru is reacted with S at early stages. Minerals of irarsite-hollingvortite series are typical for lode rocks whereas those of irarsite-platarsite and osarsite-hollingworthite series are typical for placers (Fig.5). PGE sulphoarsenides are represented as subhedral crystals of IrAsS as well as anhedral grains of IrAsS, OsAsS, RhAsS subordinate to contacts between other phases. This confirms their formation under different conditions during long time of oreforming.

Sperrylite is one of the ubiquitous minerals of the final formation stage of PGE mineralization. It replaces Pt-Fe alloys over grain periphery frequently forming epitaxial intergrowths with tulameenite or external rims over isoferroplatinum after tulameenite. Composition of sperrylite from lode rocks differs from this from alluvial deposit with increased Sb concentration which varies from 0.22 up to 6.94wt.%. The phase $(Pt_{0.96}Fe_{0.02})_{0.98}(As_{1.17}Sb_{0.75}S_{0.09})_{2.01}$ was also found, similar PtAsSb in which Sb amounts to 23.87wt.%. On the basis of mutual substitution of S and As erlihmanite PGE sulphoarsenides and sperrylite from bedrocks of Galmoenan massive and bordering placers form the complete isomorphous series from OsS_2 to $Os(S,As)_2$ and further to $Os(As,S)_2$ and OsAsS. Then the series is continued by platarsite PtAsS with compositions trends to sperrylite $PtAs_2$. Though analogues structure types of sperrylite and platarsite the gap of miscibility is observed in this part of the series (Fig. 6).

Isomorphous miner elements in Pt-Fe alloys are the indicators of their formation conditions and concentration of miner elements differs to some extent in lode rocks and placers adjoining to the massive (Fig.7). Pt-Fe alloys from the Levtyrinvayam River placier that is the most remote from the source rock (Fig.7a) are devoid of Ir, and are enriched with Pd and Rh. Pt-Fe alloys in the placer of Ledyanoy Creek contain Ir in 60 % of all the analyses and have relatively increased Os background (Fig. 7b). Platinum comes to Penisty Creek alluvium from dunites as well as from pyroxenites of the complex border parts. Iridium-bearing and rhodium-palladium-bearing Pt-Fe alloys are present in equal quantities in Penisty Creek (Fig.7c). The pattern of miner elements distribution in isoferroplatinum from lode ores of Galmoenan massive is quite different (Fig.7d). In most analyses Ir prevails over other elements and amounts almost to 10 at.%.

Actually, composition of Pt-Fe alloys and their miner elements depends on geochemical specialisation of the ore-forming system. However, it should be taken into account that in placers platinum geochemistry also depends on the following factors: 1.) The distance from the source rocks, so, from the level of erosion as the material from upper horizons of the massive is present in the most remote areas of placers. 2.) The composition of host rocks or/and proportion of dunites, chromitites and pyroxenites taking part in erosion.

Taking into account that PGE minerals from the Levtyrinvayam River placer reflects conditions in the upper eroded parts complex and those from Ledyanoy and Penisty creek placers in intermediate horizons, the vertical zonation of PGE mineral geochemistry can be traced and the following conclusions can be made.

1. Platinum from apical parts of the massive is rich in Rh - Pd contrary to Ir-bearing platinum from lower and higher levels. The quota of Rh- Pd-bearing Pt-Fe alloys from border considerably pyroxenite rocks is also great in comparison with Rh-Ir one that comes to the placer from dunites.

2. Pt-Fe alloys from lode rock are represented by isoferroplatinum Pt_3Fe while the increased iron content in platinum (Pt,Fe) was typical for alloys from Levtyrinvayam River placer as well as for upper horizons of massive. Increased iron in Pt-Fe is conditioned by secondary metasomatic processes.

3. Increased sulphur fugacity at the earlier stage of PGE mineralisation resulted in occurrence of abundant inclusions of the series RuS_2-OsS_2 and conditioned low ruthenium content in Os-Ir alloys as well as weak development of Os native phases in lode rocks. Increased arsenic activity at the late

stage of PGE mineralisation resulted in formation of superposed sperrylite mineralisation.

4. Ir concentration decreases while that of Os increases from inner parts towards upper horizons or apical parts of the massive. This is based on the fact that osmium minerals: erlihminite OsS_2 and osarsite OsAsS are widely distributed among inclusions in Pt-Fe alloys of the Levtyrinvayam River placer. Besides, isoferroplatinum-osmium parageneses are widely represented in the placer unlike isoferroplatinum-iridium parageneses typical for lode rocks.

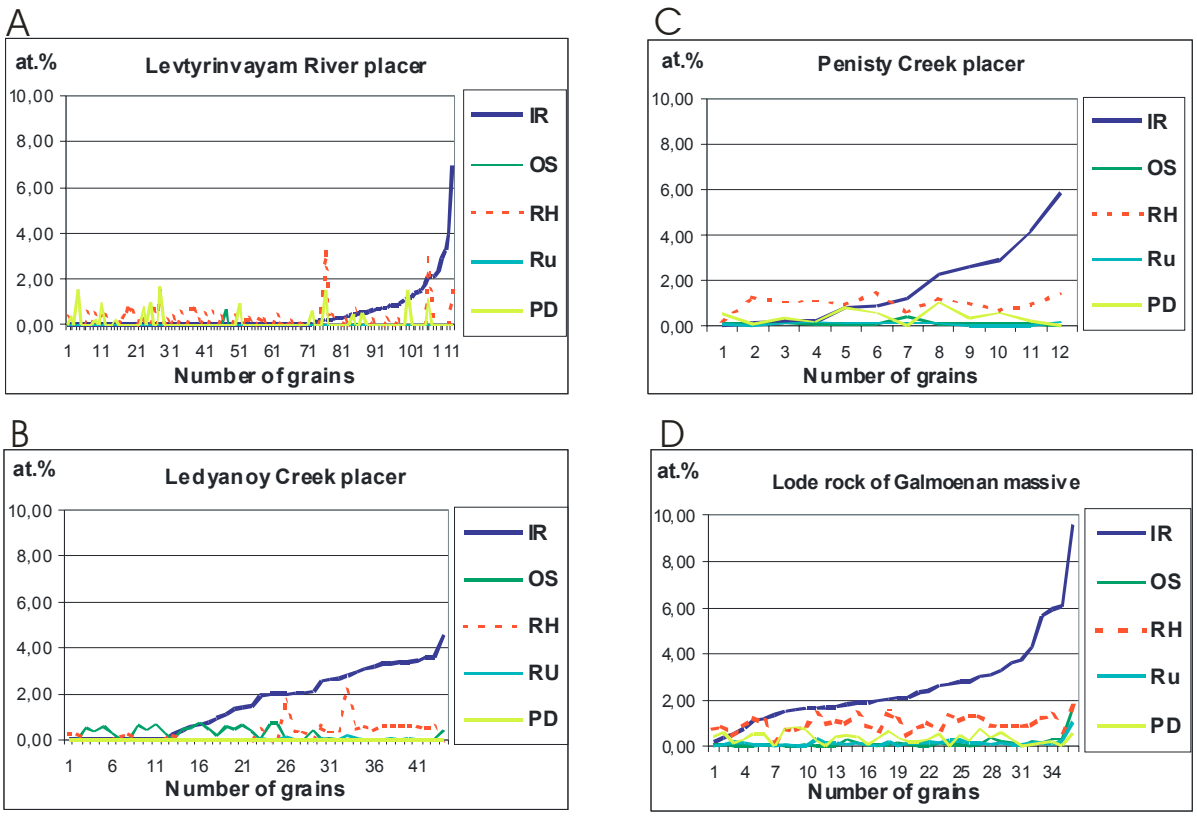

Figure 7. *Level of miner elements in Pt-Fe alloys from the Levtyrinvayam River placer (A), Ledyanoy Creek placer (B), Penisty Creek placer (C) and lode roks of Galmoenan massive (D).*