PGM-Bearing Mineral Associations and the Formation of Massive Cu-Ni Ores, Talnakh Ore Field

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Introduction

Despite of the long history of study of PGE in Cu-Ni sulphide ores in Noril'sk deposits not much information could be found in the literature about the detail relationships "sulphide – Platinum-group mineral (PGM)" even for massive ores. And it seems to be interesting to try to understand if there is any correlation between PGM and base sulphides compositions in massive sulphide ores. The most fascinating lens-like body of massive ore up to 50 m in thickness is still exploited in Oktyabr'skoje deposit. Its zoned structure is characterized by the sequence of ores which are composed of major base sulfides (cubanite, pentlandite, minerals of pyrrhotite- and chalcopyrite group) in different proportions, magnetite, and number of "rare" sulphides, PGM, and (Ag,Au) (Genkin et al., 1981). More than 20 PGM are determined in these ores. It was established (Genkin & Evstigneeva, 1986) that the main (PGM) associations belong to two types. First one is found in pyrrhotite ores (pyrrhotite group minerals > tetragonal chalcopyrite > pentlandite), and presents metacrystals, veinlets, and polymineral intergrowns of atokite-rustenburgite series minerals, paolovite, sperrylite, some Pd-Pt-Sb-Sn compounds. PGM associations of the second type consist in zoned PGM intergrowns of Pd(Pt)-Sn-Cu and (Ag,Au) in ores enriched in cubanite, i.e. chalcopyrite-cubanite, cubanite-chalcopyrite ores. According to Genkin et al. (1981) the mineral varieties of ore are changed regularly : the pyrrhotite ores are changed by ore more rich in Cu from flanks of ore body to the centre, and from the bottom to the top consecutively by cubanite-, putoranite-, and mooihoekite- ores. Cubanite ore has the "intermediate" spatial position between mostly pyrrhotite- (troilite) one and ores represented by chalcopyrite group minerals (Filimonova & Evstigneeva, 1990).

The detail mineralogical study of massive Cu-Ni sulfide ore was carried out accordingly to the latitudinal cross-section via the west part of Kharaelakh deposit (Oktyabr'skaja mine). Sampling was made every 3-10 m along the length of the section. The schematic section (~W-E) across this body is presented on the Figure 1.

Polished sections prepared from more than 150 samples have been investigated using optical (reflectivity), x-ray (phase analysis and cell parameters), and microprobe analysis. Based on results obtained during this study not only some peculiarities of phase relationships found recently (Genkin & Evstigneeva, 1986) were proved, but also some additional remarks were made.

Sulphides

"Pyrrhotite" group involves troilite and hexagonal pyrrhotite. The last can contain up to 0.4 wt % Ni. The ratio Tr:Po_h is close to 1:1 in chalcopyrite-troilite ores. Troilite associates with relatively rich in Fe pentandite (Fe/Ni ~1.21).

Among main sulphides pentlandite is the most interesting because of its variable composition. "Metal : S" ratio for the majority of analysed pentlandites is a little less of 9 (8.71-8.94). Fe/Ni ratio increases from flanks to the centre of ore body within the section: 0.96 in pyrrhotite ore, ~1 in chalcopyrite-cubanite one, and up to 1.68 in mooihoekite-cubanite (Fig.2). But Fe/(Ni+Co+Cu) ratio remains near intact, close to 1:1. The exception is Pn grains from Po, and adjacent Cp-Cub (Cub-Cp) ores, that are more ferriferous. The Fe content increases in pentlandite from Cu-rich ores and immediately at the contact with PGM (Fe/Ni=1.81). It is accompanied by Ni concentration decreased. Pentlandite "flames" in hexagonal pyrrhotite from Cp-Cub ore also are characterized by higher Fe content in comparison with pentlandite in large grains (37.98 and 29.98 wt.% correspondingly).

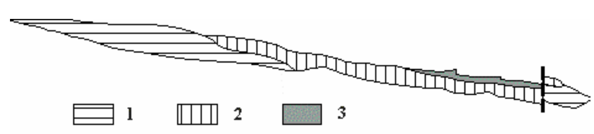


***Figure 1**. Sketch of latitudinal section across the strike of massive sulphide ore body, Oktyabr'skoje deposit. 1 – Pyrrhotite-rich ore; 2 – Chalcopyrite-mooihoekite-cubanite ore; 3 - (Pentlandite-trolilite)-Cubanite-talnakhite-putoranite-mooihoekite ore.*

Cu content in pentlandite from ores studied varies from 0 till 3.9 wt % (from mooihoekite-cubanite ores). Pentlandite from massive ores can content up to 1.4-1.5 wt %. Co concentration increases a little in pentlandite from pyrrhotite ore.

Chalcopyrite group minerals includes tetragonal chalcopyrite (samples nn. 795, 777, 765), talnakhite (samples 813, 777), and mooihoekite-putoranite (sample 765). Tetragonal chalcopyrite and mooihoekite contains up to 0.4 wt % Ni, and talnakhite – 1.44 %.

The composition of cubanite is characterising by very low level of admixture elements, and corresponds to $CuFe_2S_3$. Low Co concentrations (<0.09 wt %) are found in all cubanite grains analysed. Some analysis of cubanite show ~1.0 wt % Pb (cubanite-talnakhite ore, sample 818), ~1.3 Ni (cubanite-talnakhite-putoranite-mooihoekite ore, sample 752), 0.7 Sn, 0.09 Mn (mooihoekite-cubanite ore, sample 765), 0.49 Zn (mooihoekite-cubanite ore, sample 778), and 0.24 Bi (chalcopyrite-pyrrhotite ore, sample 829).

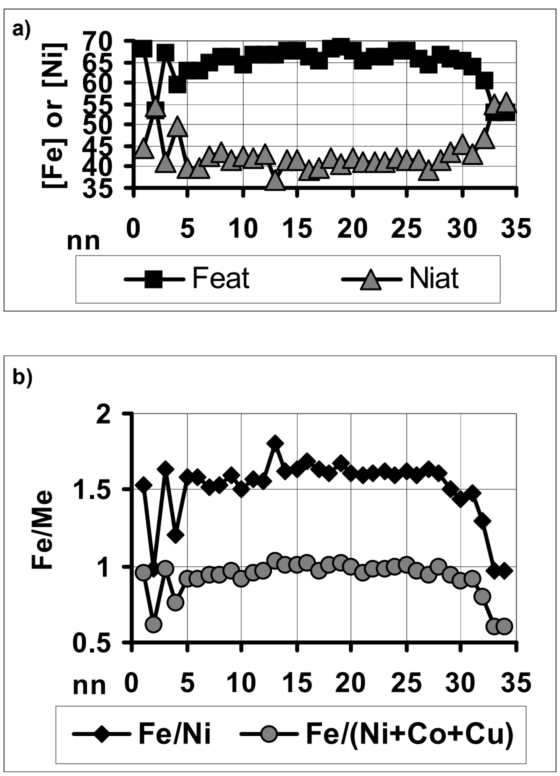


Figure 2. *Variations of Fe and Ni content (a), and Fe/Ni and Fe/(Ni+Cu+Co) ratio (b) in pentlandite. Samples (numbers increase from E to W within the cross-section): nn.1,2,4, and 34 – Po ore (1, 2 –one sample: 1- "flame"s,2 – grains); nn.3, 7-20 – Cp – Cub ore; nn.5,6 -, and 21-32 – Cub – Mh ore; n.33 – Cub – Cp ore.*

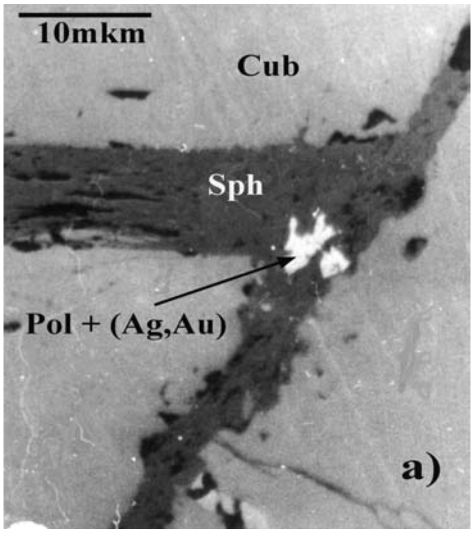
Of minerals directly associated with PGM the most common is sphalerite (Fig.3a, b). Very often it also overgrows with magnetite (Fig.3c). All sphalerite grains contain Fe and Cd: up to 8.7–9.3 and 3.0-4.6 wt % correspondingly. Cu is also typical element for ZnS from massive ores and can attempt 7.0 wt %. Some analysis of sphalerite from cubanite-talnakhite ore (sample 813) shows some concentration of Mn (1.8 wt %).

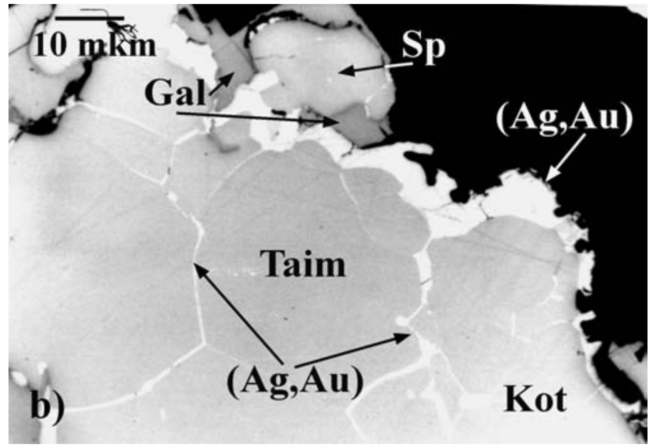
New data were obtained for minerals of shadlunite type. Two new mineral varieties of this family, the Pb-Cd-Mn- and Mn-Pb-Cd- shadlunite, with formula $(Cu,Fe)_8(Pb,Cd,Mn)_1S_8$ and $(Cu,Fe)_8(Mn,Pb,Cd)_1S_8$ correspondingly were found. According to these results it is possible that the suggestion about the ordering of Cu and Fe in the structure of shadlunite (Evstigneeva et al., 1973) is not correct and should be discarded.

We emphasise also that unusual minerals enriched in Cu with respect to cubanite and chalcopyrite group minerals have been found in cubanite-bearing ores. Microprobe analyses seems to be good, but the formula are strange: $Cu_3Fe_2S_4$ (samples 752 and 777), Cu_2FeS_2 (sample 778), or $Cu_4Fe_3S_6$ (sample 937). These "phases" occur in cubanite ores, and can be a very fine intergrowth of some Cu-Fe sulphides, formed during the transformation of sulphides crystallised earlier. The nature of theme is not clear and need the detail study with SEM.

Platinum-Group Minerals

According to previous investigations (Genkin et al., 1981, Distler et al., 1988), PGM from Okt'yabrskoje deposits are presented by: 1) $Pd_2(Sn,As)$, $Pd_2(As,Sn)$, Pd_5As_2, $(Pd,Ni)_5As_2$ (pyrrhotite ore); 2) sperrylite, froodite, maslovite, paolovite, cabriite, sobolevskite (cubanite, chalcopyrite and mooihoekite ores); 3) urvantzevite (talnakhite-cubanite ore); 4) majakite (pyrrhotite-cubanite-chalcopyrite ore). Of PGM found during our work the most abundant belong to the Pd-Pt-Cu-Sn system (stannopalladinite, taimyrite) and to Pd-Pb-Bi compounds (bismuthopolarite, and sobolevskite). PGM are related to ore enriched in Cu (Evstigneeva, 1989). The size of PGM segregations and the type of occurrence (aggregates of some PGM or separate PGM grains) vary within the cross-section. The composition of PGM from different ore varieties remains relatively constant. The mooihoekite-cubanite and cubanite-mooihoekite ores contain more PGM in comparison with others.





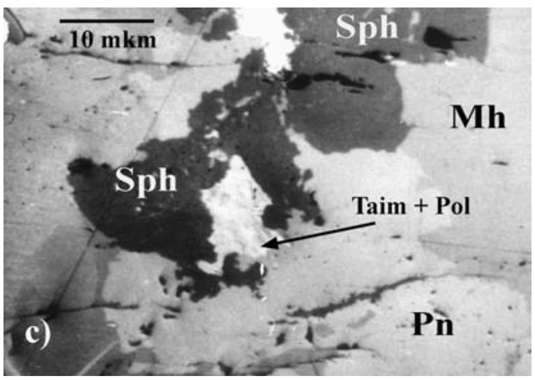


Figure 3. *PGE-bearing associations (polished sections). a) Polarite (Pol) with (Au,Ag) in sphalerite veinlet (Sph) crossed cubanite (Cub), cubanite-putoranite ore; b) Taimyrite and polarite (Taim + Pol) in sphalerite (Sph), pentlandite-mooihoekite ore; c) Aggregate of taimyrite (Taim), kotulskite (Kot), sperrylite (Sp), and Gal with rim and veinlets of (Ag,Au).*

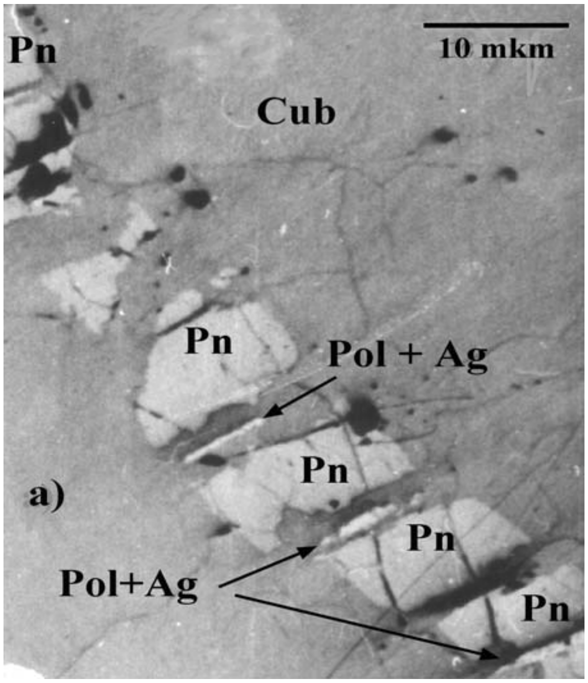
Generally Pt form the proper minerals, and Pt concentration in Pd minerals do not exceed 1.5-3 wt %. The highest Pt content, 8 wt %, is determined in taimyrite (sample 777). Polarite in Okt'yabrskoje deposit is bismuthopolarite, very poor in Pb (0.9 wt %) bismuth rich member of PdBi-PdPb series. The low Pb concentration in PGM is the peculiarity of Okt'yabrskoje deposit. Sobolevskite, PdBi, with 7.2 wt % Te is found in mooihoekite-cubanite ores.

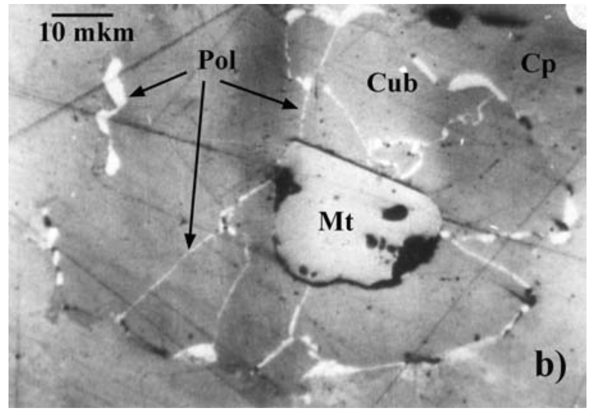
PGE-bearing sulphides present the second form of PGE occurrence. PGE are determined in all base sulphides. 0.2 wt % Pt (+ 0.5 Cu and 0.2 Bi) was determined in pentlandite associated with cabriite and polarite in cubanite-mooihoekite ore (sample 777). Pentlandite from mooihoekite-cubanite ore contains up to 0.16 wt % Pt and 0.34 wt % Pd (sample 765). About 0.2 wt % Pt is found in hexagonal pyrrhotite from mooihoekite-cubanite ore (sample 778).

Cubanite from mooihoekite-cubanite ore associated with cabriite contains ~0.4 wt % Pd, 0.2 Bi, 0.1 Ag, and 0.1 Au. Generally there is no regularity of PGE composition in base sulphides including PGM. Observations testify rather that PGE concentrations in sulphides are caused by not perfect analytical facilities, because it is likely that PGM and some other element-admixtures belong to the micro inclusions of minerals in base sulphides or in their vicinity, as shown on Figures 4a-c.

Conclusions

The significant thickness of cubanite ore could result from the developed process of ore transformation in the final stage of ore formation. Cubanitization and formation of majority of PGM in massive ore are manifestations of such transformation carried out along pyrrhotite – chalcopyrite ore contact in response to the fluids. According to the morphological and structural peculiarities of cubanite-bearing ores, the formation of massive sulphide ore body included the stage of "autometasomatic" transformation of chalcopyrite and pyrrhotite ores. The frequency of PGM occurrence in ores enriched in Cu-bearing sulphides, and the close association of PGM with sphalerite, galena, shadlunite etc. are initiated by the enrichment of residual sulphide melt in PGE, Pb, Zn, Te, and in other fusible and volatile elements during the formation of zoned massive ore body.





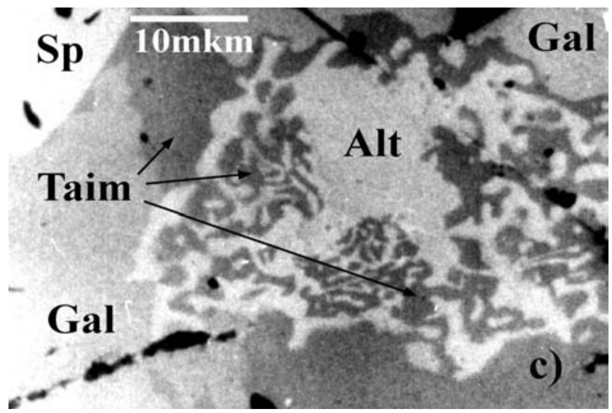


Figure 4. *PGE-bearing associations (polished sections). a) Polarite (Pol) with native Ag in cubanite (Cub) between relics of pentlandite (Pn) (Cub-Cp ore); b) Polarite (Pol) developing by fractures in cubanite (Cub) aroung magnetite grain (Mt); c) Eutectoid intergrowths of taimyrite (Tai) and altaite (Alt) in talnakhite (Tal) – galena (Gal) ore.*

The predominance of "simple" PGE separations (mono- and bi- or three- mineral intergrowths), and the composition constancy of PGM from different ore varieties within the latitudinal cross-section testify that the sulphide purification and re-crystallization were carried out in the massive sulphide ores.

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