DISSEMINATED ORES OF THE NORILSK ORE DISTRICT AS A POTENTIAL FOR INCREASING OUTPUT OF PLATINUM METALS AT THE NORILSK MINING COMPANY

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The unstable demand for base metals (copper. nickel, and cobalt) has necessitated new technologies to he worked out to significantly increase the recovery of platinum-group metals (PGE) from ores of the Norilsk deposits which would raise the profitability of mining and concentrating works. This is dictated by the constantly growing demand for PGE and the fact that the share of these metals has been rising in the commodity output by the Norilsk Mining Company processing copper-nickel ores. In order to make the PGE production more independent from that of base metals, it is, first of all, necessary to set it apart as autonomous from production of copper and nickel. This is possible through shorter process flowsheets from mining to refining of PGE. The respective choose the best from such process flowsheets and equipment should be based on the data obtained of mineralogical study of PGM ores mode of occurrence.

According to a typical economic classification, ores of the Norilsk deposits belong to a group of sulphide copper-nickel ores with associated PGE mineralization. However, to suit the present economy and market pattern. it will be more convenient to subdivide these ores into two economic classes, namely: (I) class I — the sulphide copper-nickel ores with accompanying noble and rare metals, including all kinds of rich and easy-to-concentrate ores and (2) class 2 — platinum ores with associated non-ferrous and rare metals, including all kinds of disseminated ores, some kinds of hard-to-concentrate ores, and low-sulphide platinum ores of upper contact zones of stratified intrusions (Fig. 1).

The principle characteristics of platinum ores (class 2) are listed below.

I. The total PGE content in platinum ores is equal or close to that recorded in sulphide copper-nickel ores, whereas the content of total sulphides is ten times lower. Hence, the sulphide concentrate produced from platinum ores will be up to ten times richer in total PGE.

2. In the platinum ores PGE have two equally developed modes of occurrence. They are observed as platinum and palladium minerals proper. on the one hand, and as considerable isomorphic admixtures of palladium, rhodium, iridium, osmium, and ruthenium in main sulphides, on the other. It follows, that in processing these ores, neither palladium or platinum minerals. nor iron. nickel, or copper sulphides should be lost with final tailings.

3. Ii concentration of platinum ores follow the process flowsheet applied to treat the sulphide copper-nickel ores with associated plat-

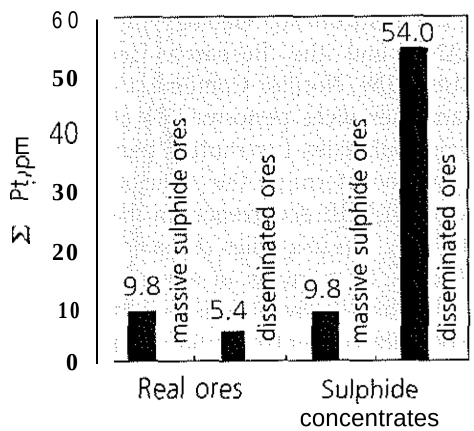

Fig.1. Ratio of RGE contents in disseminated ores to those in 100% sulphide concentrates

inum metals, a great deal of final tailings will result. Due to the density and flotation characteristics of platinum-bearing minerals, the tailings will hold up to 30 % of the PGE initially analyzed in the ores.

4. Platinum ore bodies occur apart from locations of the other types oi ores. This enables the miner to optimize the raw material quality and vary the scale of mining depending on the state of base and noble metals.

Most platinum ores (about 70 %) belong to the disseminated type. The ores of Norilsk deposit are superior in their economic characteristics. including those essential for mining, as compared with the ores mined by some of the world principle PGE producers (Table 1).

Table I

Some statistics on ores of principle platinum deposits

Parameters	Bushveld complex: Merensky reef	Bushveld complex: Reef UG-2	Bushveld complex: Platreef	Norilsk ore district: Picritic and toxite horizons of the Norilsk type
Ore body inclination, degrees	15	15	30	15
Type of mining	Under-ground	Under-ground	Open-pit	Open-pit and underground
Thickness, m	0.1-0.4	0.2-0.4	10-20	20-50
Total content of PGE adjusted for ore dilution, ppm	7	6-8	2-4	5-7
Content of associated non-ferrous metals, %	0.2	0.1	0.2	0.7 or more
Value of total PGE in mined ore, US$	106	100	35	110

The nature of PGE concentration and their forms of occurrence in platinum ores dictate the use of modern high-performance techniques of gravity separation to produce high-grade PGE concentrates. This will decrease the loss of PGE in final tailings and will make it possible to process PGE gravity concentrates without involving the pyro- and hydrometallurgical copper and nickel production cycle.

The thesis advanced above is based on special studies carried out at the Institute for Geology of Ore Deposits (IGEM RAN), and the Research Center for Mining and Smelting, the Norilsk Combine Company. The Proton microanalyses were performed to study the PGE content in major sulphides (pyrrhotite. pentlandite, and chalcopyrite) and to determine the ratio of isomorphic to mineral modes of PGE occurrence, in many varieties of disseminated ore. These studies revealed that the bulk of platinum (90 % or more) is in mineral form of occurrence (Table 2), while the balance is dissolved with the maximal in pyrrhotite concentration of 0.8 ppm. As to palladium, 27.34 % of the metal is in mineral form, whereas its bulk is incorporated in pentlandite lattices in isomorphic form with concentrations of 200-1700 ppm Few of the PGE metals are represented by solid-state solutions in pyrrhotite and pentlandite. They are largely hosted by pyrrhotite which reaches 2.4-4.0 % concentration in the ores and contains up to IO-30 ppm Rh and over 5 ppm Ru and Ir. The range of platinum and palladium minerals present in the r.o.m. ores and the data on their granulometry are presented in Table 2.

The 0.25 mm size fractions contains only occasional grains of platinum minerals, whereas size fractions of 0.05-0.25 mm, and especially 0.05-0.125 mm, appear to be most enriched in these minerals. In the minus 0.05 mm size fraction their share amounts to 32-34 %. Purely, palladium minerals occur as very fine grains.

These data were used in selecting the most effective techniques for gravity separation of ores. Taking into account great amounts of ores to be processed and the granulometric characteristics of platinum and palladium minerals studied, the preference was given to the highly productive Knelson centrifugal separators.

The separators' installation points were selected on the basis of the mineralogical investigation of concentration products obtained by the conventional flotation technology. This investigation revealed the following (Fig. 2). The bulk of the platinum and palladium mineral grains in the concentrate was found in were of 0.07 mm size. Grains of 0.3 mm size are practically non-existant. The fraction of 0.03-0.04 mm is most enriched in them. A different situation was observed in the final flotation tailings. There were no grains coarser than 0.1 mm in non-magnetic material of the tailings. The bulk of mineral grains was observed in the 0.02-0.03 mm size fraction which is finer than the flotation concentrate size. In magnetic fraction, another peak concentration was registered in the 0.1-0.2 mm size fraction, with some grains measuring up to I mm.

Such a size distribution is an indication of the fact that the flotation technology used is not adequate for completely recovery of these metals. On the one hand, this is explained by the fact that mineral grains are overcrushed (minus 0.03 mm). On the other hand, the coarsest grains of PGE minerals that can be floated are those of 0.06-0.07 mm size. In both cases the situation results in considerable losses of PGE with tailings (up to 30 % of their amount in the ores). On the one hand, the distribution observed is due to the presence of many friable PGE minerals that will be readily crushed. These are cooperite (PtS), sperrylite ($PtAs_2$), stibiopalladinite (Pd_5Sb_2), and some other PGE compounds — arsenides, tellurides, and bismuthides (see Table 3). On the other hand, there are other PGE minerals in the ores whose grains are malleable and will increase in size when being crushed. These are magnetic ferroplatinum and Pt-Pd-Sn minerals of the rustenburgite-atokite group. To prevent

Table 2

Granulometric data on the platinum and palladium minerals of disseminated ores of the Norilsk-1 deposit, %

Mineral	Formula	Sample No. 1		Sample No. 2			Sample No. 3		
		Granulometric class, mm							
		0.05-0.125	<0.05	0.125-0.25	0.05-0.125	<0.05	0.125-0.25	0.05-0.125	<0.05
Cooperite	PtS	100	1		10	3			1
Pt-Fe alloys	Pt_3Fe		8.5	50	52	40	10		5
	Pt_2Fe					7	2	15	4
	PtFe						0.5	13	2
Sperrylite	$PtAs_2$		7.5		14	12		4	18
Pd-rustenbergite	$(Pt,Pd)_3Sn$		81.5	50	15	25	87.5	30	
Pt-atokite	$(Pd,Pt)_3Sn$				4			35	2
	$(Pd,Pt)_5(Sb,Sn,As,Pb)_2$							3	51
	$(Pd,Pt)_3(Sb,Sn,As,Pb)$								
Stibiopalladinite	Pd_5Sb_2								
Zvyagintsevite	Pd_3Pb								
Guanglinite	Pd_3As								
Vincentite	$Pd_3(As,Te)$								
Stannopalladinite	Pd_5Sn_2Cu				5	2			
Paolovite	Pd_2Sn					4			3
	$Pd_2(Sn, Sb, As)$								
Kotulskite	Pd(Te,Bi)		1.5			7			
Sobolevskite	Pd(Bi,Te)								14

such losses, gravity separators shall be used at the first crushing stage, thus removing the bulk of PGE minerals from the flotation concentration cycle.

The use of gravity separators on flotation tailings only will be a partial solution of the problem of PGE losses. According to the results of the tests, conducted with 48" Knelson separators installed in the tailings cycle, they were effective only for separation of the sand-sized hydrocyclone tailings. The concentrates thus produced contained 50-100 ppm of total PGE. whereas their content in the tailings was 1.6 ppm; hence, the recovery amounted to 40.50 % for platinum and IO-15 % for palladium. However, the recovery of these metals from the hydrocyclone slime was several times lower. In total, Knelson separators could additionally recover only 2-3 % of the PGE initially contained in the ores. The analysis of the gravity concentrates produced in grinding the spiral classifier overflow (Table 3) and the high recovery level (mainly of platinum) confirm the correctness of the assumption that the PGE minerals should by-pass the ore-dressing cycle.

The Norilsk concentrator has been using Knelson separators since June. 1998. At the first stage of the technology introduction, it was applied for two thirds of the disseminated ores processing cycle. Both in the tailings and crushing cycles an automated microprocessor-controlled system was used which comprised four Knelson separators of KS-SD 48 type and a pulp divider. Under the optimal operating regime (the yield of rougher gravity concentrate of 0.25-0.4%), the recovery amounted to 50-60 % Pt, IO-13 % Pd, and 17-20 % Au. The total PGM content was 400-500 ppm. The results were obtained with ore assaying 1.1-1.3 ppm Pt, 3.4-4.6 ppm Pd. and 0.16-0.2 ppm Au. Though only a part of the ore processed was passed through the gravity installation, PGE losses with tailings substantially decreased: by 7.6 % Pt and 6.7 % Pd. It was also found out that with the use of this technology the PGE recovery in bulk flotation concentrate was higher. Obviously, sulphides and PGE minerals becomes higher due to the additional cleaning of grain surfaces in Knelson separators.

The positive results obtained in the first stage of the experiment have enabled the researchers to spread it onto a full-scale operation. In February 2000, two modified 48" separators were additionally installed. The bowl cone profile was modified to reduce water consumption by 40 %. Though the concentrate yield was twice reduced, the total PGE content in it rose to 1000 ppm; hence, the PGE recovery grew by 25 %. This phenomenon

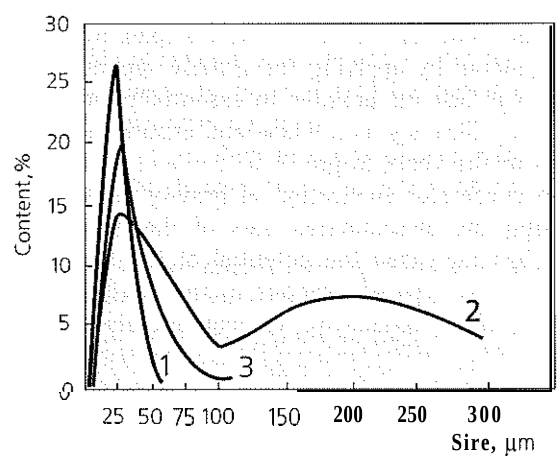

Fig.2. Distribution of platinum and palladium minerals with regard to the size fractions in gravity concentrates produced by separation of disseminated ores

Table 3

Mineral composition of the gravity concentrate separated at crushing_ stage, %

Mineral	Formula	Granulometric class, mm			
		+0.5	−0.5 +0.25	−0.25 +0.1	−0.1
Cooperite	PtS	None			2
Isoferroplatinum	Pt_3Fe		50	14	17
Tetraferroplatinum	PtFe			11	7
Sperrylite	$PtAs_2$			14	12
Pd-rustenburgite	$(Pt,Pd)_3Sn$		50	17	54
Pt-atokite	$(Pd,Pt)_3Sn$			30	
	$(Pd,Pt)_3(Sb,Sn,As,Pb)_2$			6	
	$(Pd,Pt)5(Sb,Sn,As,Pb)_2$				
Kotulskite	Pd(Te,Bi)			8	8
Sobolevskite	Pd(Bi,Te)				

can be easily explained for there exists a clear relationship between the decrease of water consumption and recovery of fine mineral grains. In a bid to enhance the recovery the duration of concentrating cycle was reduced to 20 minutes. since the longer this stage lasts the more PGE is lost in gravity tailings. The general favourable impact of the gravity-flotation technology on the results of the disseminated ores concentration cannot be challenged.

The gravity concentrates produced by Knelson separators can be reground to 95 % of -0.074 mm size and then upgraded both on concentration tables and centrifugal-vibrating concentrators produced by the Grant Company, Naro-Fominsk, Russia. The valuable components will be directly recovered in the concentrate assaying 0.5-2.0 % Pt and Pd. Similar materials can be processed along individual flowsheets until the total PGE in concentrate will reach 60-90 %. In this way the metallurgical stage can be avoided for the concentrate becomes amenable to refining. The recovery of PGE in a flowsheet like that will exceed 99.5 % PGE. Thus, this rationalization of the technological sequence will help reduce the PGE total losses at the Complex by 5-7 %.

In general, by applying the gravity separation technique it will become possible to essentially increase the production efficiency as a whole and ensure its competitiveness in the years to go.

The successful application of gravity separation for processing the disseminated ores of the Norilsk-1 ore deposit has increased the potential of the low-sulphide oi-es as a new type of minerals of the Norilsk deposits which are characterized by low content of copper and nickel (0.04-0.1 %) but high concentrations of PGE minerals (8-10 ppm). Besides. there are some specific forms of occurrence of non-ferrous and noble metals in these ores. In addition to pyrrhotite and pentlandite, typical forms of occurrence of non-ferrous metals are sulfoarsenides and arsenides of nickel and cobalt. Pyrite is more abundant. PGE are found as isomorphic impurities not only in pyrrhotite and pentlandite, but also in sulfoarsenides and arsenides. However, this form of PGE occurrence seams to be less significant than in disseminated ores. In the low-sulphide ores. the bulk of PGE associated with their own minerals. To some extent, there is some difference between low-sulphide and disseminated ores in the way of prevalence of some mineral compounds of platinum and palladium, though both ore types appear to be fairly similar in terms of mineral diversity. Low-sulphide ores contain greater amounts of tellurides, tellurobismuthides, bismuthides, and arsenobismuthides. Besides, the mineral grains are finer in these ores — about 0.01 mm.

Taking into account the data on the size distribution of low-sulphide ores. it is concluded that they have to be finer ground for better recovery of platinum and palladium minerals: i.e. until the yield of the control granulometric fraction of -0.071 mm should reach 50 % and more. The comparison of concentration results in the flotation and gravity-flotation process flowsheets has demonstrated that the latter is more efficient. The recovery levels of Pt, Pd, and Au in gravity concentrates are higher by 15. 26, and 12 %, respectively. They are estimated at 76-78 % and can be raised even further following the rationalization of the technology. Processing of low-sulphide ores by the gravity-flotation flowsheet has proved to be profitable. It can also become a source of additional PGE products since the year 2001.

Thus, the gravity-flotation process flowsheet with the gravity separation cycle at the head of the process is seemed as the most promising trend in making the PGE production autonomous at the Norilsk Complex. These flowsheets will also render the concentration techniques more effective. In future, new technologies will make it possible to start profitable treatment of the huge resources of disseminated ores of the Talnakh ore district. The availability of well-developed mining infrastructure in this district will not only help to maintain but also boost the level of noble metals production without any significant investments.